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Report of Scientific Council on the Development of Precautionary Approach to Fisheries Management

17-27 March 1998

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SCIENTIFIC COUNCIL MEETING - MARCH 1998

Report of Scientific Council Workshop on the Development of Precautionary Approach to Fisheries Management

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REPORT OF SCIENTIFIC COUNCIL
ON THE
DEVELOPMENT OF PRECAUTIONARY APPROACH TO FISHERIES MANAGEMENT

Highlights

The UN Agreement on Straddling Stocks and Highly Migratory Species specifies that a precautionary approach:

- Should implement limit and target reference points;
- Should express those both in terms of fishing mortality and spawning stock biomass (SSB);
- Should take uncertainties into consideration and, when in doubt, should err on the side of caution;
- Should use the fishing mortality at Maximum Sustainable Yield (F_{msy})as Minimum Standard for limit fishing mortality; the biomass which gives Maximum Sustainable Yield (B_{msy}) can also be used as a rebuilding target;
- Should have pre-agreed management actions when limits are exceeded.

The Workshop on Precautionary Approach (17-27 March 1998) reviewed the models available for defining reference points:

- Stock Production Analysis: global and age-structured (used for F_{msy} & B_{msy})
- Spawner per recruit relationships (used for Minimum Spawning Biomass)
- Yield per recruit models (Used for $F_{0.1}$ and F_{max})
- ICES Precautionary Points (candidates for F_{pa} and B_{pa})
- Risk Analyses (to quantify uncertainty and estimate buffer zone)

The Workshop also reviewed the effect of various types of uncertainties on the estimation of reference points. In particular:

- Statistical uncertainties: i.e. errors due to sampling and survey design (these were investigated through simulations)
- Model uncertainties: e.g.
    - the number of ages included in the analyses/models may have a significant impact on the calculation of reference points
    - effects of gear selection
    - changes in natural mortality (as demonstrated for many cod stocks in the Northwest Atlantic)
    - regime shifts

The Workshop concluded that, in order to make some concrete progress on the framework, it was better to work on specific cases. It identified specific stocks corresponding to various types of information available (e.g. age-structured data, global indices, etc.).

The Workshop discussed Decision Rules or Management Actions to be conducted when a trigger point is reached. it concluded that these have to be related to stock specific properties. Decision Rules for re-opening of fisheries are of great priority for NAFO stocks under moratoria.

The Workshop considered criteria for re-opening of closed fisheries. In the context of the proposed framework by NAFO Scientific Council there is no need for separate criteria for re-opening of closed fisheries.

Age-structured Case: American plaice in 3LNO

In the course of the Workshop, significant progress towards the identification of reference points and their use within a precautionary framework was made for that stock. First, various models were applied in an attempt to identify candidates for reference points (Table 4): e.g. $F_{0.1}$, F_{max}, F_{msy}, F_{crash}, B_{msy} and MSY.

In its deliberations, the Workshop could not agree on specific reference points based on traditional models. Instead, it agreed on using arbitrary references as follows: (the framework is illustrated in Figure 14b):

- B_{lim}: it was obvious that there has been a marked decline in recruitment at SSB levels below about 150 000 tons. Based on historical data, the value of 150 000 tons was proposed as the B_{lim} value. Accordingly, spawning stock biomass should not be allowed to fall below this level.

- B_{buf}: was put at 220 000 tons, 2 standard deviations greater than B_{lim}.
- F_{lim}: The stock declined rapidly after exploitation of 0.25 to 0.3. Thus this level of fishing is too high. For illustrative purposes, 0.21 was selected.
- F_{buf}: based on a F_{lim} of 0.21, a value of 0.15 was calculated.

The impact of implementing various decision rules (i.e. a set of pre-agreed management actions being triggered under certain conditions) was also studied through simulations which used:

- B_{lim}, B_{buf}, F_{lim} and F_{buf} as given above (roughly)
- Four levels of acceptable interannual quota change: from unlimited to 25%
- A Re-opening strategy: open with a catch of 15 000 tons when B_{lim} is reached.
- A decision rule specifying linear adjustments to fishing mortality being triggered below B_{buf} (i.e. within the precautionary zone)

It has to be noted that results are heavily depending on the S/R relationship assumed.

Some results of these simulations were (**results were given as illustrative only**):

- Expected year of re-opening: mean is 2013. 95th percentile is 2018.
- Mean yield after re-opening is 40% of MSY.
- The amount of time spent in the precautionary zone is very high (85%)
- A number of other elements of interest to the managers could be calculated: e.g. once open, how many times are we likely to have to close again.

Such a framework would permit managers to investigate the impact of various decision rules or management actions.

Cases based on age-aggegated data or global indices:

The Workshop had also a look at cases where detailed (analytical) assessments are not available. In particular, they selected Greenland halibut in Subarea 2 + Div. 3KLMNO, Shrimp in Div. 3M, Redfish in Div. 3M and Short-finned Squid in Subareas 3-6. For each stock, research requirements were identified but the participants were unable to identify reference points and decision rules for these stocks during the Workshop.

Future Development and Funding.

Scientific Council considered that the Workshop was the starting point of developing limit and target reference points in the Precautionary Approach to the management of NAFO fish stocks. Work had been continued particularly by the Designated Experts during the intersessional period before the 3-18 June 1998 Scientific Council Meeting and will be continued thereafter before the September 1998 Annual Meeting. It was agreed that additional special meetings on Precautionary Approach are required.

The need to reduce the levels of uncertainty around estimates of reference points for all of the NAFO stocks was identified. In many cases, the levels of uncertainty are broad. These uncertainties, unless narrowed down in a short time frame, may have considerable economic impacts resulting in inappropriate management decisions.

Scientific Council believes that investment toward those research initiatives is an essential commitment in the development of the Precautionary Approach to Management of NAFO Stocks.

I. INTRODUCTION

Scientific Council reviewed the report of the Workshop (SCR Doc. 98/76). It modified the report in a few instances to conform with the views of Scientific Council which are outlined in the following.

II. REVIEW OF PROGRESS ON PRECAUTIONARY APPROACH

1. Report of ICES ComFIE Meeting June/July 1997

The Workshop noted that Chapters 2, 3 and 4 of the ICES Comprehensive Fisheries Evaluation (ComFIE) Report (ComFIE, 1997) contain elements of direct relevance to NAFO's undertakings on developing Precautionary Approach (PA) guidelines. Accordingly, these were reviewed at the Workshop.

Chapter 2 examines various options for estimating the uncertainty in reference points. The Delta (Taylor series) method and bootstrapping are highlighted as easy to implement and the latter is thought to be more flexible. Bootstrap analyses conducted by ComFIE suggested that the precision of different reference points inherently varies (e.g. $F_{0.1}$ is generally more precise than F_{msy} or F_{crash}). Also, the variances estimated for any given reference point may be sensitive to the types of inputs that are bootstrapped (e.g. for $F_{0.1}$ inputs include the selection pattern and weights at age).

Chapter 3 of the ComFIE report highlights differences in the PA control rules proposed by NAFO and ICES up until June 1997. The main differences lie in NAFO's more conservative proposal to minimize F when B is below B_{buf}.

Chapter 4 presents simulation tools that can be used to evaluate the performance of alternative harvest control rules. ComFIE carried out a simulation study to develop default PA guidance for stocks that lacked detailed analyses of harvest control rule performance. The study considered a variety of target and limit reference points applied to 16 hypothetical stocks of different population dynamics and fishery characteristics. Examination of the simulation results in terms of probabilities of recovery to B_{msy} (starting at 0.5 B_{msy}) and average yields led COMFIE to recommend the following precautionary harvest control rule:

$$\begin{array}{ll} F = F_{0.1} & \text{for } B > B_{pa}, \\ F = F_{0.1} * (B - B_{lim}/(B_{pa} - B_{lim})) & \text{for } B_{lim} < B <= B_{pa}, \\ F \sim 0 & \text{for } B < B_{lim}, \end{array}$$

where $B_{lim} = 0.5\ B_{msy}$ and $B_{pa} = B_{msy}$.

2. ICES 1997 Annual Science Conference Theme Session V: "*Applying the Precautionary Approach in Fisheries and Environmental Management*"

A brief overview was provided of the Theme Session, "*Applying the Precautionary Approach in Fisheries and Environmental Management*" that was held 25-26 September 1997 at the ICES Annual Science Conference in Baltimore, Maryland, USA. The Session consisted of 12 different presentations addressing various aspects and issues related to the PA including: quantifying risk in stock assessments; multispecies considerations in developing and providing precautionary advice; determination and application of biological reference points (RPs) and harvest control rules (HCRs); use and evaluation of marine refugia, protected areas, and essential fish habitat as precautionary management measures; and evaluation of real-world experiences in using the PA. Some of the major themes highlighted in the presentations and the subsequent discussions were: (1) the PA applies not just to science, but to the entire range of resource utilization and management activities, including management regimes and decision-making frameworks; (2) biological RPs are not management goals but can be used with harvest control rules to achieve management objectives; (3) since management objectives are often not specified, there is a need to specify default working objectives to provide a working framework for applying the PA; (4) specifying quantifiable measures which relate to attaining objectives is essential, especially when statements concerning risk are to be made and used in decision-making; (5) at the scientific level, there is a need to make the PA operational; (6) beyond science, the PA requires consideration of (and perhaps changes in) management regimes and decision structures; (7) scientists can evaluate risks and trade-offs but the degree of caution and weighting of objectives is a policy matter for managers; and (8) scientists need to communicate with managers using clear and unambiguous language and keep their messages simple.

In 1998, ICES will be convening two additional scientific events related to the use and application of the PA. The 1998 ICES Annual Science Conference to be held 16-19 September 1998 in Cascais, Portugal will include a Theme Session, *"Management Under The Precautionary Approach: Ecological, Social and Economic Consequences"*. An ICES Symposium entitled *"Confronting Uncertainty in the Evaluation and Implementation of Fisheries Management Systems"* will be held 16-19 November 1998 in Cape Town, South Africa.

3. ICES Study Group on Precautionary Approach to Fisheries Management, February 1998 (SGPAGM)

The ICES Study Group on the Precautionary Approach (SGPAFM) was held at ICES headquarters, Copenhagen, 3-6 February 1998. The report preparation of SGPAFM is still in progress and therefore not available until ACFM adopts the final report at its May 1998 Meeting. Nevertheless the following is a summary of the draft guidelines to the Assessment Working Groups. This summary gives an overview of ongoing work on implementing the precautionary approach into the framework of ICES and into its advisory process.

The SGPAFM suggested limit and precautionary reference points for a number of stocks, where analytical assessments were available. It was noted that the proposed points should be regarded as tentative, and for each case the comments from the appropriate WG would be sought whether or not the proposed precautionary reference are sensible considering the history of the stock and the fisheries. In order to allow ACFM to implement the PA in its advice during 1998, assessment WGs were requested to report back their comments during the year.

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

> **F_{lim}**: will generally only be used for calculation purposes to arrive at F_{pa} and it will generally not be provided in scientific advice, nor used in management actions. F_{lim} might be set with reference to F_{loss}, F_{crash} or F_{med}.
>
> When F_{loss} or F_{crash} appear to be reliable estimates of a collapse fishing mortality, then either can be selected as F_{lim}. If neither is available and there are any doubts as to whether F_{med} is sustainable, then F_{med} can be taken as F_{lim}.
>
> **F_{pa}**: is the upper bound on fishing mortality rate to be used by ACFM in providing advice. Fishing mortality rates in excess of F_{pa} will be regarded as "overfishing".
>
> F_{pa} should be set so that the implied equilibrium biomass is above B_{pa}. with a probability of approximately 0.1, then B_{pa} would be held with fishing held constant at F_{pa}.
>
> F_{pa} must have a high probability of being sustainable, based on the history of the fishery; i.e. it should be set in the range, and imply a biomass, within those previously perceived. F_{pa} might be set with reference to F_{med} or to F_{lim}.
>
> If F_{lim} is available, then F_{pa} could be defined through $F_{pa}=F_{lim}\ e^{-1.645\ \times\sigma}$ (where σ is a measure of uncertainty in the total F estimate, typically in the range of 0.2-0.3).
>
> F_{pa} can also be defined as F_{lpg} where F_{lpg} is defined as the F value having only 10% probability of giving a Spawner-per-Recruit (SPR) above G_{loss} as in Cook (1998) the slope corresponding to the lowest SSBs observed.
>
> If there is no F_{lim}, and F_{med} goes through a cloud of points which appears to come from the right-hand limb of a stock-recruitment relationship, then use F_{med} for F_{pa}.
>
> If selected appropriately, and if adhered to as a maximum fishing mortality rate, F_{pa} would generally maintain the stock within safe biological limits.

Biomass reference points. Stocks may be depleted due to reduced recruitment even if fishing mortality is successfully maintained at or below F_{pa}. This may result from an environmental effect, for example. Clearly, therefore, in addition to a constraint on fishing mortality, it is desirable to have a biomass-based constraint to prevent stock decline through reduced recruitment. In addition to F_{pa} set as an "overfishing threshold", a definition of when the stock is regarded as being in a "depleted state" is also necessary. A threshold in this respect, B_{pa}, needs to be set to ensure a high probability of avoiding reducing the stock to a point, B_{lim}, at which the probability of recruitment failure is high. B_{lim} and B_{pa} may be set in a variety of ways:

> $\mathbf{B_{lim}}$: will generally only be used for calculation purposes, to arrive at B_{pa}, because management will ensure a high probability that B_{lim} is avoided, it will generally not be provided in scientific advice nor used in management actions. B_{lim} might be set with reference to B_{loss}.
>
> $\mathbf{B_{pa}}$: is the biomass below which the stock would be regarded as potentially depleted or overfished; it should be set to ensure with high probability that B_{lim} is not reached; it might be set with reference to B_{loss}, B_{lim} or defined MBAL levels.
>
> If there is no obvious candidate for B_{lim}, consider the lowest observed biomass B_{loss}. Use B_{loss} as B_{pa} if there is no indication of recruitment reduction at low biomass. Use B_{loss} as B_{lim} otherwise, particularly if there is any indication at all of reduced recruitment at this low biomass or if the stock has explored a very wide range of SSB values.
>
> When only B_{lim} is available from the above, select B_{pa} so that there is low probability that a biomass estimate which appears to be above B_{pa} will really be below B_{lim}. In this case use, $B_{pa}=B_{lim}\ e^{-1.645 \times \sigma}$ (where σ is a measure of uncertainty in the total F estimate, typically taken in the range of 0.2-0.3).

$\mathbf{F_{pa}}$ ***versus*** $\mathbf{B_{pa}}$. In equilibrium SPR calculations, there is a unique equilibrium biomass corresponding to each fishing mortality and, at first, it would seem reasonable that B_{pa} would be the biomass in SPR calculations corresponding to F_{pa}. However, because estimates of both B_{pa} and F_{pa} will have uncertainties, a close correspondence between the two would mean that if F is close to F_{pa} and B close to B_{pa}, the advised fishing mortality would constantly need to be changed in reaction to changes in the estimated biomass. In order to prevent such unstable advice when the stock would be fluctuating around B_{pa}, F_{pa} needs to be selected such that the implied equilibrium biomass at F_{pa} is above B_{pa}. If the implied equilibrium biomass is sufficiently high, if F_{pa} is appropriately set, and if it is adequately implemented, there will be a low probability that B_{pa} will ever be reached and therefore a high probability that B_{lim} will be avoided.

Selection of limit reference points and precautionary reference points. The validity of F_{loss}, F_{med} and other statistics as precautionary or limit reference points depends of the history of the fishery. The SGAFM considered that the guidelines above for fishing mortality and biomass reference points serve as a starting point and that the assessment WG aware of stock and fishery details, may well make case-specific adjustments as appropriate; taking in account for example of multispecies considerations or technical interactions.

Assessment WGs should also calculate other biological reference points for the purpose of "groundtruthing" the precautionary reference points selected above. In particular , F_{msy}, B_{msy}, $F_{0.1}$, F_{max}, 35% SPR may be useful for comparison with the precautionary approach used elsewhere based on the use of F_{msy} as a limit on the target fishing mortality.

What is the role of $\mathbf{F_{msy}}$ in the precautionary approach? SGPAFM did not use the concept of F_{msy} during this meeting. It is not clear how ICES will proceed with regards to the interpretation of Annex II of UN - Agreement on Straddling Fish Stocks and Highly Migrating Fish Stocks. The SGPAFM believed that if F_{msy} is to be used, it would be more appropriate to view F_{msy} merely as an upper bound of target reference point for fishing mortality which implies that there should be more than 50% probability that F_{msy} is not exceeded. The primary argument against using F_{msy} at all is that it is highly dependent on the shape of the stock-recruitment relationship assumed, which is usually poorly determined (likewise F_{crash}). Thus it may be necessary to adopt proxies for both F_{msy} and F_{crash}.

Precautionary science. SGPAFM noted that:

> "Estimates of assessment-related quantities should be best estimate not precautionary estimates. If stock-recruitment data are fitted by two different theoretical curves, the fit chosen for further calculation should be based on scientific arguments, not on which curve has the most precautionary interpretation. As in other scientific circles, the term "scientific arguments" refers to statistical methodology, biological knowledge, relationship to ecological theory and so on. It is poor scientific practice to deliberately bias estimators, which are supposed to relate to biological entities. Nevertheless, it is imperative that any evaluation of risk (and determination of related

biological reference points which avoid high risk) take into account possibilities such as the fact that assessments may be over-optimistic and some stock recruitment curves show maxima outside the range of the data and thus leading to results which can be considered highly suspect. It is particularly important to clearly deal with the latter, since this can have major effect on results from evaluations of management strategies. In particular fitting to non-informative stock and recruitment data may well indicate that recruitment will increase dramatically at low stock sizes or that F_{crash} should be taken arbitrary large.

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

4. Progress on Precautionary Approach in Other Fora

a) Progress in ICCAT

The International Commission for the Conservation of Atlantic Tunas, ICCAT, recently formed an *ad hoc* Working Group to examine options for incorporating precautionary targets as part of the advice presented to the Commission. This group plans to meet later this year to examine progress in other fora as well as to determine useful reference points that may be suitable to the life history characteristics of tunas and billfishes. The ICCAT work will generally be carried out in parallel to a planned (1999) FAO expert consultation that will integrate efforts made by other international commissions concerned with tunas.

b) Progress in the U.S.A.

The Magnuson-Stevens Fishery Conservation and Management Act, reauthorized in 1996, has a set of National Standards for the management of fisheries in the USA. One of these standards requires that the "optimum yield" be achieved, where the optimum is constrained to be no greater than the maximum average yield obtained under a chosen harvest control rule (the "MSY control rule"). Currently, there are efforts to develop technical guidance on how the relevant control rule computations can be made, including the estimation of limit F and limit biomass, which are used to determine when a stock is being overfished or can be classified to be in an overfished status. Additionally, guidance is being developed for establishing target control rules that are safely below the MSY control rule in accordance with the PA.

c) FAO

Some current FAO approaches were presented to applying PAs in developing country situations where quantitative data and data time series are relatively scarce. One approach, through the use of questionnaires, is similar to the approach employed in environmental assessment, and will probably also be a component of eco-certification schemes. One example (Caddy, 1996) is a check list which translates the management-oriented provisions of the FAO Code of Conduct into a semi-quantitative scoring for an individual fishery, to see the extent to which it corresponds to the provisions of the Code.

Given that the Code incorporates the PA, the scoring from this questionnaire, mainly aimed at fishery managers, is itself an index of the extent to which a fishery conforms to precautionary management.

A second draft questionnaire (see Caddy, 1998) seeks to provide a broad-based approach to identification of those aspects of fishery where potential risks may exist; using a 'traffic light' analogy whereby a 'red' scoring for one of the 20+ criteria included, implies that special concern should be devoted to addressing the risks it implies, either by formulating a relevant Limit Reference Point (LRP), or taking other management action. Total scoring of 'red' categories may even be used for comparing different stocks or fisheries as to their need for precautionary approaches.

Accordingly, the method suggests that an appropriate approach to precaution should begin with the general and move to the particular (i.e. from ecosystem considerations to single stock parameters); an approach implicit also in the 2 questionnaires mentioned above, which are believed to be equally, if not more, relevant, to management than to scientific advisors. The use of a suite of simple LRPs in 'traffic light' mode is illustrated, where a hypothetical situation is shown of a fishery operating under a harvest law such that the current number of 'red lights' triggered when LRPs are surpassed, leads to specific pre-negotiated levels of harvest; this example is expressed in relation to MSY conditions. Once the stock begins to recover, thus 'turning on' more green reference points, fisheries management could presumably allow a phased return to increased yield.

This example and the accompanying tables illustrate the importance of expressing precautionary considerations and LRPs in a manner readily understood by all concerned, including industry. It is also believed to illustrate that with multiple LRPs it is possible to use best available data and even analogies with other stocks, to develop a suite of LRPs. Such a suite of LRPs, and the management actions they apply, will inevitably need to be 'tuned' with experience in their use. It is noted that it is equally important that managers apply the PA in deciding LRPs, as it is for the scientists to propose them. Table 1 from the FAO report on precaution shows that one of the major sources of uncertainty and risk in taking management decisions is influenced by implementation uncertainly which is directly under control of the managers for fishery. Evidently, the successful application of precaution will involve coordinated responses through the whole assessment and management process.

TABLE 1. Classification of sources of uncertainty in the assessment and management process which will need to be taken into account in designing a precautionary approach.

TYPES OF UNCERTAINTY

There are several sources of uncertainty in the calculation of reference points, and in the evaluation of stock status relegate to these reference points. Five types of uncertainty arising from an imprecise knowledge of the state of nature are (Rosenberg and Restrepo, 1994):

- Measurement uncertainty is the error in the observed quantities such as the catch or biological parameters;
- Process uncertainty is the underlying stochasticity in the population dynamics such as the variability in recruitment;
- Model uncertainty is the misspecification of model structure;
- Estimation uncertainty can result from any, or a combination of the above uncertainties and is the inaccuracy and imprecision in abundance or fishing mortality rate;
- Implementation uncertainty results from variability in the resulting implementation of a management policy, i.e. inability to exactly achieve a target harvest strategy.

Note that sources of uncertainty include not only statistical error in detecting stock status and environmental trends or errors in population analysis, but also wrong decisions and an inefficient management framework; issues dealt with later in this paper.

III. THEORETICAL CONSIDERATIONS

1. Methods for Determination of Reference Points

Many related documents were circulated at this meeting (see List of Reference, Appendix III). Without any expressed preference, the Scientific Council Workshop reviewed several methods for calculating precautionary RPs. Theoretical considerations, which may be applied to all analyses were first discussed. For each method, it was concluded that Designated Experts should take into account underlying assumptions, data requirements, quality of the data to be included, and incorporate information on uncertainty or degree of acceptable risk. It was found that the models could be classified into 3 groups: a) those based on stock production, b) those based on yield- and SSB-per-recruit considerations, and c) those based on other considerations (such as growth, maturation, age structure, and other biological factors), as follows:

a) Methods Based on Production

ASPIC Model (Prager, 1994)

A surplus production model incorporating covariates was described and examples of previous applications were reviewed. ASPIC is an observational model incorporating information on total catch and indices of abundance or biomass based on CPUE or research surveys. Up to 10 indices may be incorporated in the model. The ASPIC model assumes logistic population growth with no explicit age structure. Residuals from a least squares minimization of observed and predicted abundance or biomass indices are used in a bootstrap procedure to derive variance estimates of biomass and F, and to initiate a stochastic projection of biomass and catch. Model outputs include parameter estimates of intrinsic rate of population growth (*r*), carrying capacity (*K*), catchability (*q*) of the indices, and initial biomass. Stock biomass in the first year is estimated directly, and biomass in subsequent years is fit by time series analysis. Biological reference points are calculated from the production model parameters as: MSY = $rK/4$, $B_{msy} = K/2$, and $F_{msy} = r/2$.

ASPIC is a flexible tool for determining stock production parameters, but the model is sensitive to the information quality of the input data. Catches should be as complete as possible and the biomass indices should ideally reflect a wide dynamic range in stock sizes incorporating periods of decline and rebuilding. This pattern is most likely to be realized if the data set includes a long history of exploitation, although each index may represent a series of shorter periods with sufficient overlap. The Scientific Council Workshop noted that considerable care must be exercised by stock assessment experts in evaluating the parameter estimates with particular emphasis on *q* for each index and the estimate of *r*. The estimated intrinsic rate of growth of a particular stock must be considered in light of the life history characteristics of the species with reference to other stocks by analogy. Likewise, estimates of *q* may be evaluated for a series of indices by analogy to other stocks.

It was further noted that parameter estimates which appear unreasonable for a given stock may be improved by conditioning the model fit on independent external information such as VPA-based stock biomass estimates. The most reasonable solution to poor initial results is to fix the *q* values by computing ratios of the indices to the external biomass estimates. This may be particularly useful for some NAFO stocks for which historical VPA-based biomass estimates are available, but the fishery is currently under moratorium. It is strongly cautioned that *r* should not be fixed since Fmsy is computed directly as r/2.

Age-Structured Projection Model (Constable and de la Mare, 1996)

An age-structured projection model was also introduced to the Workshop. This model satisfies several objectives for the maintenance of spawning sock biomass within certain criteria. Three main points were emphasized:

1) The criteria include specifying a bound on the probability that the spawning biomass will become depleted to below some specified level over a specified period, and set a further constraint on the long-term status of the stock relative to the pre-exploitation biomass.

2) The model provides a flexible method for assessing the influence of different patterns of growth, natural mortality, spawning, and fishing on estimates of yield and yield-per-recruit in an age-structured framework.

3) The model can be used to evaluate stochastic stock trajectories under a specified catch regime over a specified simulation period. These may be useful in evaluating harvest control rules.

It was noted that other production models, which are available for deriving biomass-based reference points, include those of Shepherd (1982) and the generalized production model of Pella and Tomlinson (1969).

b) Yield and SSB per Recruit Methods

Several approaches for analyzing production in an age-structured yield and SSB framework were available for analysis at this Scientific Council Workshop. A typical approach as outlined by Sissenwine and Shepherd (1987) was reviewed. In essence, this approach translates relationships between spawning stock biomass (SSB) and recruitment (R) to measures of SSB/R and associated percent of maximum potential spawning stock biomass, and measures of yield/R for corresponding levels of F. This approach may be used to derive estimates of F_{max}, $F_{0.1}$ and F_{msy}.

Each of the above models should account for possible changes in the exploitation pattern over time. In such cases it may be possible to use a relative F; e.g. the ratio of F/F_{ref} may be compared from various periods when the exploitation pattern has changed among periods.

It was also noted that initial work on yield-per-recruit explicitly took account of age-at-entry as well as variation in F. It is possible that age-at-entry can be used as a control variable in the precautionary framework and that management under the PA may account for gear selectivity.

Finally, it is useful to consider that the age structure of many stocks is currently truncated compared to earlier periods. The present as well as the potential age structure of each stock must be considered when computing F-based reference points. The Workshop considerations on this item are further elaborated in section III.5b (Other Aspects of Precautionary Approach).

c) Other Methods

Combining Limit and Target Reference Points: Examples of precautionary pairs of Target Reference Point (TRPs) and Limit Reference Points (LRPs) could be values of F set as a proportion x of the natural mortality rate for the stock, e.g.:

$$F(\text{Target}) = x_{TRP}.M, \text{ and } F(\text{Limit}) = x_{LRP}.M, \text{ where } x_{TRP} < x_{LRP}).$$

Such an approach might be used to formulate a precautionary pair of LRPs and TRPs. The value of x_{TRP} should be less than 0.5 for small pelagics (e.g. Patterson, 1992) but could be somewhat larger for demersals (see Die and Caddy, 1997).

The management strategy conceived with explicit use of LRPs should be quite different; as soon as evidence that one or more LRPs has been passed, the management response should be immediate, prenegotiated, and should involve cuts in catch and/or fishing effort until the stock has been restored to safe levels.

In the paper on "*Targets or Limits for Management of Fisheries?*" by Caddy and McGarvey (1996), the use of LRPs still remains to be conventionalized. One procedure in which reference points were defined in terms of fishing mortality as the control variable was described in this paper. The uncertainty and problems in estimating CV of F are recognized, but from a precautionary point of view it would probably be realistic for many fisheries to consider in absence of emperical estimates of precision values for CV of F greater than 0.3. Using such a value, the method should predict TRPs that are precautionary.

"Sustainable yield indictors from biomass: are there appropriate reference points for use in tropical fisheries?" by Die and Caddy (1997). This paper re-examines first the postulated point of Maximum Biological Production originally proposed by Caddy and Csirke (1983) in their paper on 'Approximations to sustainable yield', which derived this reference point from the postulated relationship between annual mortality rate Z_t and yield, and between Z_t and biological production: both relationships assumed to be equilibrium yield models logistic in form. Without suggesting that these models necessarily be fitted, the following definition:

> $F_{MBP} = F_{MSY} - 0.5\ M$ was derived. Evidently, F_{MBP} differs considerably from F_{MSY} for short-lived species, a conclusion also reached for small pelagics by Patterson (1992).

The same paper also proposes an extreme limit approach to using growth parameters and mean size, as embedded in the Beverton and Holt (1957) equation:

$$Z = K.(L_\infty - L) / (L - L_c)$$

where L is the mean length in the catch, L_c length at first capture and L_∞ the asymptotic length. The inequality $L < L_m$ (L_m is mean length at maturity) represents a non-precautionary approach to management, since reproduction before the stock is caught is not assured. Substituting L in the preceding equation by L_m leads to a limit reference point $Z^* < K\ (L_\infty - L_m) / (L_m - L_c)$ and by subtracting M, a value F* can be derived which may be compared with other F-based reference points, e.g. $F_{0.1}$. As an example, if $F_{0.1} > F^*$ it may not be precautionary.

If $L < L_m$, a further derivation from the same equation provides a LRP for L_c such that:

> $L_c > L_m - (L_\infty - L_m)\ K/M$. This length at first capture should allow reproduction prior to capture, and $L > L_m$.

The results of this method have to be considered in the context of the actual exploitation pattern.

2. Evaluation of Uncertainty

The Scientific Council Workshop noted that this Agenda item included many inter-related subject areas such as a) calculation of buffer reference points, b) precision of limit and target reference points, and c) precision of actual stock status, as listed in the Agenda (at Appendix I). Many publications were considered without preference. Highlights of papers considered at by the Workshop are summarized below.

A paper on "*A Simple Simulation Approach to Risk and Cost Analysis, with Applications to Swordfish and Cod Fisheries*" (Restrepo *et al.*, 1992, and a paper on "*The Role of Uncertainty in Fish Stock Assessment and Management: A Case Study of the Spanish Mackerel, Scomber scombrus maculatus, in the US Gulf of Mexico*" (Ehrhardt and Legault, 1997) were reviewed.

It was noted that stock assessments utilize many parameters, which contain uncertainty about the point estimate. This uncertainty can arise from many sources including natural variability, estimation procedures, statistical fitting and lack of knowledge regarding the parameter. The uncertainty can be incorporated into the assessment to produce a variable result under a given management scheme. Input data for stock assessments including catch-at-age, weights-at-age, maturity and growth estimates have inherent variability, which can be captured in the estimation process. Probability density functions can describe the measured or perceived uncertainty in the inputs by nesting bootstrapping methods directly into the VPA calibration procedures.

For example, bootstrapping the catch-at-age and the calibration indices can be accomplished during each iteration of the VPA to produce a combined probability density function which reflect error in the input data as well as model error. It was noted, however, that continued application of bootstrapping of more and more input data may ultimately lead to a flatter probability density function, with the largest effects in the tails of the distributions. Under this condition, the median values may remain relatively unchanged, but biomass or fishing mortality based on 5%, 10% and 25% probability levels may be altered considerably.

The Working Paper tabled at the ICES SGPAFM February 1998 meeting, on the "*Sensitivity of the "a" Parameter of Beverton-Holt and Ricker Models to Uncertainty in Stock and Recruitment*" (Rice, 1998) was reviewed. It began with the premise that biomass limit reference points should pay special attention to recruitments, which had been observed at small spawning biomasses. It investigated the sensitivity of the parameter of stock recruit functions, which represented the slope through the origin to perturbations in individual SSB and recruitment values. It found that this "a" parameter could be strongly influenced by the sizes of recruitments at high SSB (particularly in Ricker models), and by the SSB associated with small recruitments (particularly in Beverton-Holt models). It noted that the study did not negate the value of parameters reflecting the slope of stock recruit relations at low SSB as potential reference points, but did highlight the need to ensure that the parameter reflected the desired biological properties in specific applications. The paper also suggested non-parametric alternatives to stock - recruit model should be considered as tools for estimating biomass reference points.

A procedure for estimating stock and recruitment parameters in the presence of measurement errors was described in the paper on "*Measurement Errors and Uncertainty in Parameter Estimates for Stock and Recruitment*" (Ludwig and Walters, 1981). The method requires an independent assessment of the ratio of environmental and measurement error variances and provides maximum likelihood estimates of the time series of errors as well as the average stock-recruit parameters. Measurement errors may have two effects on the assessment of stock and recruitment: 1) the parameter estimates may be inconsistent as a result of hidden correlations in the regression equations, and 2) the amount of information available may be overestimated. Large observation errors will be translated into substantial uncertainty in parameter estimates and this effect frequently overwhelms effects of density dependence in the stock-recruitment relationship.

The effect of parameter uncertainty increases sharply at the ends of the spawner range where data are available. In most cases, the effect is most pronounced at the upper end of the spawner range. Thus, extrapolation of the stock-recruitment relation to higher values is not warranted. On the basis of the data, it may not be possible to predict the effect of a substantial increase in the number of spawners. In such a case, some unlikely outcomes may have large positive or negative effects on the expected performance of a given management strategy.

In the paper by Gabriel (MS 1994) on "*A Simple Method for Estimating Uncertainty Associated with F_{med}*", a procedure was presented whereby SSB/R data were summarized in units of percent maximum spawning potential (%MSP) as cumulative frequency distributions. The procedure can be used to evaluate the probability of stock persistence under a specified %MSP regime. Unconditional non-parametric bootstrap estimates of median SSB/R can be used to develop confidence intervals for F_{med}. In the stocks examined, the confidence intervals for F_{med} values were wide and asymmetrical; cumulative and raw frequency distributions were irregular, and skewed in some cases. The distributional properties of F_{med} from bootstrap procedures serve as summary indices to managers of likely levels of interannual variability in recruitment pattern, which become crucial when stocks reach low abundance levels with truncated age distributions. Alternative estimators of F_{rep} (rep = replacement) would thus benefit from some time-specific element related to stock age structure.

In the paper on "*The Maximum Reproduction Rate of Fish at Low Population Sizes*" (Myers *et al.*, MS 1998), a database of over 500 spawner-recruit series was used to search for parameters that are constant, or nearly so, at the level of a species or above. It was noted that the number of spawners produced per spawner each year at low populations is relatively constant within the species and that there is relatively little variation among species. This quantity can be interpreted as a standardized slope at the origin of a spawner-recruit function. The results were used to evaluate the reproductive rate at low population sizes which is a fundamental factor in estimating the population growth rate (r) and biological reference points for management purposes. The analyses suggested that at low population sizes, the number of spawner sizes per spawner each year typically ranged between 1 and 6 for most species.

General Discussion. Several points emerged from a general discussion of these papers. It was noted that most of the methods for addressing uncertainty were not new. Each of the various methods addressed one of two general problems: 1) estimating the uncertainty in a RP, and 2) estimating the uncertainty in the current state of a resource being evaluated against a reference point. There is a wide choice of analysis methods available for each of the two types of tasks, and no general guidelines had emerged for selecting which method(s) should be preferred overall, or in individual applications. Even without general guidelines, two things were clear. First, uncertainty or known changes (e.g. regime shifts) in many biological characteristics of a stock could affect the appropriate values for reference points - or the probabilities of complying with them. Second, even if the uncertainty in reference points and stock status were quantified well, the quantification becomes useful only when there is an agreed linkage of management actions to specific probabilities that reference points will be exceeded. It is a function of management to decide on the degree of risk, which can be tolerated. Therefore, the Workshop considered that dialogue with managers on this important point would be a necessary component of the precautionary approach.

3. Decision Rules or Management Actions (§69 resp. §66 of FAO Fisheries Technical Paper No. 350, Part 1, Guidelines on the Precautionary Approach to Capture Fisheries and Species Introductions)

Six papers dealing with various aspects of Harvest Control Rules (HCR) were reviewed, noting that specific reference to the methods by Caddy and McGarvery (1996) were addressed under Section III.1c above.

"*Illustrations of the precautionary approach using 4TVW haddock and 4VsW cod*" by Mohn and Black (SCR Doc. 98/10). An analysis was presented based upon integration of traditional yield-per-recruit and stock-recruitment models and resulted in a series of curves displaying the importance of the underlying biology of a stock as well as fishery management concepts.

"*Performance of some harvest control rules*" by Bell and Steffansson (SCR Doc. 98/7). The paper evaluated and searched for possible definitions of the bounds on implemented harvest control rule (HCR) in terms of satisfying the PA, yet giving maximal catches. The paper presented simulations of a number of HCR for 33 ICES stocks and concluded that the use of $F_{0.1}$ as a target and limiting interannual catch changes to 50% is satisfactory for the majority of stocks.

"*Halting declining stocks*" by Bell and Steffanson (SCR Doc. 98/12). The paper examined the use of the Magnusson-Stefansson feedback gain rule to halt the decline of a stock when only commercial catch and survey indecies are available. This process changes quotas to reflect changes in the survey index with some scaling factor. In its latest version, precautionary survey indicies were defined and the quotas reduced more drastically as the index passed between the target and limit reference points. This approach does not seem to improve the long term management possibilities of the original approach. It still, however, rapidly halts a declining stock and returns it to sustainable use.

In the paper on "*Checking of Some Conventional Management Reference Points for the Cod Stock off Greenland*" by Rätz and Lloret (SCR Doc. 98/4), based on relations between a number of parameters, stock developments for the Greenland cod stock were simulated under different conventionally applied management reference points in order to investigate their applicability. The simulations revealed that the stock does not sustain continuous exploitation at a level of the natural mortality, mainly due to slow growth, late maturation and emigration.

In the paper on "*Problems of Fishery Management: Precautionary Approach and Some Others*" by Rikhter (SCR Doc. 98/2), the author comments on some of the results presented by the Scientific Council Working Group dealing with the development of a strategy for a PA during its meeting in June 1997. Doubt was expressed concerning the possibility of getting a scientifically substantiated assessment of some reference points. Further, considerations relevant to general principles of fisheries management for fish stocks with stable and fluctuating recruitment were presented, i.e.: i) a management strategy that maintain the spawning biomass at an optimum level, ii) to keep the fishing mortality at an fixed optimal level, respectively.

In the paper on "*The limits of exploitation: a precautionary approach*" (Myers and Mertz, 1998), the authors formulated a model to demonstrate the safety benefits of prohibiting the harvesting of juvenile fish and concluded that from a precautionary perspective one should control selectivity. The model leads to a natural rescaling of maximum per capita recruitment rate, and it is shown that if this quantity is >1, then a spawn-at-least-once policy will prevent a collapse of the stock if fishing mortality targets are exceeded. Based on the result of the analyses the authors give a concrete recommendation saying that "fish should be permitted to spawn at least once before they become vulnerable to commercial gear". Furthermore if the spawn-at-least-once policy cannot be imposed, then the strategy should be to reduce the selection of younger fish sufficiently to provide a wide gap between F_{med} and the limit of sustainable fishing.

General Discussions. The differences in concepts of ICES and NAFO in relation to trigger points and decision rules were discussed. Furthermore, it was agreed that decision rules have to be related to stock specific properties. Most stocks in the NAFO area are considered to be outside biological safe limits and it was agreed that discussion should focus on decision rules to provide for a rebuilding of stocks and actions for reopening of fisheries.

4. Reopening Criteria Under Precautionary Approach

In June 1997, the Scientific Council reviewed the experience of the Fisheries Resource Conservation Council (FRCC) in developing criteria for re-opening fisheries. In particular, the FRCC pursued in 1995 a process of deliberation and consultation on the question of when and how to re-open fisheries which were put under moratoria. A framework based on the history of the indicators available (e.g. total biomass, spawning biomass, recruitment, fish growth, stock age composition, geographical distribution, fish condition factor, physical environment, etc.) was developed and used as guidance for the deliberations of the FRCC or for public consultations.

A key consideration in developing re-opening criteria was to attempt to define them, so as to obtain a real improvement from the conditions that prevailed at closure. Accordingly, the conditions at closure were characterized by low stock size, poor recruitment, and poor growth (as evidenced by declines in mean weight-at-age in catch samples and in survey samples). For each variable or indicator, a level representing a sufficient improvement upon the conditions that existed at closure was chosen. For discussion purposes, the halfway point between the low level that existed when the fishery was closed and the average level observed was chosen as a reference.

The "half-way point" criterion was proven difficult to implement, as it was considered to be arbitrary (not based on biology) and because of its high degree of dependence upon information from scientific surveys, which were considered unreliable for certain stocks (e.g. incomplete coverage of inshore areas). Nevertheless, the FRCC discussion paper provided a useful guide or checklist for "what to look at" when making decision on re-opening.

In the context of the NAFO Scientific Council proposed framework, there is no need for separate criteria for re-opening since pre-agreed management actions are already defined to match the limit reference points or thresholds. Also, the uncertainties inherent in the data do not justify separate limits for closing and re-opening. The intent is that if a limit reference point triggers a given action (e.g. closure) "on the way down", the same limit can be used to trigger a relevant action (e.g. re-opening) "on the way up". It was noted, in particular, that many biological features of a stock may be different when it is "on the way up", compared to when it is "on the way down" (for example, the age composition of the spawning biomass). Some of these differences may make it necessary to trigger different restrictive actions when a stock is in decline, than those used to permit some degree of re-opening when the stock is increasing (e.g. measures to ensure additional protection on spawners if the stock is composed only of a few year-classes). However, it was noted that using the same limit for closing and re-opening may result, in some cases, in having repeated closures/re-openings if the biomass trapped in the boundary of the "danger zone". Various ways to avoid that situation were discussed: e.g. forcing a greater reduction of fishing mortality when approaching the danger zone, increasing the time horizon for projections so as to avoid short-lived recoveries, using information on recruitment to evaluate the likelihood of a downturn following re-opening.

The Scientific Council noted that the "reference points at closure" or the "half-way point" criterion could be used directly as limit reference points in the PA, mainly when the limitations of the data do not permit the definition of analytical reference points. Despite the fact that these have been defined in absence of a biological framework, they constitute valuable guideposts that could serve, in the context of the PA, to identify zones that managers may wish to avoid. In particular, the "half-way point" could become a potential candidate for a limit reference point when it is clear that the quantity to which it is applied (e.g. SSB index, CPUE index, etc.) has been a key consideration for the closure of given fishery.

The Scientific Council further noted that the work of the FRCC serves to illustrate that the dimension of the precautionary framework need not be limited to the SSB and F planes, but could be complemented with information from other sources as well: e.g. recruitment index, fish growth, fish condition factor, stock age-composition, geographical distribution, etc. While in theory a multi-dimensional framework could be developed to do so, it may be sufficient at this stage to use information from other sources outside of the framework, *a posteriori*, to corroborate the conclusions of the present Precautionary Framework.

5. Other Aspects of Precautionary Approach

a) Exploitation Patterns

In managing a fishery, control of the exploitation rate is an effective tool. The exploitation rate is a function of fishing mortality which can be considered as a multiple of selectivity and effort. Selectivity of fishing gears is both size and species dependent while effort control is size and species independent. Selectivity properties of fishing gears are useful for improving the exploitation (partial recruitment) pattern, i.e. age dependent mortality can be managed by altering the selectivity ogive. On the other hand, effort controls, which reduce the mortality on all size or age groups by the same proportion, are more useful for controlling the overall exploitation rate. Thus fishing mortality can be controlled by controlling effort, selectivity or both. In the PA to fisheries management, the calculation of fishing mortality reference points and B_{MSY} require information on the exploitation pattern.

Changing the regulated codend mesh size of towed fishing gears is generally initiated to reduce the F on juveniles of the target species with a subsequent expected increase in long term yield. The expected consequence of a mesh size increase is an increase in the age of first entry of the target species into the fishery (Fig. 1). This will then necessitate the re-calculation of the partial recruitment pattern, which subsequently affects the indices of fishing mortality and the precautionary RPs, e.g. changes in selectivity will change the yield/recruit pattern. The magnitude of these changes depends on the level of mesh size increase. If the long term strategy is to manage the fishery at a reference target level of F such as $F_{0.1}$ then the fishery will be more dependent on older age groups such that the $F_{0.1}$ level of mortality will increase and a new target level of F may need to be defined.

For a given stock, an optimum mesh size should be chosen. In selecting this optimum mesh size both changes in yield-per-recruit and changes to SSB-per-recruit should be considered since there may be compromises between the two. Increasing mesh size can result in technical interactions between gear types in a fishery prosecuted by more than one towed gear, e.g. trawl and seine, due to inequalities in selectivity patterns caused by differences in catchability. Technical interactions can also occur in a multispecies fishery for example when changing codend mesh shape from diamond to square (mesh size remains the same) to reduce F on juveniles in roundfish fisheries such as cod and haddock, there could be an increase in F on juvenile flatfish. Furthermore, altering selectivity which increases F on older fish (Fig. 2) can be detrimental if spawning stock biomass is low. Increasing mesh size will also decrease the post selection (escapement) mortality of groundfish which die due to injuries sustained escaping through the codend meshes, i.e. unaccounted mortality. Such is not the case for herring taken in midwater trawling where post selection mortality is very high.

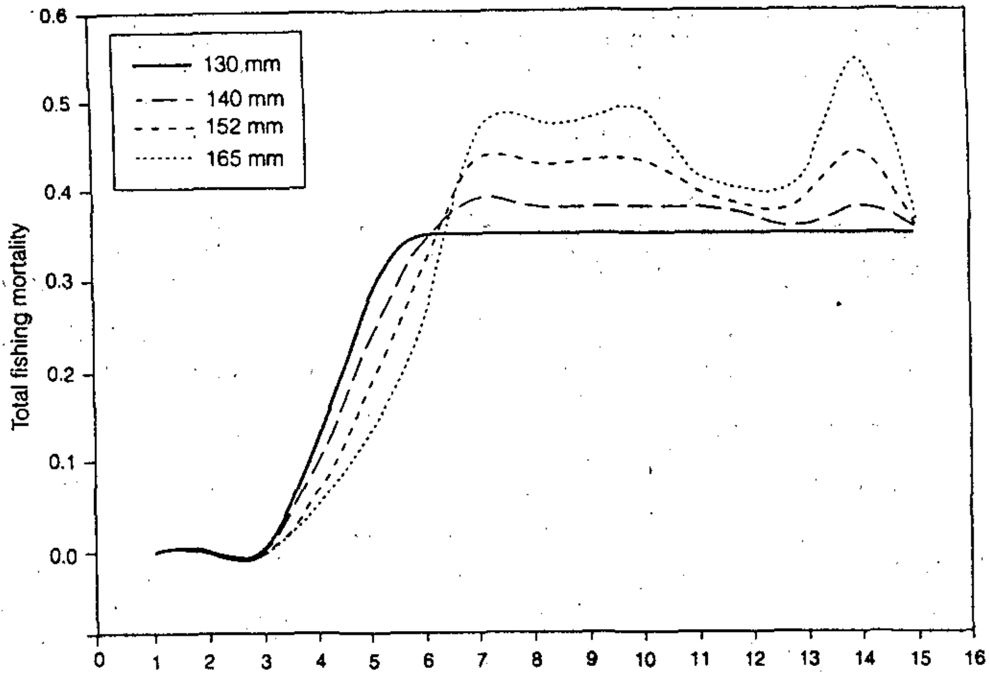


Fig. 1. Effects of increasing codend mesh size in a trawl fishery for cod managed at the $F_{0.1}$ level.

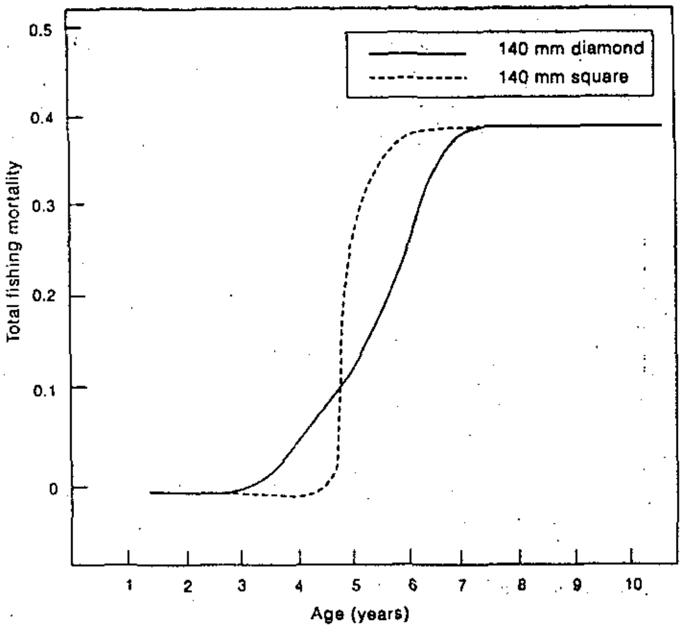


Fig. 2. An illustrative example of how a change in mesh shape can reduce mortality on juvenile while increasing mortality on adults in a bottom trawl fishery for cod.

The setting of minimum landing sizes (MLS) can also influence the exploitation pattern. If the management objective is to control F on juveniles, the MLS may be set at the 25% retention length of the legal mesh size, then a large number of marketable fish will escape. Consequently, there will be a loss in yield for the fisherman. In order to compensate for this loss, the fishermen will either increase the effort to make up for this loss or alter the gear in a manner to negate the loss of marketable fish. This is further complicated if it is decided that the MLS strategy should be based on length at first or 50% maturity which would result in the retention length moving toward 50% retention length or higher, i.e. a shift in effort from pre-spawners to post-spawners. If management objectives are the rebuilding of the SSB or reducing F on incoming year-classes to the fishery, then a strategy of increasing a mesh size, maintaining a *status quo* mesh size or introducing a new fishing gear can have a significant effect on achieving and sustaining those objectives. Hence, mesh size is an important tool when implementing management strategies .

New fishing methods are required that will reduce the mortality on juveniles and not increase it for older fish. For example, whole-gear selectivity can prevent juveniles and other unwanted by-catch from entering the trawl. Additionally, sorting (grids) grates placed ahead of the codend can reduce the juvenile and unwanted by-catches after they enter the trawl. However, more experimental development is necessary for them to be widely effective. Together with other technical measures such as small fish protocols, closed seasons and closed areas, these new fishing methods should be effective in reducing fishing mortalities on various age groups. When that happens, there should be an increase in the long term CPUE with future yields being comprised of more older, larger fish. However various scenarios of mesh size along with other technical measures should be explored. The economics of gear change is important.

It was also noted that the selection of a mesh size by management is an important decision as it influences the age and survival rate of the youngest year-class entering the fishery.

b) Stock Age and Length Composition

A common feature among many of the NAFO stocks is a truncated length and age distribution, most noticeable among stocks that have declined substantially in recent years. Some examples were shown at this Workshop for American plaice on the Grand Bank, and cod at West Greenland (Fig 3a, b). This has a number of implications when considering precautionary management approaches. In stocks where the truncation is most severe, the make-up of the remaining SSB is dominated by smaller fish relative to the past. Often the declines in stock size have been coincident with declines in the age and length at 50% maturity, resulting in fish spawning at smaller sizes and younger ages than was the case historically. Various studies suggest that SSB comprised largely of young or first-time spawners will not produce the same recruitment as the same weight of SSB comprised of more experienced or older spawners, for a number of reasons (see Section III.5.c).

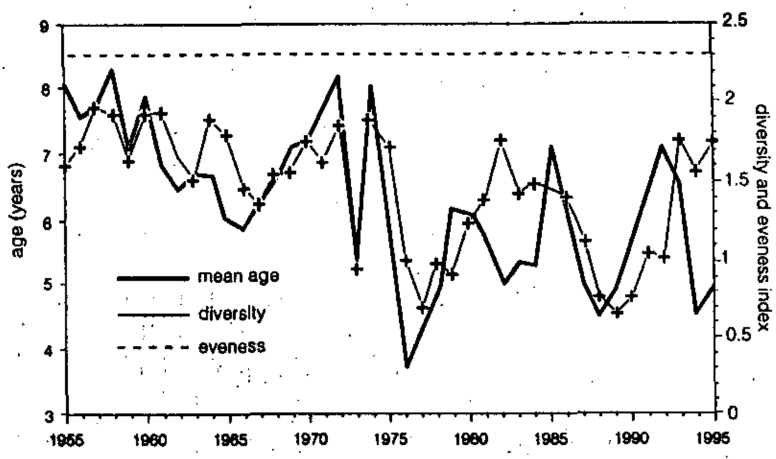


Fig. 3A. Data for West Greenland cod showing mean age in the stock and diversity and evenness index.

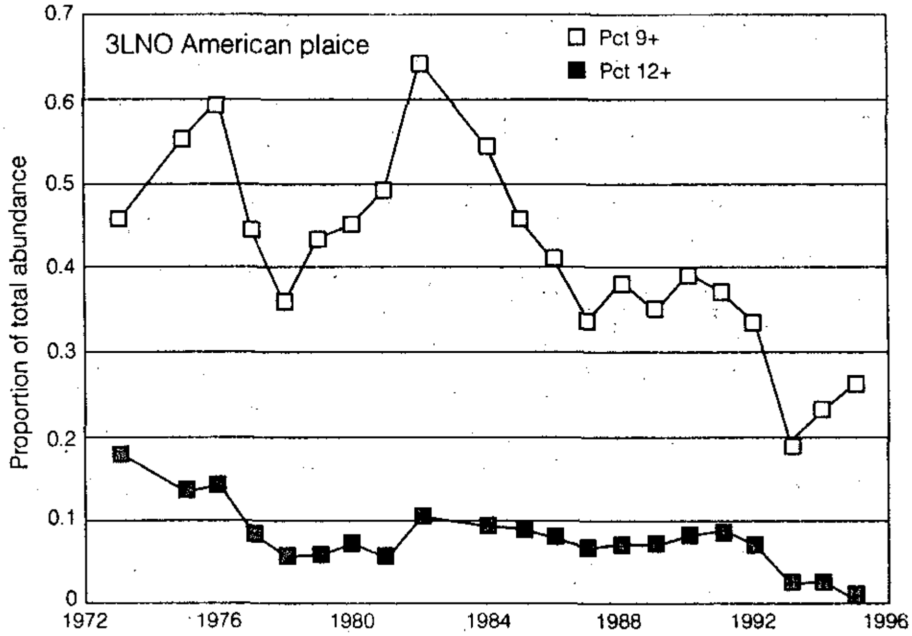


Fig. 3B. Proportion of American plaice abundance (from RV surveys) comprised of fish aged 9+ and 12+.

Another consideration with truncated populations is the effect on calculation of RPs in various equilibrium models such as yield-per-recruit. The effect of reducing the age span (as in a truncated population) is to increase the value of $F_{0.1}$, under equilibrium conditions (Fig. 4). Although the effect can be lessened by using a plus group for the last age, the choice of the age range is still important. For many stocks there are little or no current data on these older ages which once existed in the population, and there is the question of whether stocks will return to the age structure observed some time ago, under present environmental and biological conditions. Decisions on what ages to use in calculation of RP are important, and necessary on a stock-by-stock basis.

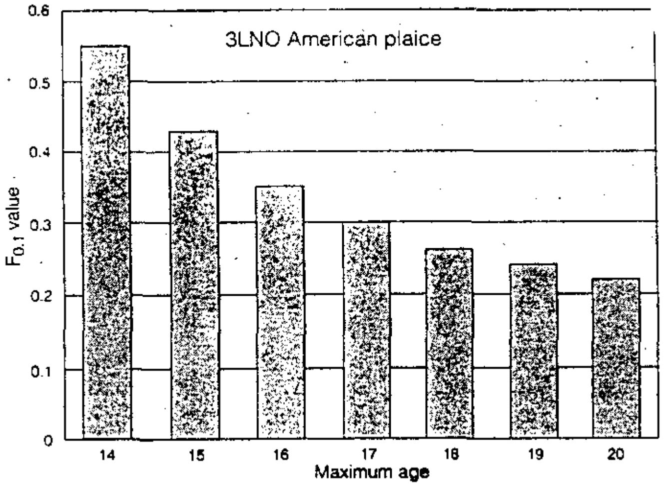


Fig. 4. Affect of $F_{0.1}$ calculation of the maximum age use din the Thompson-Bell Y/R model.

c) Growth, Maturation and Mortality

In the context of the PA to fisheries management, information on growth (length and weight-at-age), maturity (age and size at sexual maturity and fecundity) and natural mortality are critical for: (a) the evaluation of stock status; (b) the estimation of spawning stock size biomass and S/R relationships; and (c) the determination of biological RPs. Growth and maturity data may also used to detect growth and recruitment overfishing, assess the impact and response of size-selective harvesting on stock productivity, and guide the selection of conservation measures and fishing practices (e.g. mesh sizes and gear types) used to achieve management objectives.

Substantial declines in age and size at sexual maturity have occurred in many Northwest Atlantic fish stocks since the 1980s (e.g. see Trippel *et al.* 1997; O'Brien *et al.*, 1993) coincident with marked reductions in stock abundance. In most of these stocks, the current age and size at sexual maturity are at, or near, the lowest values on record implying that young fish dominate the spawning stocks, a situation very much different than former times. Apart from the reduced abundance of spawning fish in these stocks, the shift towards younger, first-time spawners raises concerns regarding diminished reproductive potential; as the egg viability of these spawners may be much lower than that of older, repeat spawners (Trippel, 1997).

The calculation/estimation of most precautionary biological RPs require weight-at-age, maturity-at-age and/or SSB data (see Serchuk *et al.*, SCS Doc. 97/12). It is therefore important that these input data be as accurate as possible. For example, using weights-at-age values derived from either the catch or the stock to characterize the weights-at-age of the spawning stock may be inappropriate as the weights of spawning fish can be considerably greater than non-spawning fish of the same cohort (Trippel, 1995). Equally, if maturity-at-age data are available, these should be used in estimating SSB rather than assuming knife-edge maturation at a particular age.

Maturity data should be collected during the seasons/time periods of the year when the gonads of mature and immature are best distinguished. (this will obviously be species-dependent). There is also a need to validate the methods (visual; histological; blood hormones; liver weights, etc) used to determine maturity.

Analyses have indicated increases in non-fishing mortality for some Northwest Atlantic cod stocks in recent years. Such changes will have important impacts on both the calculation and relevance of reference points and therefore, these types of changes must be fully evaluated so as to be incorporated in the most appropriate manner.

d) Species Interactions

Two working groups of ICES have reviewed multispecies and ecosystem aspects of RPs and PA to assessment and management.

The Multispecies Assessment Working Group Report (ICES, MS 1997) reports on the results of several studies on RP and management strategies in multispecies contexts.

When two-species interactions are added to Sissenwine and Shepherd (1987) Model, the shapes of both the recruits-per-spawner and the yield-per-recruit as a function of fishing mortality curves are changed. When predation is added to the recruits-per-spawner curve, it shows that single-species treatments underestimate the true numbers of progeny produced per spawner, and the effect increases as spawning biomass increases. Single species treatments overestimate the yield-per-recruit, though, and the effect is largest at low F. The effect is small for $F >$ about 0.6. Both effects are sensitive to the relative timing of predation mortality and fishing mortality. When the predation mortality is due to cannibalism, the effects of the predation on recruits per spawner and on yield-per-recruit roughly cancel, so the various reference points (F_{msy}, F_{crash}, B_{msy}) are nearly the same between single-species and multispecies estimations. However, if the predation mortality is by another species, the consequences for recruits per spawner and for yield per recruit can be quite different. If the predation mortality occurs on the same ages as are fished, then single species treatments may over-estimate F_{crash} and B_{msy}, and underestimate F_{msy}, compared to the multispecies treatment. If the predation mortality is largely on younger ages than are fished, then single species analyses may underestimate B_{msy}. Effects on F reference points appear to be case specific.

The assessment WG found that inaccuracies in estimates of B and F reference points have fairly small effects overall, as long as F remains fairly consistent. However if F changes substantially for any reason, the inaccuracies can have substantial consequences. This was shown in several rebuilding simulations, where rebuilding trajectories were estimated for both single-species and multispecies representations of various scenarios. Rebuilding was generally much slower when multispecies relationships were accounted for than was predicted by single species analyses. During rebuilding both initial recruitments and yields were not as high as predicted by single-species treatments. This means that if rebuilding was supposed to occur while fisheries harvested the yield estimated for the lower F with single species yield-per-recruit analyses, the actual lower yield-per-recruit due to unaccounted predation mortality would delay rebuilding further. These difficulties in achieving rebuilding targets estimated with single species analyses were present in all the scenarios investigated, regardless of the timing of predation and fishing, but the magnitudes did vary.

The assessment WG also considered multispecies VPA models of the 3 species Baltic Sea system (cod, herring, sprat). For three models of increasing biological complexity, the analyses estimated the F levels on cod and the prey stocks which were consistent with achieving a specific (but arbitrary) management goal. It was shown that including predation mortality can change the mix of Fs on predators and prey which were "sustainable", and adding effects on the growth and maturation of cod due to the sizes of the prey stocks can change the mix of sustainable fishing strategies further. The WG also reviewed results of using two species models of predators and prey, or two competing species, within Lotka-Volterra models. The work demonstrated how such models can be used to identify regions of permissible management (Fs on predators and prey, or on competitors, which allow all species to persist). The assessment WG stressed that these studies were illustrative, rather than definitive treatments of the problems. They highlighted the need for such work to be pursued further.

The major conclusions to the assessment WG were:

1. In multispecies systems, F reference points (particularly F_{crash}) may be over-estimated by single species methods.
2. In multispecies systems recovery times of depleted populations may be underestimated badly by single-species methods. Recovery can be slowed further by fishing to a target F during the recover period.
3. Rebuilding populations of predators may change what is thought to be precautionary for prey stocks. Knowledge is inadequate for general rules about "complementary measures" for precautionary management of predators and prey together.
4. True multispecies systems will exhibit more complex behaviour than the two and three species models investigated at the meeting.
5. The tools are not available at present to conduct appropriate evaluations of proposed single-species reference points within a multispecies framework.
6. There is no universal treatment appropriate for all multispecies associations. Even our preliminary work has shown that factors like timing of fisheries relative to predation is important.
7. Within a precautionary framework, complexity, like uncertainty, is not a reason to delay coming to grips with these important considerations.

The Report of the Working Group on Ecosystem Effects of Fishing (ICES, MS 1998) discusses precautionary management in a full ecosystem context. It began with a review of present ICES practice, noting the use and interpretation of "Safe Biological Limits" and "MBAL". It also noted the recommendation from ComFIE that F should be kept below F_{lim} with $P > 0.95$, and B should be kept above B_{msy} with $P >= 0.50$. It posed the question:

> "If all fisheries were managed so that there was a high probability of achieving conservation objectives for the target fish stocks, would there be a high likelihood of achieving conservation objectives for ecosystems?"

The WG concluded that the answer to that question was clearly "No", and additional reference points were needed for four classes of concerns:

1. Genetic diversity of target stocks could be at risk, even if the stock overall was not;
2. Conservation of non-target species could be at risk;
3. Conservation of dependent predatory species could be at risk;
4. Conservation of some species could be placed at risk due to increasing the abundance of scavengers on discards and offal.

The WG further noted that each of these concerns could be addressed by adding additional single species reference points. It then posed the question:

> "If appropriate single-species reference points were added to address the four additional considerations, and if fisheries were managed to have a high likelihood of complying with those reference points; Would conservation and sustainability of the ecosystem be achieved with at least equal likelihood?"

To this it was concluded that "we do not know". It did stress that despite considering diverse modeling approaches to ecosystem dynamics, no modeling framework which was reviewed had identified a property of the ecosystem which would be at risk, if none of the constituent species were at risk. It noted, however, that there was sufficient knowledge to demonstrate that:

1. Fishing had changed the size composition of fish and larger invertebrates in many ecosystems.
2. Changing the size composition of predators will change the way that predation pressure is distributed among lower trophic levels.
3. Because fishing has changed the numbers and biomass in different trophic levels, it has changed the flux and residency of nutrients in ecosystems. However, different models make very different predictions about the consequences of these changes. The WG concluded that to progress further with looking at precautionary approaches in an ecosystem context would require programs which would identify:
   a) What ecosystem properties require more than just the conservation of the individual component species?
   b) Which of these properties could be placed at risk by fishing?
   c) What management measures would be necessary to have a high likelihood of achieving conservation of the properties in b)?
   d) How could the properties potentially at risk from fishing be measured and monitored?

This Scientific Council Workshop considered this information to be a useful contribution to its discussions. It was agreed that the general approaches taken by the ICES Working Groups were sound, and endorsed the importance of pursuing these investigations further.

The considerations implied by the results should be kept in mind when using reference points from single-species analyses.

The Scientific Council Workshop noted there are several circumstances which are not adequately addressed in fish population dynamics, and can potentially jeopardize any PA implementation. Some of them known in the NAFO area such as changes in the productivity and dynamics of fish stocks including migration pattern and geographical distribution are commented on here.

For example changes in fisheries not attributable to fishing activity were considered. Changes of this nature are often observed without being predicted and as such decompose any forecast based on current population dynamics. They reduce the capacity for medium or even short-term projection. When such changes occur, there is no management action which could be used to reverse the situation. Many long-term changes in marine fisheries are documented (e.g. Wyatt and Larrañeta, 1988).

Several stocks of marine fish in the Northwest Atlantic have shown major changes in distribution, migration and productivity within the last decade. Some stocks have shown dramatic declines in stock under little or no fishing pressure, e.g. American plaice in SA 2 and Div. 3K. Others have shown no signs of recovery or continue to decline under fishing moratoria, e.g. cod and American plaice on the Grand Bank (see also Section 5a of this report, last paragraph).

e) Technical Interaction

By-catch where it is a matter of concern and may continue to be: by-catch is a consequence of the species being distributed in the same area as the target species, and although some by-catch can be retained and landed, under-sized fish by-catch, currently discarded, is largely detrimental to stock yield. One aim in the development of gear technology is to produce more selective devices and although some progress has been recently made in sorting grates, it is expected that further advances will improve selectivity of the gears (as previously discussed in Section III.5.a).

The shrimp fishery on Flemish Cap has small redfish as its main by-catch. This by-catch has been at a minimum by the use of sorting grates introduced in 1994 (NAFO, 1993). However, the recruitment of redfish was also very poor, thus the ability to avoid this by-catch is not well known. When good redfish year-classes finally occur, their abundance and subsequent yield can be sharply reduced if sorting grates are inefficient.

The management of re-opening of a single species fishery is complicated when the distribution of other commercial fishes under fishery moratoria overlap in distribution For example, a directed yellowtail flounder fishery on the southern Grand Bank, NAFO Div. 3NO, in August of 1998, will have varying levels of by-catch of American plaice and Atlantic cod, depending on area location of the fishery, whose fisheries are still under moratoria.

Up to now, the moratorium or closure of fisheries was only used sporadically to rebuild overfished stocks, however, moratoria may became a common regulatory tool under the PA regime. The possible overlapping of species distribution with different exploitation situations and the coincidence of closed and open fisheries in the same area, may make their implementation and control more complex. Area closure is the more classical tool to solve these conflicts among species regulations, but closure must be almost permanent when applied to long living species, as most of the resources in the NAFO area are. Technological advances in gear design and performance may contribute to more effective ways to solve some of these problems. Desired gears improvements showed increased size and species selectivity, and reduced mortality on non-retained fish (see Section III.5.a).

IV. CONSIDERATIONS FOR NAFO STOCKS

Categorization of NAFO Stocks

The Workshop noted the difficulty of categorizing the various NAFO stocks under defined criteria. It was agreed that the best approach was to select one stock for detailed consideration and developing ideas from it on how to address the other stocks. American plaice in Div. 3LNO was selected because of the long data series available for the stock and because a VPA had been applied during earlier assessments of the stock. In addition, the Workshop selected a few stocks for which assessments were problematic; Greenland halibut in Subareas 2 and 3, Shrimp in Div. 3M, Redfish in Div. 3M and Squid in Subareas 3 and 4, for consideration of different methods of developing reference points.

For those stocks not considered at the plenary sessions, a list of methods explored for the definition of reference points is given for each stock in Annex 1.

The discussions initially considered categorization of stocks under the framework of consideration of 'data-poor' *versus* 'data-rich' conditions. They broadly fell into two types: quantity and quality of data. In general it was concluded that all considered methods could be applied to stocks with age based data although the quality of the data may influence the validity of results. The absence of age-based data constrains the number of methods for determination of reference points considerably.

General Considerations

In the Guidelines of Annex II, item 6 of the UN Agreement it is indicated that in the case of insufficient information for the determination of RPs provisional RPs should be set. Survey data mostly provide biomass estimates, which would provide a lowest observed biomass. The Workshop considered it unwise to use the lowest observed biomass from short survey data series when there is no basis to judge if the minimum biomass observed in the time series is adequate or inadequate to ensure sustainable productivity of the stock in future. Many of the NAFO survey data series show levels of biomass which are very low and considered to be too low to serve as limit RPs.

A non-parametric precautionary framework (Rivard, MS 1998) was presented and discussed. Simple data descriptions are useful for communicating complex information. The suggested method displays time series on stock performance or condition (see Table 2). The approach offers a simple framework to evaluate information from a wide variety of sources, including catch and effort information, indices of recruitment or biomass, results generated through analytical assessments, or non-quantitative performance indices amenable to a classification scheme (e.g. low, medium, high). The method was applied to eight cod stocks of the Northwest Atlantic (see Table 3). A possible benefit of that approach is that non-parametric treatments of data are often more robust to anomalies in the data than parametric approaches. This approach appear to be most useful when stock condition has varied over time, so as to cover the dynamic range of possible stock trajectories. It was noted that if the biomass has remained relatively constant over time, then the condition categories established from the time series may not be "biologically meaningful". However, in such cases, other means would have to be taken to establish the categories. This non-parametric framework would be amenable to a PA framework whereby pre-agreed management actions would be triggered under each of the categories of overall stock performance. The end result would be a management-testing scheme whereby simple feedback control rules based on the performance categories could be tested. While the framework would not allow for catch projections in the context of TAC setting, a scheme could be developed to define sets of rules (or procedures) by which adjustments to catch levels would be made. The method, however, requires a sufficient long time series to provide reliable categorization.

The problem of developing fisheries was generally addressed. When data are not available to estimate the impact of rapidly increasing fisheries on the stock development, conservative caps should be placed on both fishing capacity and fishing mortality rates. This could be achieved by for instance limiting effort or TAC. The caps should remain in place until data analyses justify an increase in fishing effort or fishing mortality.

A simulation approach (Bell and Steffansson, MS 1998) was considered appropriate to evaluate a strategy for reopening closed fisheries. In a rebuilding phase, catches should be constrained in order to guarantee a precautionary development of the reopened fishery (see Section IV.1 American plaice in Div. 3LNO). Other aspects of reopening of fisheries were discussed. If it is decided to reopen a fishery but other fisheries are still kept closed in the same area, technical interactions such as by-catch of species under closure have to be considered in the precautionary framework.

Stocks, which have declined to a very low level, may not demonstrate the same production dynamics during and after recovery and hence reference points should be recalculated for management purposes after reopening of the fishery.

The influence of environmental effects on stock dynamics was discussed. Reference points have to be determined in such a way that effects of environmental changes are included in the evaluation of limit reference points and buffer reference points.

Detailed considerations of these general aspects in stock specific situations are addressed in the following stock reports.

TABLE 2. Historical performance for the principal cod stocks of the Northwest Atlantic.

	Cod 2J3KL	Cod 3NO	Cod 3Ps	Cod 3Pn4RS	Cod 4TVn	Cod 4VsW	Cod 4X	Cod 5Zjm
1960		⊙	○		⊙	○	◉	
1961		○	⊙		⊙	○	⊙	
1962	○	⊙	○		⊙	○	⊙	
1963	○	⊙	○		⊙	○	⊙	
1964	○	○	○		⊙	○	⊙	
1965	○	⊙	○		⊙	○	○	
1966	○	⊙	⊙		◉	○	⊙	
1967	○	⊙	○		⊙	○	⊙	
1968	○	⊙	○		◉	○	⊙	
1969	○	⊙	⊙		⊙	○	⊙	
1970	○	⊙	⊙		◉	○	⊙	
1971	○	⊙	○		⊙	⊙	⊙	
1972	○	⊙	⊙		⊙	⊙	◉	
1973	⊙	⊙	⊙		◉	◉	⊙	
1974	⊙	⊙	◉	⊙	◉	◉	◉	
1975	◉	◉	◉	⊙	◉	◉	⊙	
1976	◉	◉	◉	⊙	⊙	◉	⊙	
1977	◉	◉	⊙	⊙	⊙	◉	⊙	
1978	◉	◉	◉	○	⊙	⊙	⊙	◉
1979	◉	◉	◉	⊙	⊙	⊙	○	⊙
1980	◉	◉	◉	○	⊙	⊙	⊙	⊙
1981	⊙	⊙	⊙	○	⊙	⊙	○	⊙
1982	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
1983	○	⊙	○	⊙	○	⊙	◉	◉
1984	⊙	⊙	○	⊙	⊙	⊙	⊙	⊙
1985	⊙	⊙	○	⊙	⊙	⊙	●	◉
1986	◉	⊙	⊙	◉	⊙	⊙	◉	⊙
1987	◉	◉	⊙	●	⊙	◉	◉	⊙
1988	◉	◉	◉	◉	◉	◉	◉	⊙
1989	◉	◉	⊙	●	◉	◉	◉	◉
1990	◉	◉	◉	●	◉	◉	⊙	⊙
1991	●	◉	◉	●	●	●	◉	◉
1992	●	◉	●	◉	●	●	◉	◉
1993	●	◉	●	●	◉	●	●	●

Comparison to average performance

○	Much better	⊙	Better
◉	Worse	●	Much worse

TABLE 3. Stock performance - annual view.

1983	Fishery		Stock Status					
STOCK	Catch	CPUE	Recruitment	Biomass	SSB	Fishing Mortalit	Growth	Overall
COD 2J3KL	⊙		○	○	⊙	○	○	○
COD 3NO	⭘	○	⊙	⊙	⊙	○	○	⊙
COD 3Ps	⭘		○	○	⊙	○	○	○
COD 3Pn4RS	○		⊙	○	○	○	○	⊙
COD 4TVn	○	⊙	○	○	○	○	⭘	○
COD 4VsW	⊙	⊙	⭘	○	○	○	○	⊙
COD 4X	○		●		⊙	⭘	●	⭘
COD 5Zjm	○		●	⭘	○	⭘	●	⭘

1993	Fishery		Stock Status					
STOCK	Catch	CPUE	Recruitment	Biomass	SSB	Fishing Mortalit	Growth	Overall
COD 2J3KL	●						●	●
COD 3NO	●		⊙	●	●	○	●	⭘
COD 3Ps	●		⭘	●	●		●	●
COD 3Pn4RS	●		●	●	●	●	●	●
COD 4TVn	●	●	●	●	●	○	⭘	⭘
COD 4VsW	●	●	●	●	●	○	●	●
COD 4X	●		⭘		●	●	⭘	●
COD 5Zjm	●	●	●	●	●	●	●	●

Comparison to average performance

○ Much better	⊙ Better
⭘ Worse	● Much worse

1. American Plaice in Divisions 3LNO

a) Description of Fishery

Catches increased rapidly from about 20 000 tons in the early-1960s to a peak of 94 000 tons in 1967, were relatively stable around 45 000-50 000 tons in 1973-82, then declined to 39 000 tons in 1984-85. Catches increased to 65 000 tons in 1986 and then declined steadily to about 15 000 tons in 1992-93. The 1994 catch was estimated at 7 400 tons, although no directed fishing was permitted on the stock in that year. Following closure of the fishery, by-catches were reduced to 637 tons in 1995 and 913 tons in 1996.

Many fleets participated in the fishery up to the mid-1970s. From 1977 to 1982, the catch was taken almost exclusively by Canadian vessels, but the catch by other nations increased rapidly from less than 2 000 tons in 1981-82 to over 30 000 tons in 1986 as new fisheries were developed in the Regulatory Area. Catches from these fleets have generally declined in recent years, as has the Canadian catch, although catches by Non-Contracting Parties in 1993 were an exception to this trend.

Various catch estimates were used in the late-1980s and early-1990s, including surveillance estimates, breakdowns of unspecified flounder catches by S. Korea prior to 1991, and any other estimates deemed by STACFIS to be reliable. There is also some uncertainty regarding catches prior to 1973, when large amounts of unspecified flounder catches from some nations were broken down by species based on estimates of species composition.

b) Quality of Available Data

VPA (1960-92 data)

- Catch-at-age and weights-at-age are not well estimated from 1960-64. These data were usually included in VPA runs but excluded from calibrations in earlier assessments.
- No plus group was used in the catch-at-age. This has the effect of underestimating biomass and SSB in earlier years, when more old fish existed in the population. This is not important when considering recent years only
- Catch-at-age data prior to 1974 are from Div. 3LN only, and include an adjustment to make them comparable to the data from 1974 onward, which are for Div. 3LNO.
- Catch-at-age (and total catches) are not well estimated from about 1986 to 1993 due to substantial catches by fleets of Non-Contracting Parties, and suspected wide-spread use of small mesh in some fleets.
- Reference F levels were calculated as the mean F at ages 8-12. This includes partially recruited ages but covers a substantial portion of the catch in most years.
- Substantial discarding existed during several periods, and was likely quite variable over time. No discard estimates are available for inclusion in the catch-at-age.
- VPA models run in the early-1990s for this stock showed a lack of fit with available tuning indices, and were rejected by STACFIS as the basis for assessment advice in 1991 and not used after 1993.
- A severe retrospective pattern in VPAs resulted in substantial downward revisions of population sizes in subsequent assessments. Thus the most recent years in the last VPA (1993) would likely have lower biomass estimates if VPAs were available up to the present.
- Maturity data by sex exist annually since 1960, but corresponding catch-at-age and population-at-age data were not available by sex. Using 9+ biomass as a proxy for SSB is reasonable under current maturity-at-age conditions, but may overestimate SSB in earlier times due to the substantial decline in maturity-at-age, which has occurred in this stock. Nonetheless, estimates of SSB for the 1960s used in this workshop (300 000 + tons) agreed with those obtained in earlier ICNAF assessments of this stock.

RV Surveys (1971-97)

- There have been 2 gear changes in the Canadian survey series covering the period 1971-97. The first was in 1983 and the second in 1995. The period 1971-82 has been linked with the period 1983-1995, and the periods from 1983-95 and 1996 onward have also been linked. However, the acceptability of linking all the data (double-converting the data from the earliest time) has not been determined.
- USSR/Russian survey data exist for 1972-91, but not for the period after 1991. Data from shorter Canadian survey series (fall 1990-96, and juvenile 1985-94) were also examined. Data also exist from Spanish surveys in the NAFO Regulatory Area in Div. 3NO in the years 1995-97 but were not examined here.
- SSB estimates exist from surveys for the period 1975-95, based on yearly maturity ogives for the female portion of the stock. They show a slight increasing trend up to the mid-1980s, and a precipitous decline after 1988. The SSB estimated from VPA shows relative stability from

the mid-1970s to 1985, and a sharp decline thereafter. VPA biomass was used in most analyses because of the longer time series (back to 1960), even though estimates of the female portion of the SSB could not be calculated.

CPUE

Annual estimates of CPUE were available from a model which standardized Canadian catch-rate data for area, month, and vessel category. This series did not include data from other fleets which comprised important components of the fishery prior to the mid-1970s, and after the mid-1980s. Data from NAFO Statistical Bulletins for other nations exist for certain periods but were not used in any analyses.

Natural Mortality

The value of M may have increased. The adjacent stock of American plaice (SA 2 + Div. 3K) declined by over 90% after 1984, despite catches in the range of 1-4% of RV trawlable biomass. This decrease corresponds with the period of severe decline in the Div. 3LNO plaice stock, which continued to decline after the moratorium in the mid-1990s, particularly in the northern part of the stock, Div. 3L. Severe declines were also observed for other species, with varying levels of fishing, and increased values for M have recently been estimated for some cod stocks in the Northwest Atlantic during the 1990s.

c) Calculation of Reference Points

In considering the data for this stock for various analyses, it was recognized that there had been a number of changes over time. For example, catches were much higher in the 1960s, than in most other years, and were reduced to very low levels in the mid-1990s. As well, there had been substantial changes in some parameters such as maturity (Fig. 5) and mean weights-at-age. There also appeared to be substantial changes in the SSB-recruitment relationship over time. The current stock size is dominated by young fish, with few older fish relative to earlier years (Fig. 6), and recent surveys suggest that the stock continued to decline after the moratorium in 1995. Preliminary results with some models gave very different results depending on the range of years selected, so it was decided to conduct analyses over 2 time periods: 1960-77, and 1980-95. The biological data did not indicate a single year which could be used to separate the data, so the break point was chosen as a time when a major change was introduced in the fishery i.e. the declaration of the Canadian 200-mile limit. The results from each period were compared with the full time series where possible.

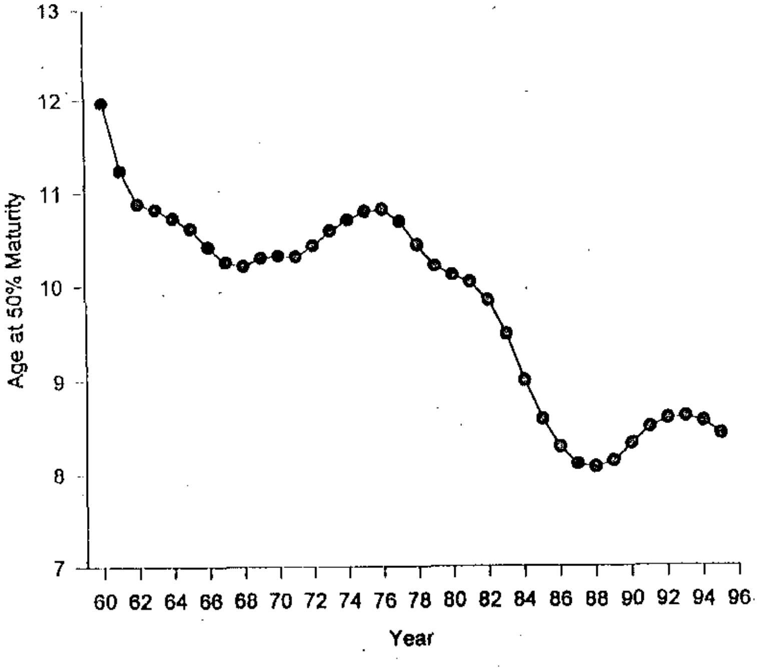


Fig. 5. American plaice in Div. 3LNO: age at 50% maturity for females.

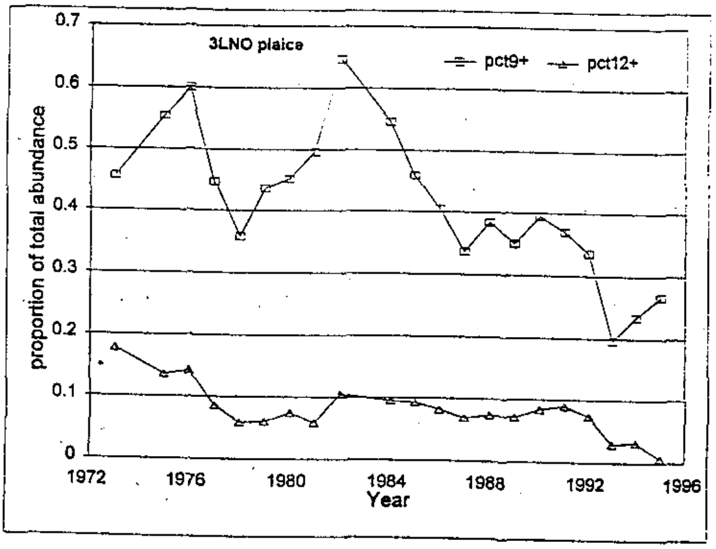


Fig. 6. American plaice in Div. 3LNO: proportion of abundance (from RV surveys) comprised of fish aged 9+ and 12+.

Non-equilibrium stock production model incorporating covariates (ASPIC). A non-equilibrium surplus production model - ASPIC (Prager, 1994; 1995) was used with catch, CPUE, and survey indices. Several analyses were conducted using different combinations of indices and various ranges of years. CPUE data back to 1960 were included, given the dynamic range of these data, and were supplemented with survey series starting in 1971 or later. When the datasets were split into the earlier and later periods (1960-77, 1980 onward), the model could only find a solution within strict constraints, and there were strong residual patterns within the separate time periods. Estimates of MSY and ratios of F and biomass to MSY reference points are more robust than the absolute levels of biomass or F coming from the models. Estimates of MSY, based on either the full time series or 1960-77, were in the range of 44 000 to 56 000 tons, and agreed with various equilibrium surplus production models which have been run. The ratio of recent stock biomass to B_{MSY} was very low in all cases, and the ratio of biomass to B_{MSY} was below 1 after the late-1960s. Figures 7a, b, c shows the model results for the long time series. Figures 7d and 7e show the resultant relationship of yield over fishing mortality and between yield and spawning stock biomass, respectively.

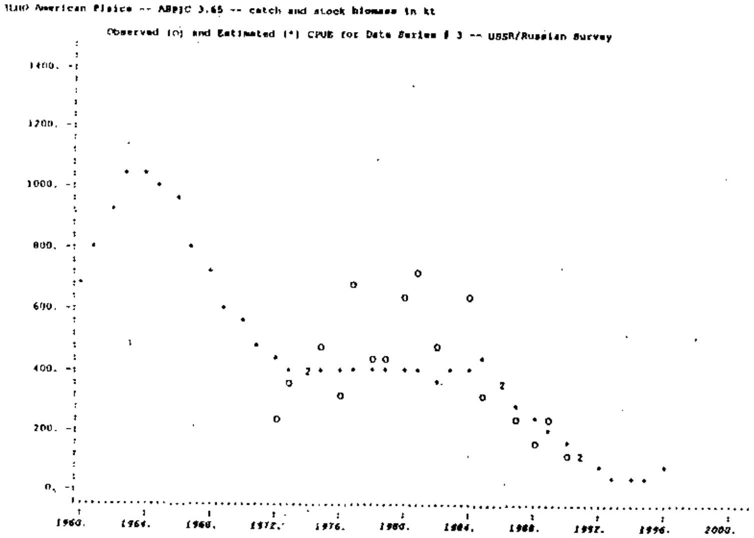


Fig. 7a. American plaice in Div. 3LNO: results of ASPIC model, showing model fit *vs* USSR/Russian survey data.

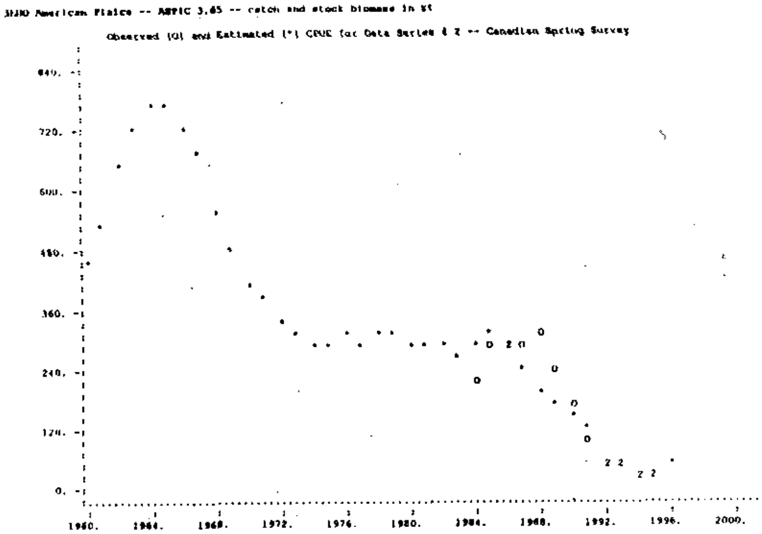


Fig. 7b. American plaice in Div. 3LNO: results of ASPIC model, showing model fit *vs* Canadian spring survey data.

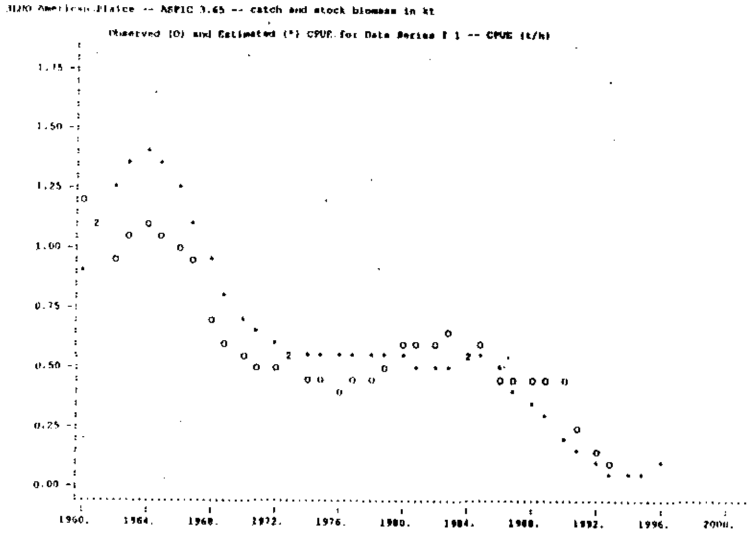


Fig. 7c. American plaice in Div. 3LNO: results of ASPIC model, showing model fit *vs* Canadian CPUE data.

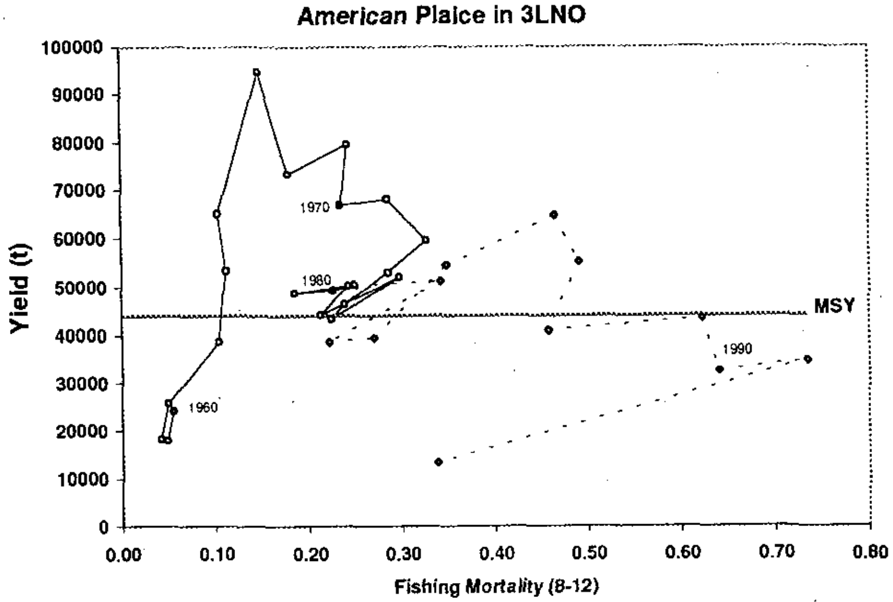


Fig. 7d. American plaice in Div. 3LNO: trajectory of yield as a function of Fishing Mortality.

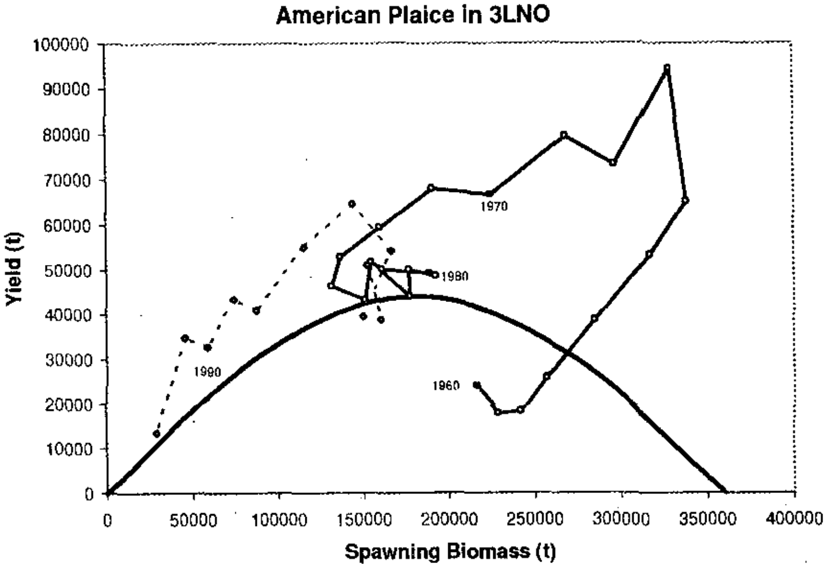


Fig. 7e. American plaice in Div. 3LNO: yield as a function of SSB.

G_{LOSS} analysis. An analysis was carried out to investigate sustainable fishing mortality rates and to compare the history of the stock with expected equilibrium conditions. G_{loss} is the replacement line which corresponds to the lowest observed spawning stock (LOSS) and is a minimum estimate of G_{crash} (Cook, 1997).

Clearly the wish is 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.

The method was tried with data from 1960-77, 1960-92 , and 1980-92. These analyses suggest that the stock was fished outside sustainable levels for an extended period. The results for 1960-77 are shown in Fig. 8. The analysis with the data for 1980-92 did not yield meaningful results.

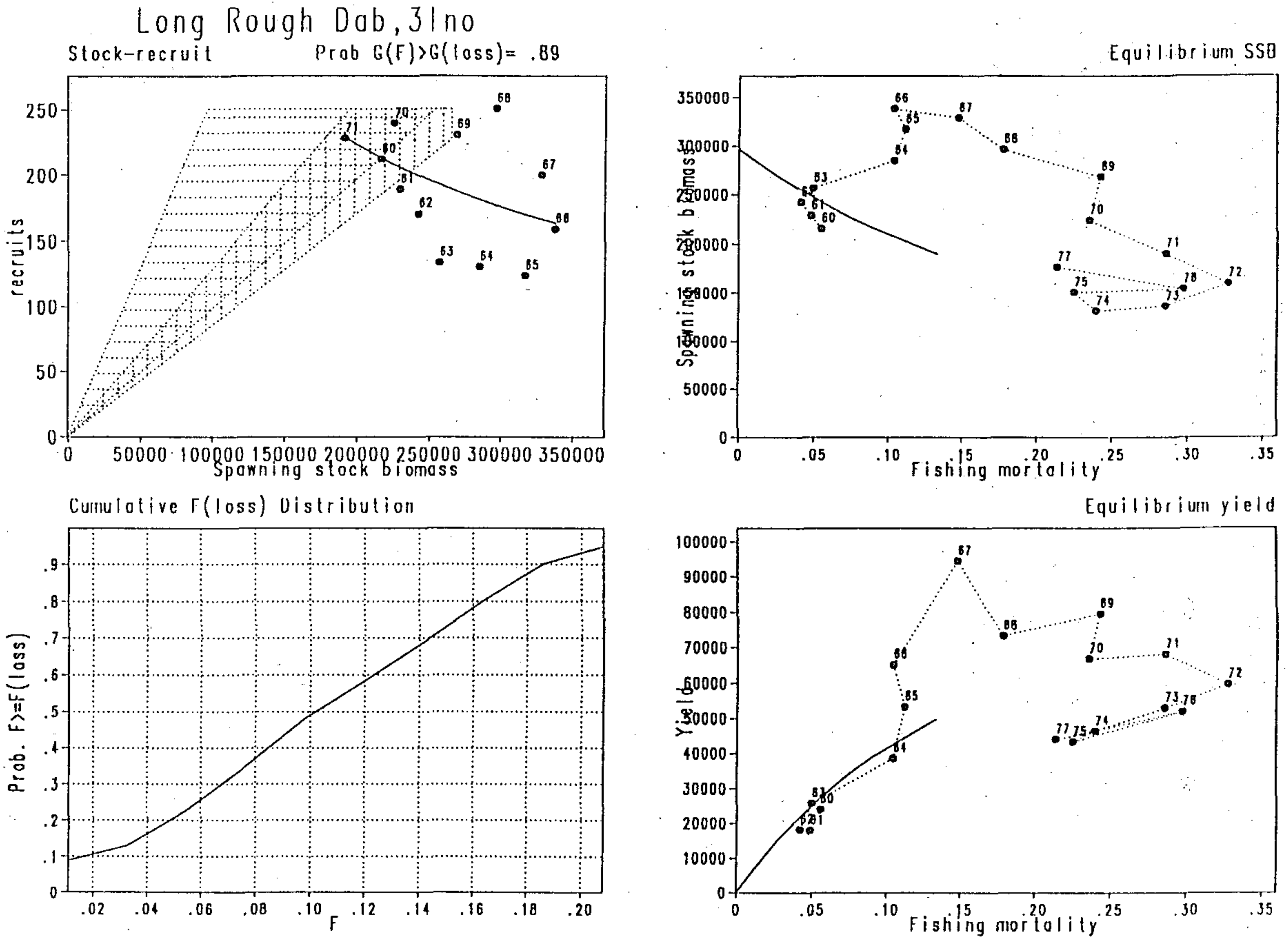


Fig. 8. American plaice in Div. 3LNO: results of G_{loss} analysis.

Estimation of measurement and process error for precautionary analysis. A standard SPA is performed using ACON software (Black, 1992). The residuals from the tuning (in this case ages 6-11) are resampled for each age (conditioned bootstrapping) to produce 1 000 pseudo-surveys. Then, the original catch data and each pseudo-survey are used to estimate new SPA numbers. After bias correction, the resultant 1 000 numbers-at-age estimates are used to approximate the probable distribution of American plaice in Div. 3LNO in 1993, i.e. the measurement error. This step is the basis of standard risk analysis. For SPAs using catch data for the period 1960-92, the coefficient of variation (CV) for spawning stock biomass in 1993 is about 20%

Equilibrium yield as a function of fishing mortality and spawning stock biomass is estimated following the approach of Sissenwine and Shepherd (1987). This method of yield estimation requires a stock-recruit relationship. For this study a Ricker (1975) relationship is assumed. The residuals between the stock-recruit function and the SPA data upon which is based, reflects process error. Analogous to the measurement error estimation, these residuals were resampled and new stock recruit parameters estimated. For each pair of bootstrapped Ricker parameters, the MSY and B_{MSY} were estimated in the Sissenwine-Shepherd framework. The bootstrap B_{MSY} estimates were then compiled to approximate underlying distribution. If B_{lim} is assumed to be half of B_{MSY} *its* uncertainty is approximated using B_{MSY} distribution scaled by one half. Although the distribution is fairly skewed, it CV is about 30%.

Figure 9 summarizes these results. The measurement error is depicted as the small distributions in the lower left corner. The lower one is for Jan 1993 and the upper is a projection to Jan 1, 1994 assuming a catch of 10 kt. B_{lim} is the broad set of lines in the neighborhood of 120 kt. For this analysis spawning stock is approximated by 10+ biomass. This figure shows the relative magnitude of process and measurement errors. It also shows a provisional estimation of B_{buff} as the 95% percentile of the B_{lim} distribution.

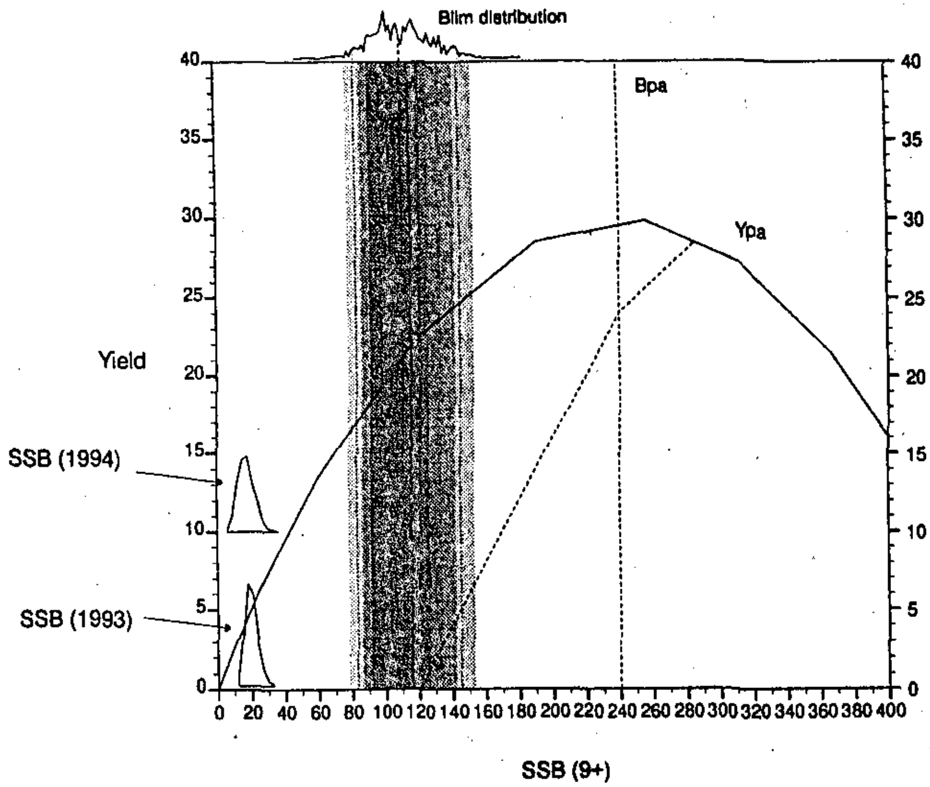


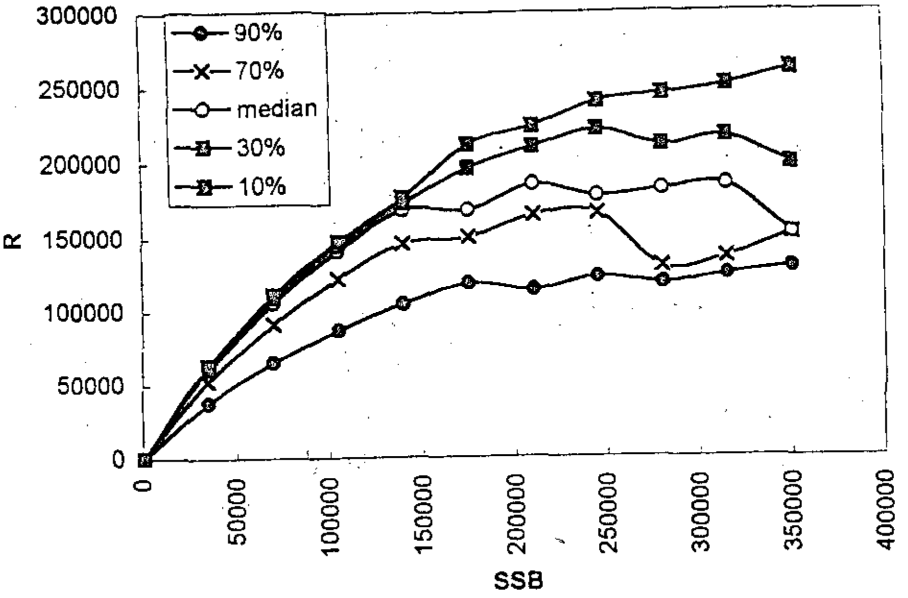
Fig. 9. American plaice in Div. 3LNO: results of analysis of measurement and process error, with reference points indicated.

Semi-parametric description of recruitment as a function of spawning biomass. An extension of the approach used by Evans and Rice (1988) to describe recruitment as a function of spawning biomass was applied to American plaice in Div. 3LNO. The extension attempts to describe the characteristics of the spawner-recruit dynamics in probabilistic terms, including a description of the "ascending limb" (area close to the origin) where information is often limited.

The method provided an evaluation of the probability that a given level of recruitment would be exceeded as a function of spawners. It was noted that some reference points (e.g. F_{crash}) are particularly sensitive to the shape of the s-r curve close to the origin. By forcing a Beverton-Holt form for that area, the method will likely mask a depensatory effect if it is present and would cause, in such a case, an over-estimation of the RP. On the other hand, forcing a depensatory effect when there is none would result in the opposite, i.e. being over-cautious. The Scientific Council noted that in absence of observations close to the origin, it is typically not possible to estimate the shape of the s-r curve and that the sensitivity of various assumptions on the calculation of RPs should be investigated.

Applying this technique to two time periods (1960-77 and 1978-86) showed very different results. For the earlier period, the probability that a given recruitment level would be exceeded 50% of the time dropped sharply when SSB decreased below 150 000 tons. These results are summarized in Fig. 10a, b. The results from the later period, when SSB and recruitment were at much lower levels, are shown in Fig. 11a, b.

Recruitment that would be exceeded 10%, 30%, 50% (median), 70% and 90% of the time as a function of SSB.



Probability that a given recruitment level will be exceeded, as a function of SSB

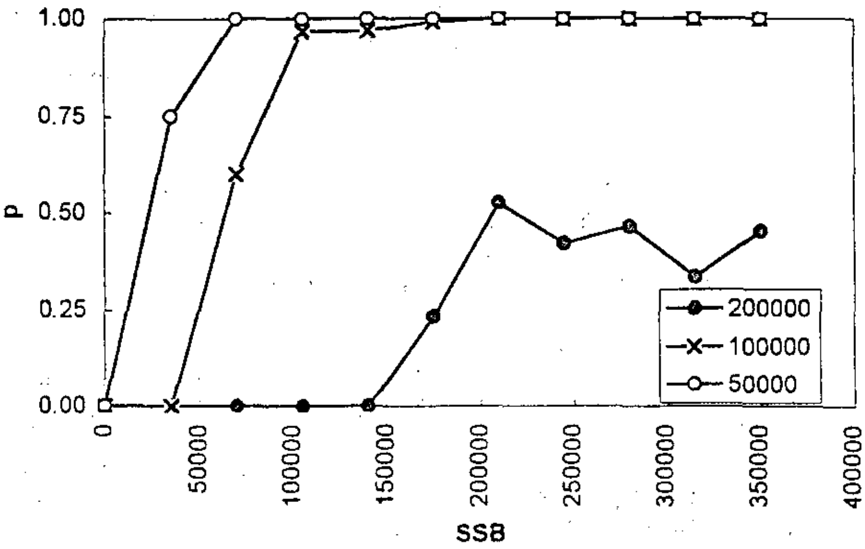
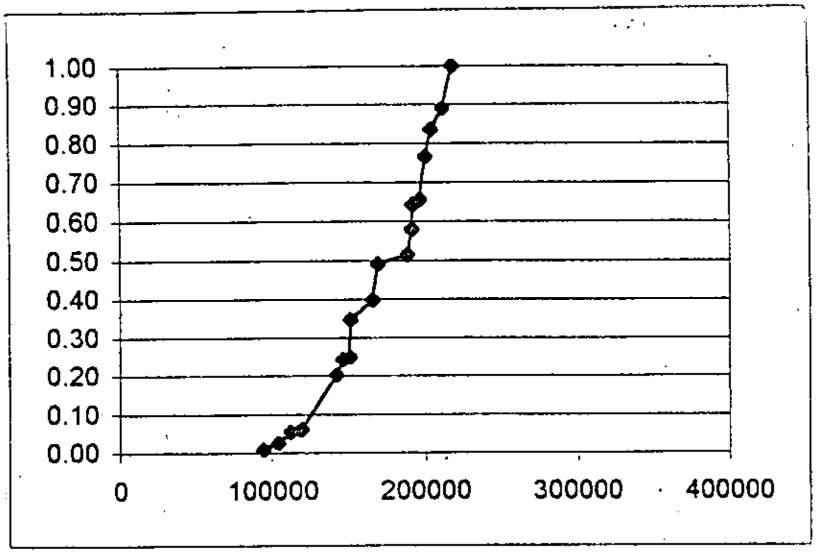


Fig. 10a. American plaice in Div. 3LNO: results of semi-parametric description of recruitment as function of SSB. Data are for 1960-77.

Cumulative probability of recruitment if SSB is 175000



Cumulative probability of recruitment if SSB is 35000

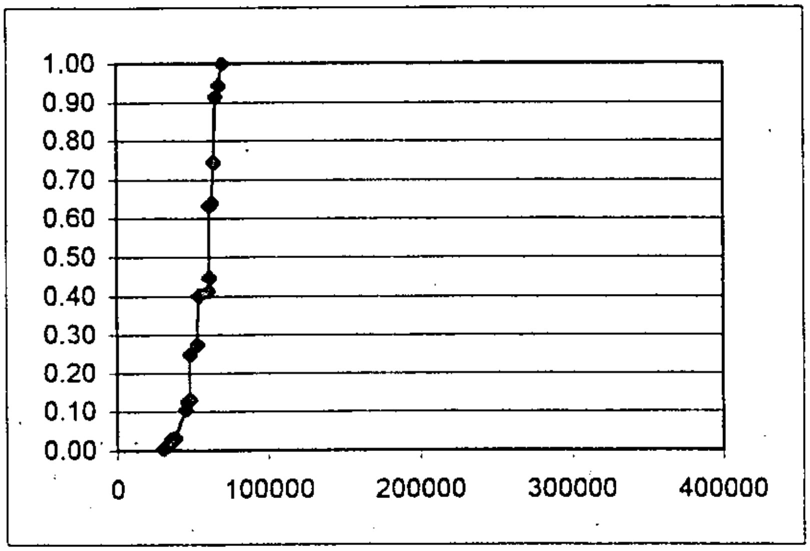
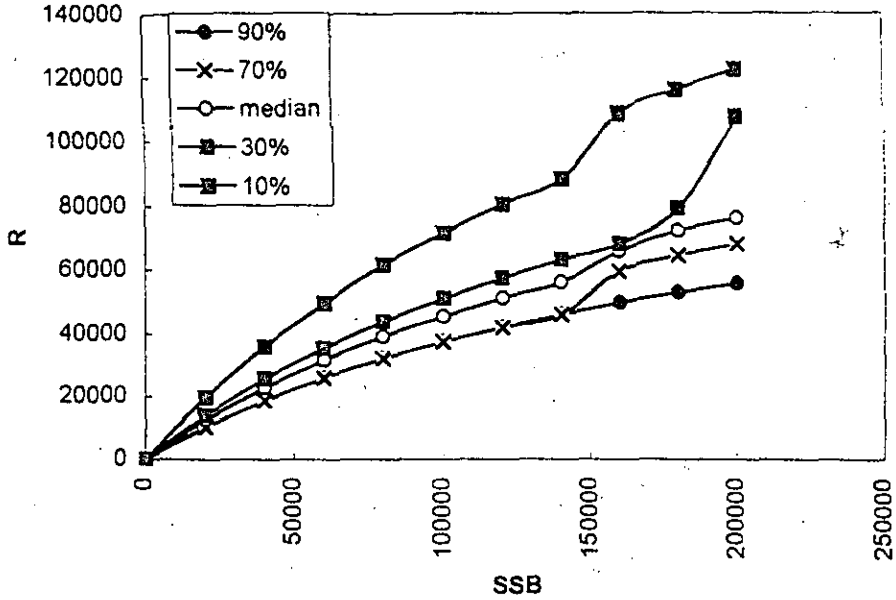


Fig. 10b. American plaice in Div. 3LNO: cumulative recruitment probability, data from 1960-77.

Recruitment that would be exceeded 10%, 30%, 50% (median), 70% and 90% of the time as a function of SSB



Probability that a given recruitment level will be exceeded, as a function of SSB

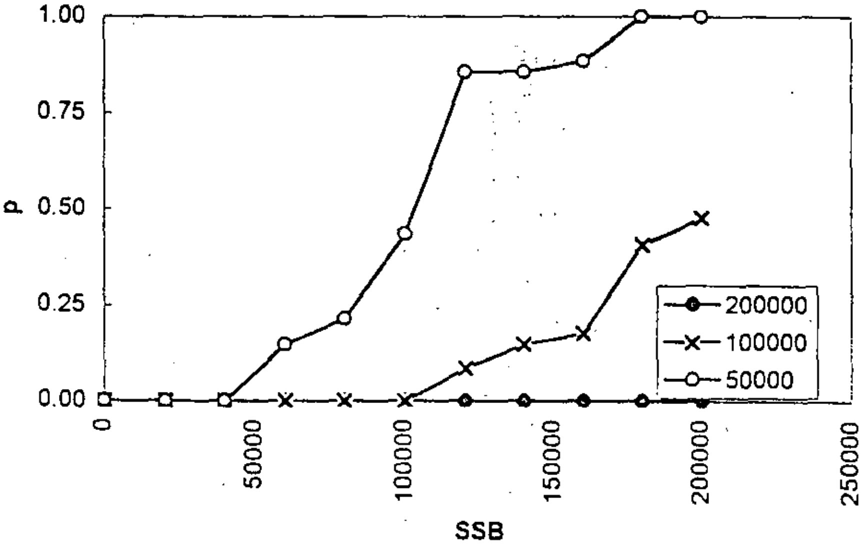
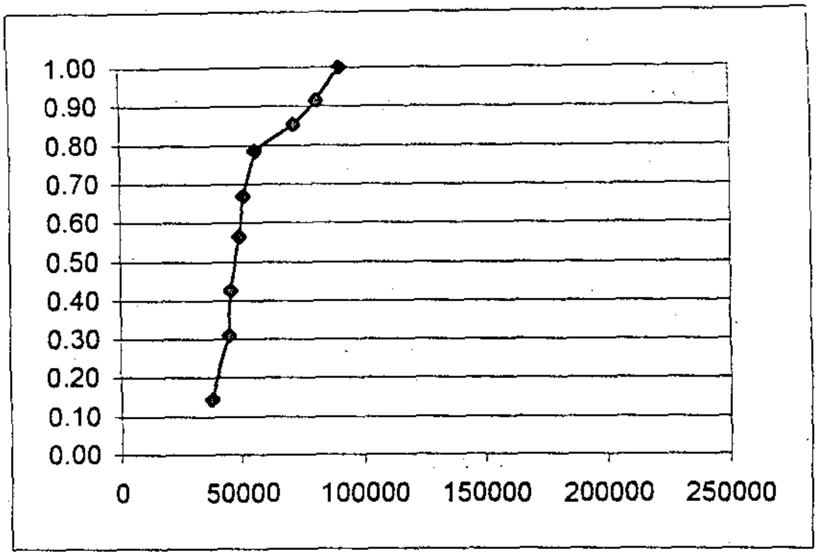
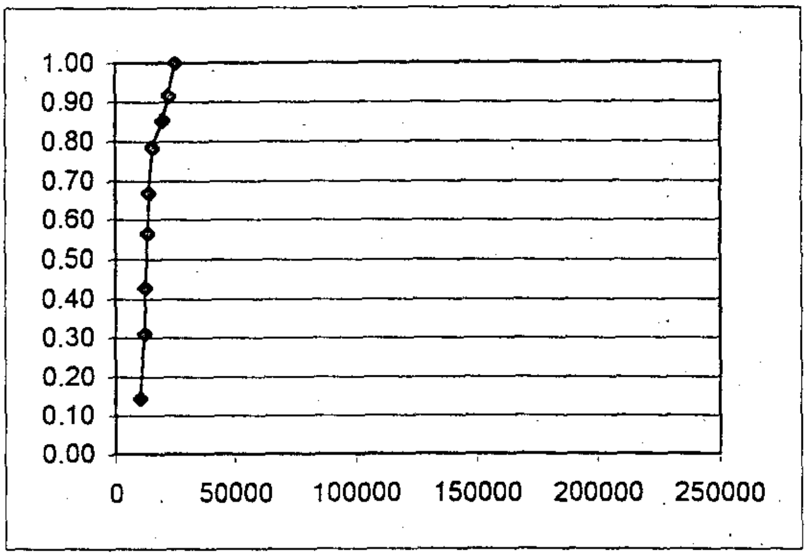


Fig. 11a. American plaice in Div. 3LNO: results of semi-parametric description of recruitment as function of SSB. Data are for 1978-86.



Cumulative probability of recruitment if SSB is 100000



Cumulative probability of recruitment if SSB is 20000

Fig. 11b. American plaice in Div. 3LNO: cumulative recruitment probability, data from 1978-86.

Age-structured analysis of stock productivity. An analysis of production (Sissenwine and Shepherd, 1987) using a model integrating a yield-per-recruit, a spawner-per-recruit model and a spawner-recruit relationship was applied to American plaice in Div. 3LNO. The spawner-recruit observations were first assessed using the approach developed by Evans and Rice (1988) to describe their distribution. Then, the spawners at equilibrium were obtained from the Beverton-Holt spawner-recruit model that best approximated the Evans and Rice median descriptor (i.e. the mid-point of observations of recruitment as a function of spawners). Following the approach used by Sinclair (1997), an age-structured yield-per-recruit model and a spawner-per-recruit model were obtained using the average weight-at-age, partial selection pattern and maturity information (knife-edge, starting at age 9). Natural mortality was assumed constant (0.2) for the entire time period covered by the analyses.

In order to gain insight into the changes of productivity over time, the method was applied to two time periods, namely 1960-77 (pre-extension of jurisdiction) and 1978-86 (post-extension of jurisdiction). It was also applied to the entire time series available, i.e. 1960-86, to obtain an indication of average conditions over this period. This approach provided estimates of $F_{0.1}$, F_{max}, F_{msy}, F_{crash}, MSY and B_{MSY} based on SSB data.

The results for the 2 time periods can be seen in Fig. 12 and 13, and a comparison of the reference points, including those for the combined time period, in Table 4. There is a marked difference in the results, with MSY for the recent period just over 10% of the value for the earlier period.

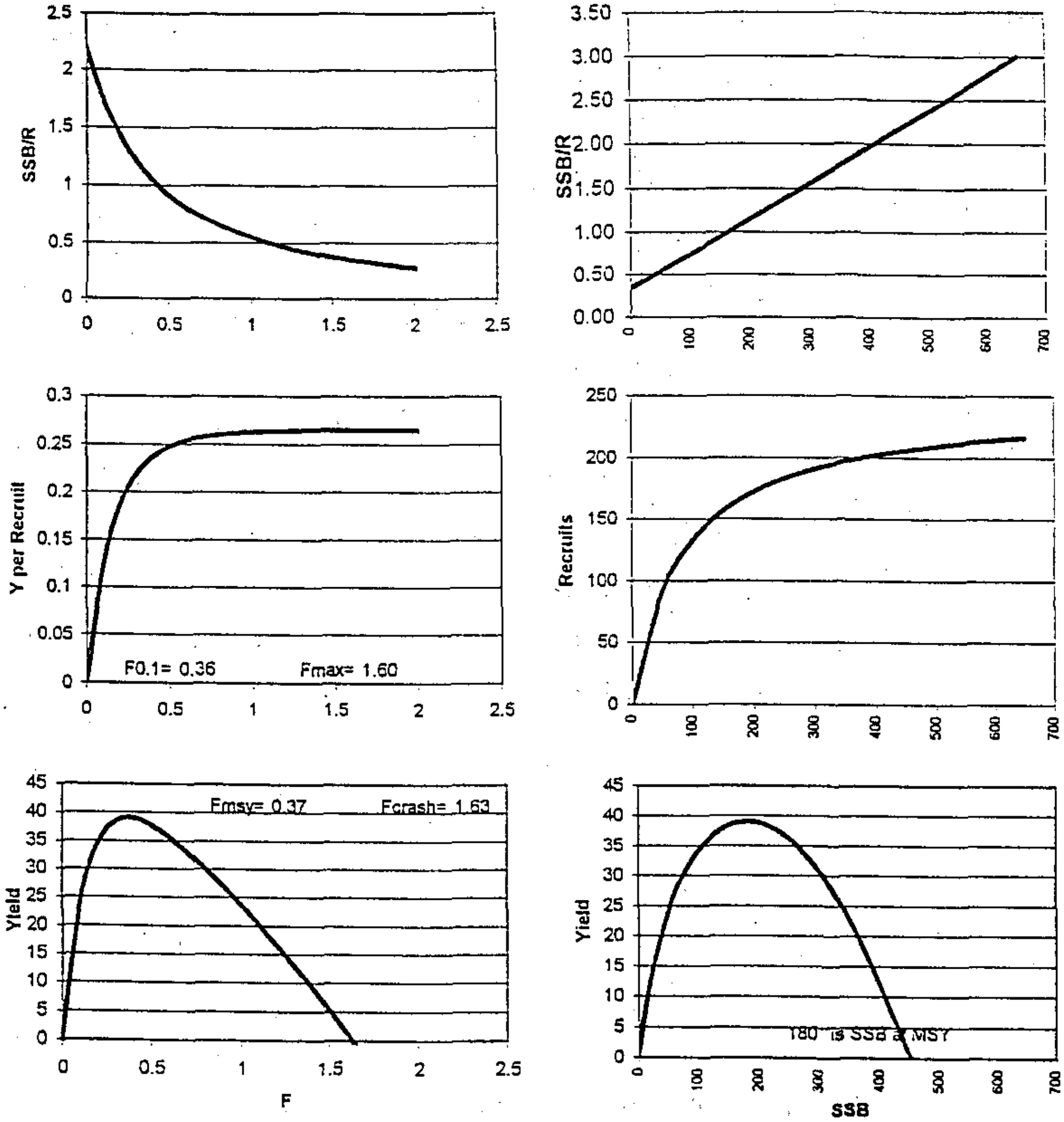


Fig. 12. American plaice in Div. 3LNO: results of age-structured analysis of stock productivity, data for 1960-77.

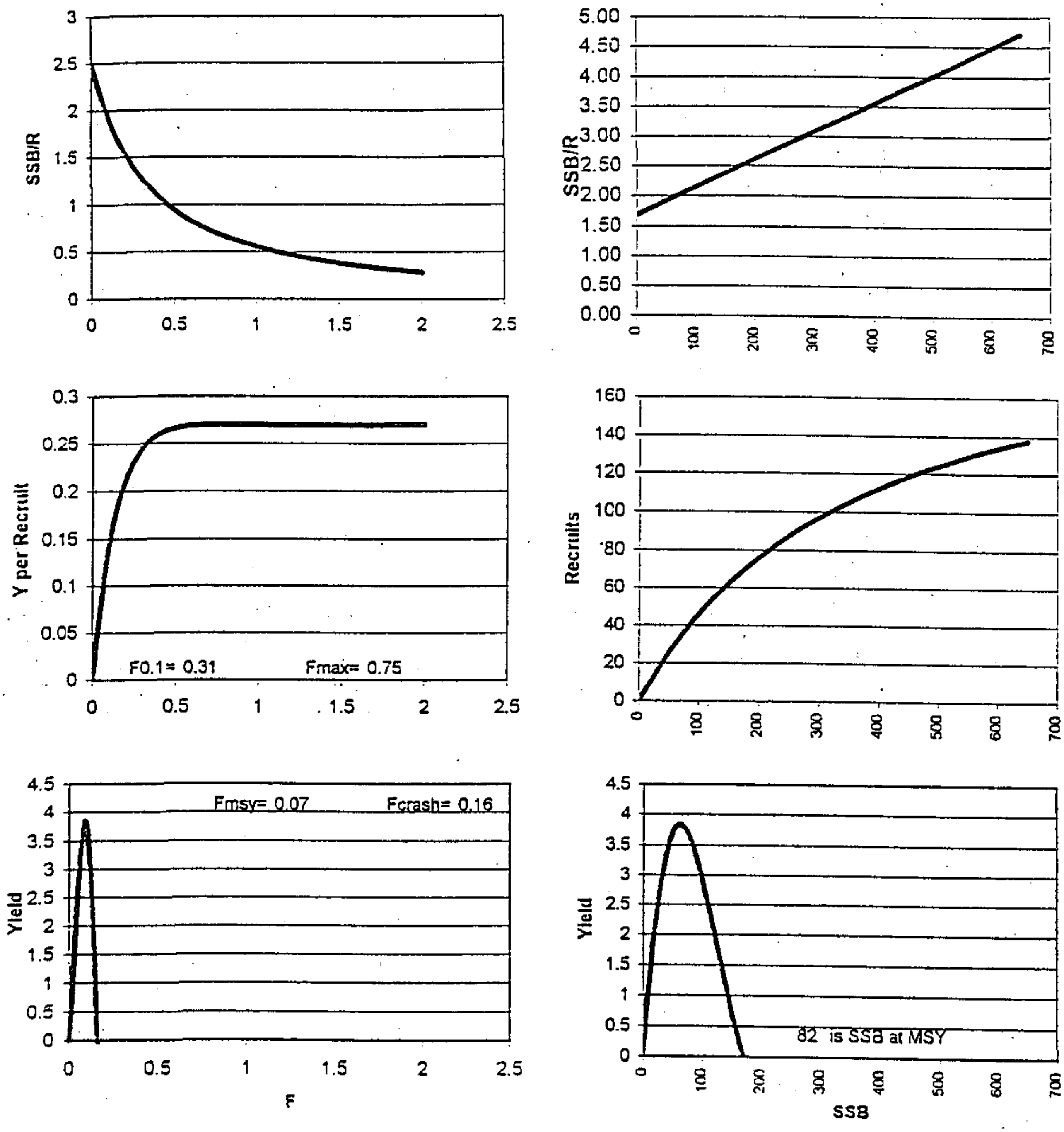


Fig. 13. American plaice in Div. 3LNO: results of age-structured analysis of stock productivity, data for 1978-86.

TABLE 4. Summary of results from age-structured analysis of stock productivity, covering the periods 1960-77, 1978-86 and 1960-86.

	1960-77	1978-86	1960-86
S-R model parameters			
Slope a origin	2.95	0.59	1.43
Asymptote for R (× 1000)	243 657	214 855	262 841
Reference Points			
$F_{0.1}$	0.36	0.31	0.32
F_{max}	1.60	0.75	1.50
F_{msy}	0.37	0.07	0.21
F_{crash}	1.63	0.16	0.65
B_{msy} (tons)	180 180	81 571	184 366
MSY (tons)	39 010	4 359	26 961

d) Selection of Reference Points

In all of the methods providing estimates of B_{MSY} and F_{MSY} these estimates show low stability except for MSY which appeared to be robust. Therefore, it was agreed not to relate Blim to BMSY. In examining the stock recruit scatterplot from the VPA results (Fig. 14a), it was obvious that there was a marked decline in recruitment at SSB levels below about 150 000 tons, particularly in the more recent time period. This was also borne out in many of the analyses conducted (e.g. the Evans method). Based on the historical data, the value of 150 000 tons (SSB) was proposed as the B_{lim} value. With CVs on population estimates from VPA typically in the range of 20-30%, a value for B_{buf} which was approximately 2 standard deviations greater than B_{lim} would put B_{buf} at about 220 000 tons. There was also some debate on the necessity of establishing B_{buf} separately from harvest control rules. Assuming harvest control rules for the period considered would be speculative, B_{buf} was chosen in the way described above.

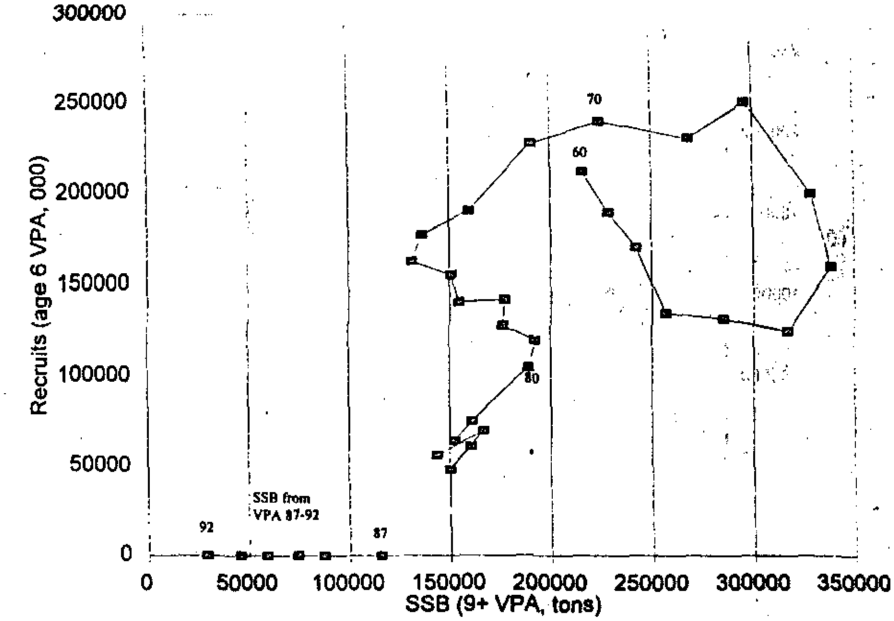


Fig. 14a. American plaice in Div. 3LNO: recruits *vs* SSB scatter plot. Note: the SSB for 1987-92 are shown on the figure without the corresponding recruitment estimates of age 6, which were not available in the 1993 VPA.

Also there was no clear agreement on how to define limit reference points for fishing mortality for this stock. It was argued that an F_{lim} of 0.25 was too high for this stock, although perhaps not for the largest stock sizes. The stock size was relatively stable for an extended period in the 1970s and 1980s with Fs around 0.25 to 0.3, although the stock declined rapidly after then. It was thought that if the value of 150 000 tons was appropriate for B_{lim}, then F_{lim} should be around 0.15. For illustrative purposes, F_{lim} was drawn on Fig. 14b at around 0.21, and F_{buf} at 0.15. It was noted that there were few points in the bottom right hand ("safe") zone in this figure, and that these points were all from the earliest years of the fishery. Most of the data points in the 1970s and 1980s were slightly above B_{lim}, but corresponding Fs were above the illustrative F_{lim} mark.

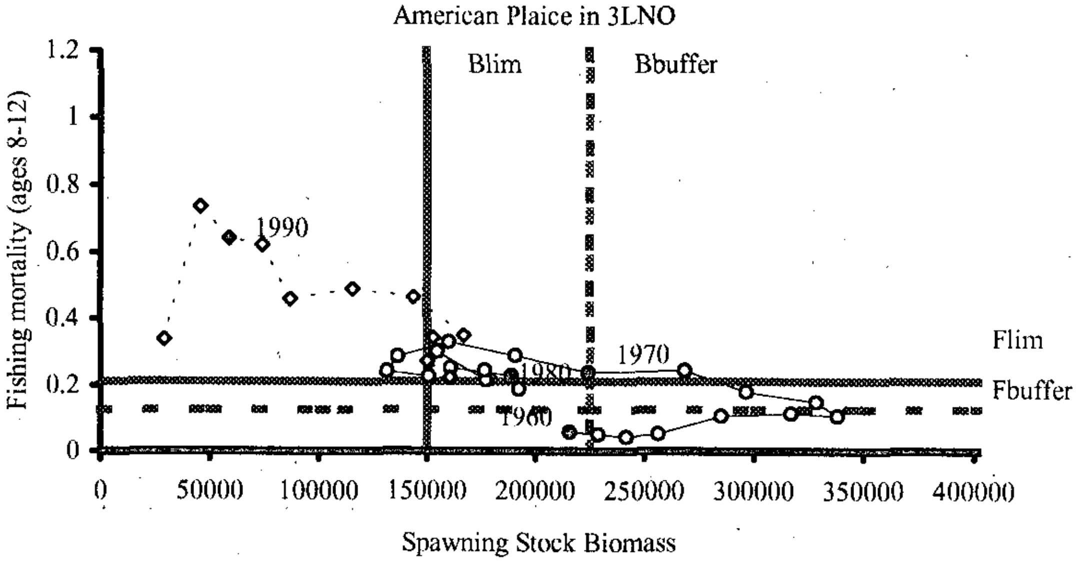


Fig. 14b. American plaice in Div. 3LNO: schematic of a possible implementation of precautionary reference points.

It was clear that in its present condition, the stock is far below B_{lim}, and may even be declining with little or no fishery in recent years. If there has been a change in productivity in the stock, the reference points chosen must protect against the future possibility of the stock declining into such an unproductive state. It was also pointed out that the dynamics of a rebuilding stock maybe different, and that SSB comprised of young fish may not be as successful as SSB comprised of more experienced spawners.

e) Decision Rules

Little could be done with decision rules for this stock, given that the implementation of these rules would have had to be applied to the historical fishery. However, Fig. 14b shows the area outside of which these rules might have been applied.

The more relevant situation for this stock was reopening criteria. Until the stock shows some signs of surplus production, even this question does not require an immediate answer, given the current SSB, the lack of older ages in the population, and other biological indicators. When the stock shows signs of increasing, the reopening target could be B_{lim}, and decisions on reopening the fishery at a low F could be made when this level of SSB is achieved. The question was raised whether the stock will ever reach the historical B_{lim} level if productivity remains low, and whether reference points should be recalculated based on the newer stock dynamics in this period of lower productivity. It was concluded that the B_{lim} calculated from the historic data should remain as the lower threshold, for biological reasons.

Forecasting under Decision Rules. A Decision Rule was applied to American plaice in Div. 3LNO and the resulting population trajectory forecast for 30 years. The model applied was that described in Bell and Stefansson (SCR Doc. 98/7), an evaluation model which projects stock size and composition using age based population dynamic parameters estimated from historical data. Uncertainty is included in both recruitment and stock assessment (observational error), the model using Monte Carlo simulation to obtain frequency distributions of parameters including time for stock rebuilding and mean yield.

The following SSB-recruit relationship was used:

$$R = \frac{a \times b \times S}{(a \times S) + b}$$

with a and b estimated from the full data set. This does not account for the apparent change in the SSB recruitment relationship or productivity of the recent past and is thus an optimistic view of recruitment at low SSB.

The reference point of B_{lim} was described in Section d above, which was SSB = 150 000 tons. B_{buf} was calculated as $B_{lim} * e^{1.854*CV}$, which equals 217 334 tons. This is two standard deviations from this using a CV estimated from the data. $F_{lim} = 0.2$, $F_{buf} = 0.138$, again two standard deviations from F_{lim}.

- Four levels of acceptable interannual quota change are investigated, unlimited change, 50%, 33% and 25%.

A reopening strategy was simulated as the fishery is currently closed. The fishery was set to open with a quota of 15 000 tons once B_{lim} was reached. The opening biomass would need to be set much higher if the depensatory stock-recruitment relationship was invoked. The Decision Rule decreased fishing mortality linearly from F_{buf} to F_{lim}.

The following figure (Fig. 15) **shows a typical time series** out of 100 simulations for illustration, this run allowing unlimited interannual change. The fishery can be seen to open the year following a perceived SSB above B_{lim}. This is immediately closed again the following year due to the perceived stock falling back below B_{lim}. The fishery never opens permanently, instead alternating between closure and fishery. The stock trajectory can be seen to continue rising right up to the end of projection time suggesting the period is too short to locate a time of sustained fishing for such a slow developing species.

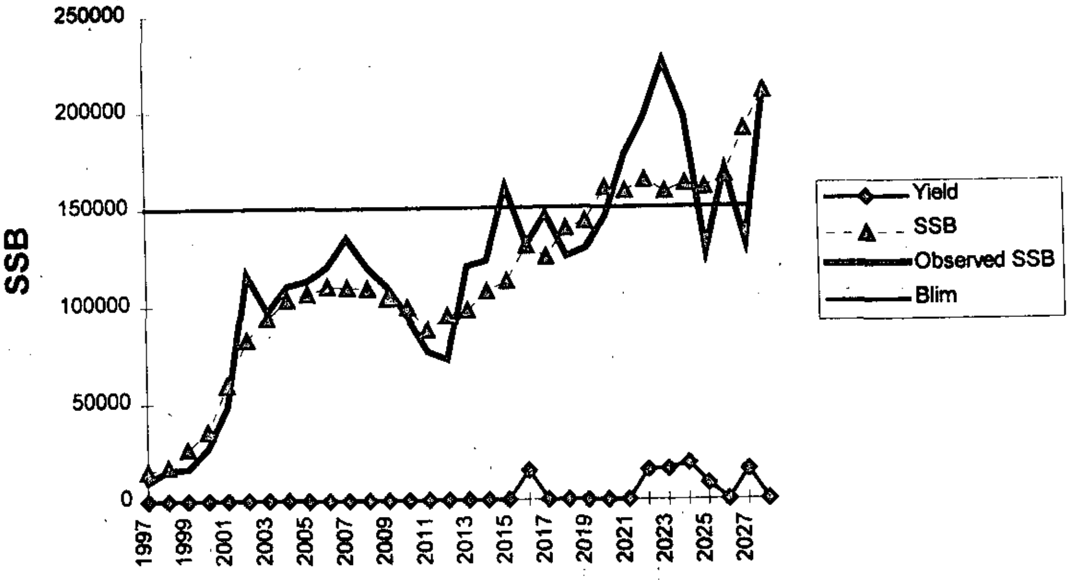


Fig. 15. American plaice in Div. 3LNO: projection using precautionary Decision Rules.

The following figure (Fig. 16) shows the distribution of first reopening year based on 200 projections and unlimited interannual change.

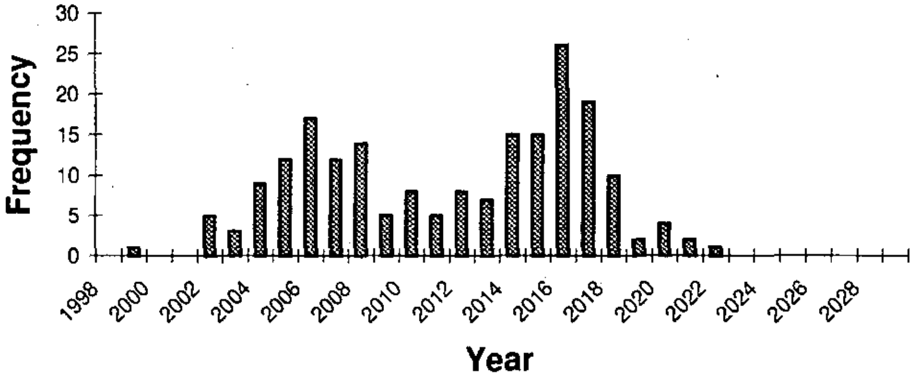


Fig. 16. American plaice in Div. 3LNO: distribution function of year of reopening, unlimited change.

The bimodal distribution is an artifact of the starting stock size and recent SSB from the VPA. There is a brief period of stock stability just below B_{lim} which is occasionally misreported as being over B_{lim}, or occasionally this stable period lies just over B_{lim} due to exceptional recruitment. The mean reopening year is 2013, and the 95th percentile is 2018. A more reliable function would be the year of reopening for more than 3 years.

Limiting interannual catch change has a negligible effect on this stock in terms of reopening year, yield after opening, time to reach Bl_{im} and amount of time satisfying the PA. This can be attributable to the stock being at such critically low levels that there is rarely any catch to limit and the rate of population increase giving interannual changes of less that 25% thus negating the need for a limit.

The amount of time spent precautionary fishing is very high with a mean of 85%. This is not surprising as there is a long period of fishery closure (which satisfies the PA in itself), thus the level of precautionary fishing should perhaps be measured once the fishery is reopened.

The mean yield (measured after the first opening of the fishery) is 40% of MSY. This is heavily influenced by re-closure of the fishery, a regular action (on average 2.3 times in the 30-year projection).

These projections are greatly influenced by the stock recruit function which as previously mentioned appears highly optimistic at SSBs below 150 000 tons. Thus the estimates of reopening year and time to reach B_{lim} are too early.

f) Research Requirements

The sensitivity of the RP calculations to various assumptions must be established. These would include changes in growth- and maturity-at-age, possible increases in natural mortality, accuracy of VPAs, etc. Data quality must be improved if VPAs are to be used in future. Ways to link the SSB reference points calculated from VPAs with survey data must be found, given that current assessments are based almost entirely on survey data. Simulations should be carried out to see if the RPs are sufficiently precautionary to protect the stock against changes in productivity under various decision rules.

2. Greenland Halibut in Subarea 2 and Divisions 3KLMNO

a) Description of the Fishery

The fishery for Greenland halibut in this management area began in the early-1960s, using synthetic gillnets in the deepwater bays of eastern Newfoundland. Catches increased from fairly low levels in the early-1960s to over 36 000 tons by 1969 and ranged from 24 000 tons to 39 000 tons over the next 15 years. With the exception of 1987, catches in the late-1980s were around 18 000 tons. In 1990, an intense fishery for Greenland halibut developed in the NAFO Regulatory Area (NRA) of Div. 3L and 3M, in the deepwater areas known as Sackville Spur and Flemish Pass. The development of this fishery resulted in a rapid escalation of catches to about 47 000 tons in 1990. Catches in the NRA in 1991 to 1993 were estimated to be around 55 000 tons in each year, although there was some doubt as to the actual catch levels. Overall, catches from the stock during 1991 to 1993 were estimated to be between 62 000 and 65 000 tons annually, with a slight decline in 1994. As a result of new management measures introduced by the NAFO Fisheries Commission in 1995 i.e. extensive quota restrictions and 100% observer coverage in the NRA, catches were greatly reduced. The major participants in this fishery in the NRA have been EU/Spain and EU/Portugal, as well as a variety of non-Contracting Parties such as Panama.

Prior to 1990, Canada, USSR, GDR, and Poland were usually the main participants in the fishery, although Portugal and Japan became increasingly involved in the fishery after 1984. Canadian catches have been taken mostly by gillnet, although a significant proportion is taken by otter trawlers. With the exception of 1987, catches declined steadily inside the Canadian zone since the late 1970s from a high of over 30 000 tons to less than 3 000 tons in 1994 and 1995. This declining trend was mainly a result of low catch rates and reduced effort, although catches in 1996 increased to around 6 000 tons, with the main increase occurring in Div. 3K. The Canadian gillnet catches taken during recent years are mainly from a newly developed fishery along the deep edge of the continental slope in Div. 3L and north, although some fishing still occurs nearshore.

b) Available Data

Catch-at-age and mean weights-at age. Due to uncertainty regarding catch information on fisheries in the NRA since 1989, catch-at-age for Canadian catches only were available from 1988-96. Some estimates of catch at age exist from the fisheries in the NRA in the 1990s, but the data are incomplete. Prior to 1989, data are available from the entire annual fisheries which took place mainly in the Canadian zone.

VPA. VPAs have been attempted for this stock in the past but have never been accepted as the basis for assessment advice. The most recent attempt, in 1990, gave inconsistent results, and it was concluded that there was little chance of explaining the results until migration rates could be quantified.

CPUE. Catch and effort data from the directed fishery for Greenland halibut during the period 1975 to 1992 were obtained from ICNAF/NAFO Statistical Bulletins and were combined with provisional 1993-96 NAFO data. The catch/effort data were analysed with a multiplicative model to derive a standardized catch rate index for hours fished. Factors included in the model were a combination country-gear-tonnage class category type, month, NAFO Division and year.

Research vessel surveys. From 1977-94 in Div. 2J and 1978-94 in Div. 3K, Canadian surveys were conducted during autumn using an Engel 145' bottom trawl. In Div. 3L from 1981-83, surveys were conducted using a Yankee 41.5 bottom trawl and in 1984-94 using an Engel 145 bottom trawl, which differed somewhat from the trawl used in the Div. 2J and 3K surveys. In 1995-97, the surveys in Div. 2J, 3K and 3L were conducted using a Campelen 1800 shrimp trawl with rockhopper footgear. An EU survey has been conducted on Flemish Cap from 1988 to 1997. Surveys in Div. 2GH were conducted occasionally throughout the time period, and various deepwater surveys have been carried out in and around the NRA in SA 3. There is also a Spanish survey in the NRA in Div. 3NO from 1995-97. The biomass and abundance indices used for the stock cover only Div. 2J and 3K for the period 1978-97, although in 1996 and 1997 research vessel surveys covered much of the area of stock distribution.

Maturity data at age exist from surveys and commercial catch data to allow calculation of maturity ogives, but data are not complete for all areas and times.

c) Calculation of Reference Points

Methods. A non-equilibrium stock production model - ASPIC (Prager, 1994, 1995) was attempted with CPUE and research vessel indices of abundance. Various formulations were attempted but the results were not consistent and further investigation is required.

Yield-per-recruit models are available covering a variety of selectivity and natural mortality patterns.

Models employing SSB-recruit relationships could not be used because the surveys do not provide an adequate index of SSB. Recruitment estimates in the 1990s are higher than previous years, but SSB as measured by the Div. 2J and 3K surveys is much lower than in the earlier years. The biomass of spawners outside the surveyed area is likely to be substantial and may not be a constant proportion of the total over time. As noted previously, there are no reliable VPA data for this stock.

Total mortality estimates (Z-values) from Div. 2J and 3K survey data at ages 7+/6+ were available and were compared with trends in yield from the stock. Comparison of catch and stock biomass from surveys in 1996 and 1997 provide a crude measure of the exploitation rate in these years.

d) Selection of Reference Points

Given that no reference points were agreed for this stock, there was no discussion on these agenda items.

e) Decision Rules

Given that no reference points were agreed for this stock, there was no discussion on these agenda items.

f) Research Requirements

Surveys covering the entire stock distribution are essential, given the changes in distribution observed for this stock. The 1996 and 1997 surveys cover almost the entire range. Catch-at-age data should be re-examined to see if age-based models can be used. Examination of the sensitivity of yield-per-recruit analyses to various assumptions should be continued. Further investigation of ASPIC model results are required. A method, based on survey data, to calculate probabilities of juveniles reaching spawning age, will be examined.

3. Shrimp in Division 3M

a) Description of Fishery

The fishery for northern shrimp (*Pandalus borealis*) in Div. 3M (Flemish Cap) began in 1993 and produced provisional annual catches as follows:

Year	Catch (tons)
1993	28 000
1994	24 000
1995	33 000
1996	51 000
1997	25 000

The multi-national fishery was unregulated in 1993. Sorting grates and a related by-catch regulation were introduced in 1994. Effort regulations were implemented in 1996 and continued in 1997 and 1998.

Fishing effort in 1993 was distributed on Flemish Cap in an arc north of 47°N centered near the 400 m depth contour. Effort was displaced to the west and southwest portions of the Flemish Cap in 1994 and 1995, compared to 1993, but returned to the eastern slope in 1996. Further, fishing occurred in much shallower depths in both 1995 and 1996. In 1997, a return to deeper water was evident for some vessels.

The fishing pattern reflects the initial targeting of the 1988 year-class in 1993 and a subsequent shift to smaller and younger animals, thereafter. The 1993 year-class was evident in the catches in 1995 and maintained the fishery in 1996 and 1997.

b) Data

- Catch, effort and standardized CPUE data from 1993 to 1997: considered representative of all fleet operations.
- Commercial sampling of catches for length, age, sex and maturity: assumed to be representative of catch composition.
- Research groundfish trawl survey biomass indices from EU-Spain from 1988 to 1997: reflect the general pattern in age 3+ and female stock components but not considered as a reliable substitute for directed surveys for shrimp.
- Research shrimp trawl survey biomass indices for 1996 (Canada) and 1997 (Faroe Islands): not comparable between years due to unknown catchabilities.
- Biological sampling data (length, age, sex and maturity) from both groundfish and shrimp trawl surveys: believed to reflect overall demographic changes in the stock.

c) Biology

This species is a protandric hermaphrodite, maturing first as males followed by sex inversion. Fisheries generally target the large sizes most of which are females. In Div. 3M, the fishery after 1993 was directed towards small males as young as age 2 which has implications for the future spawning stock. The PA for shrimp in Div. 3M needs to address this life history characteristic.

d) Analyses

i) Methods: ASPIC - Catch and standardized CPUE, EU Survey indices (1993-97).
Y/R, SSB/R - from NAFO (1996).
Precautionary checklist - Caddy (SCR Doc. 98/8)
ii) Results: ASPIC - The data series was too short (5 years) for reliable parameter estimation (no dynamic range).

Y/R implied high F on males which compromises conservation of the future spawning (female) stock. The stock-recruitment relationship for shrimp in this area is unknown and recruitment is highly irregular.

Die and Caddy (1997) results for Z calculations were difficult to interpret. Changes in mean length, length at first capture and 50% maturity over the brief time-series reflected the year-class effect (1988 year-class in 1993, and 1993 year-class in 1996) rather than a fishery effect. Calculating upper limits for Z on an annual basis can be used to monitor the fishery as it develops.

Precautionary checklist of 29 criteria indicated 15 in the "red" zone emphasizing the need for a PA in the management of this resource.

e) Selection of Reference Points

Due to the problems associated with lack of data and methods described above, no reliable precautionary RPs were selected. The precautionary, qualitative "Traffic Light" checklist proposed by Caddy (SCR Doc. 98/8), was viewed positively as a first step to applying the PA to Div. 3M shrimp and, possibly, to other stocks which can be described as data poor (time series and/or quality). The method has the potential for incorporating data on stock composition, distribution, environment, predators, etc. which, otherwise, would be treated as qualitative, ancillary information.

f) Decision Rules

No control rules were developed at this Workshop. However, the shrimp fishery in Div. 3M can still be viewed as a relatively new fishery and, in that context, reference is made to the FAO guidelines for responsible fisheries (FAO 1996: 13-14).

By-catch of other species was reduced substantially after 1993 with the mandatory use of sorting grates. Small fish still pass through the bar spacings and, if strong year-classes are produced intermittently, there is a potential for significant incidental mortality that can affect the future yield for the affected species. In such cases, appropriate decision rules will be required.

g) Future Research Needs

At the September, 1997 Annual Meeting, Scientific Council concluded that: "in the absence of a time-series of directed research trawl surveys for shrimp, assessing the recruitment and predicting the exploitable stock is not possible." (NAFO, 1998). Therefore, the priority for research remains to establish a data base to facilitate reliable stock assessments, a long-term objective. However, non-parametric methods can be investigated for the available information which are, largely, qualitative. The precautionary checklist proposed by Caddy (SCR Doc. 98/8) at this meeting represents a first step in this direction.

Given that decision rules regarding by-catch will be necessary, detailed information on the numbers taken for commercially important species is required. Therefore, the fishery needs to be closely monitored in order to effectively implement these rules.

4. Redfish in Division 3M

a) Background Biological Information

There are three stocks of redfish in NAFO Div. 3M: deep-sea redfish (*Sebastes mentella*), golden redfish (*Sebastes marinus*) and Acadian redfish (*Sebastes fasciatus*). Each of the three species of redfish has both a pelagic and demersal behaviour, and wide interannual shifts in their concentrations between the Flemish Cap bank and other Div. 3M fishing grounds in the vicinity of this bank. All redfish species are long living and with slow (and very similar) growth, along with a low natural mortality. Reproduction is viviparous with mean length of first maturation varying from 26.5 cm for Acadian redfish, 30.1 cm for deep-sea redfish, and 33.8 cm for golden redfish.

b) Description of Fishery

The Div. 3M redfish stocks have been exploited both by pelagic and bottom trawl. Due to the similarity of their external morphology the commercial catches of Div. 3M redfish are reported together. The majority of the bottom trawl commercial catches is composed of beaked redfish (deep'sea and Acadian) but the species composition of the pelagic redfish catches, remains unknown.

The redfish catch in Div. 3M increased from 20 000 tons in 1985 to 81 000 tons in 1990, falling continuously since then till 1997, when a catch of only 547 tons has been recorded, most as by-catch in the Greenland halibut fishery. The quick drop of the Div. 3M redfish catches from 1990 to 1997 is related with the abrupt decline of fishing effort deployed in this fishery, caused by the vanishing from the NAFO Regulatory Area of the fleets responsible for the high level of catches from the late-1980s to early-1990s (former USSR, former DDR and Korean crewed Non Contracting Party vessels). For the remaining fleets, such as the Portuguese trawlers, Div. 3M redfish has been a second choice target compared to cod or American plaice and, more recently, Greenland halibut.

c) Available Data Used

Three bottom trawl biomass indices were available: Canadian survey series (1978-85), EU survey series (1988-97) and the USSR/Russian survey series (1983-97). This last series is coupled with an acoustic biomass estimate for the years 1987-93.

Two commercial CPUE series were used, one just from standardized observed catch and effort data of the Portuguese trawl (1988-96) and the other from standardized catch and effort STATLANT data for most of the components of the fishery (1959-93).

Mean weights- and lengths-at-age and mean lengths in the Portuguese commercial catch for the most recent years (1995-97) were incorporated in the analysis, taking notice of the very low level of the present catches and the small proportion that the Portuguese catches represented during the period with the highest level of catches.

Mean weights-at-age in the stock (as well as in the female component) was derived from EU survey data (1995-97) together with the female ratio at age (1992-97). The histological analysis of gonads collected during the 1991-94 EU surveys provide the data for the maturity ogive-at-age adopted.

Abundance-at-age for 1992-97 period, estimated from the EU survey, was used to calculate average total mortality-at-age. All biological information is referred to deep-sea redfish taking into account not only its predominance in the bottom commercial catches but also its growth and maturity being positioned between those of the two other redfish species.

d) Methods Used

A yield-per-recruit analysis using the above weights-at-age, percentage of females and female maturity-at-age. The partial recruitment vector was derived from the total mortality-at-age, estimated from the EU survey abundance-at-age. Natural mortality was assumed to be constant at 0.1. From the yield, biomass and spawning biomass-per-recruit curves, different levels of reduction of spawning and total biomass were determined for corresponding levels of fishing mortality. With the assumption of constant recruitment, the results indicated a reduction of 70% of the female spawning biomass from its unexploited level when fishing at $F_{0.1}$ and, if a logistic natural growth of the biomass is accepted, the fishing mortality associated with a 50% reduction of total biomass (corresponding to F_{msy}) is below $F_{0.1}$.

A growth based model was also applied (Beverton and Holt, 1957 from Die and Caddy, 1997) in order to get an estimate of the mean total mortality (Z) for the most recent years (1995-97) and a precautionary limit of Z, corresponding to a fishery where the mean length in the catch is above the mean length-at-maturity. The fishing mortality derived from the mean Z, assuming natural mortality of 0.1, was similar to an implied F from the catch/total biomass ratio for the same period. As for the F given by the Z "at maturity", its value was near the F associated with a 50% reduction on the female spawning stock biomass.

Finally all the biomass index series (but the Russian acoustic index) were incorporated in a non-equilibrium surplus-production model - ASPIC (Prager, 1994) together with the 1959-97 redfish catches. Inclusion of the Canadian and EU survey indices as well as the STALANT and Portuguese CPUE series resulted in negative or very low correlations. The STATLANT commercial CPUE (1959-93) and the EU bottom biomass (1988-97) alone gave reasonable correlations. On the second set of runs the catchability of the EU survey was fixed at the ratio of the mean bottom biomass (EU survey)/ total biomass (EU survey plus Russian acoustic) for the overlapping years of these two series, and the intrinsic rate of increase of the biomass was lowered to allow for the slow growth of redfish species. The results of the production model converge to a total biomass above the B_{msy} level for most of time period, declining from the mid-1980s till the early-1980s and recovering in the last years of the series. The model predicted that total biomass should be in 1998 at, or above, the B_{msy} level, the $F_{0.1}$ is within the range but higher than the $F_{0.1}$ given by the yield-per-recruit analysis, while the 1998 yields at F_{msy} predicted by the yield-per-recruit and the production models were identical. However, the model also suggested that throughout the period biomass was always above B_{msy} and that in recent years surplus production increased although indices suggested a stock decline. These apparent problems could not be resolved during the Workshop.

Examination of models based on stock/recruitment relationships was not possible due to short time series of data available.

e) Selection of Reference Points

No RPs were selected mainly due to the difficulty found in the assessment of recent and historical levels of SSB of the Div. 3M redfish stocks. From the EU survey results the proportion of adult redfish near the bottom remained low at least during the most recent years and no information is available of what this proportion would be on the pelagic component of these stocks. In the Northwest Atlantic redfish stocks have been observed to generally produce one or two strong year-classes every 5 or 10 years. Further study of possible stock recruit relationships is necessary.

f) Decision Rules

Sustainable yields will not be possible if uncontrolled exploitation by non-Contracting Party fleets, attracted by the possibility of good yields, is allowed to occur again in the future. However, decision rules related to sustainability need to incorporate uncertainties in by catch of small redfish in the shrimp fishery (see Section IV.3)

g) Needs for Further Research.

Assuming that changes in the bottom SSB reflect similar changes occurring in the total SSB, future research should focus on the evolution of the proportion of bottom spawning biomass to total bottom biomass estimated from different bottom trawl survey series in order to check, over the last two decades, the trend in spawning stock biomass in relation to the total biomass.

Given that measures regarding by-catch will be necessary, detailed information on the numbers of redfish taken is required. Therefore, the fishery needs to be closely monitored in order to effectively implement these rules.

5. Short-finned Squid in Subareas 3 to 6

a) Description of Historical and Recent Fisheries

Total landings ranged about 500-11 000 tons during 1953-67 and were primarily from the directed inshore jig fishery at Newfoundland (Table 5, Fig. 17a). Landings have occurred in Subarea 2 only during 6 years since 1953, with a maximum of only 30 tons, and so these small catches are here included in the Subarea 3 total for convenience. International trawler fisheries developed in Subareas 4 and 5+6 during 1968-70 and, although Subarea 3 landings remained below 2 000 tons, total landings increased to 29 000 tons in 1973. Total landings peaked at 179 000 tons in 1979, with 162 000 tons derived from Subareas 3-4. Landings subsequently declined regularly in Subareas 3-4 to 400 tons in 1983, remained below 5 000 tons until 1989 and ranged between 1 000 to 11 000 tons during 1989-96. During these years, Subareas 5+6 landings generally remained higher than in Subareas 3-4, ranging 2 000-18 000 tons as the fishery became predominantly a domestic trawler fishery. Meanwhile, Subarea 4 landings have been mostly by-catch in the silver hake fishery. Total landings increased from 15 000 tons in 1995 to about 28 000 tons in 1997, due primarily to increases in Subarea 3.

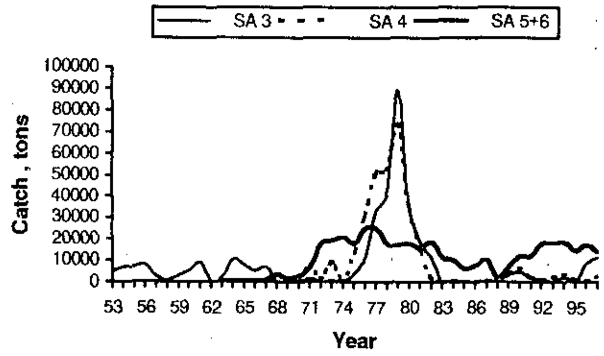


Fig. 17a. Squid in Subareas 3 to 6: trends in landings and survey biomass indices by fishery data.

TABLE 5. Annual landings and TACs by NAFO Subarea.

	Landings					TAC	
Year	**SA 3**[1]	**SA 4**	**Total**[1] **SA 3+4**	**SA 5+6**	**Total overall**	**SA 3-4**	**SA 5+6**[2]
1953	4 460	-	4 460	-	4 460	-	
1954	6 700	-	6 700	-	6 700	-	
1955	7 019	-	7 019	-	7 019	-	
1956	7 779	-	7 779	-	7 779	-	
1957	2 634	-	2 634	-	2 634	-	
1958	718	-	718	-	718	-	
1959	2 853	-	2 853	-	2 853	-	
1960	5 067	-	5 067	-	5 067	-	
1961	8 971	-	8 971	-	8 971	-	
1962	482	-	482	-	482	-	
1963	2 119	103	2 222	810	3 032	-	
1964	10 408	369	10 777	360	11 137	-	
1965	7 831	433	8 264	522	8 786	-	
1966	5 017	201	5 218	570	5 788	-	
1967	6 907	126	7 033	995	8 028	-	
1968	9	47	56	3 271	3 327	-	
1969	21	65	86	1 537	1 623	-	
1970	111	1 274	1 385	2 826	4 211	-	
1971	1 607	7 299	8 906	6 614	15 520	-	
1972	26	1 842	1 868	17 641	19 509	-	
1973	622	9 255	9 877	19 155	29 032	-	
1974	48	389	437	20 628	21 065	-	71 000
1975	3 751	13 945	17 696	17 926	35 622	25 000	71 000
1976	11 257	30 510	41 767	24 936	66 703	25 000	30 000
1977	32 754	50 726	83 480	24 795	108 275	25 000	35 000
1978	41 376	52 688	94 064	17 592	111 656	100 000	30 000
1979	88 833	73 259	162 092	17 241	179 333	120 000	30 000
1980	34 780	34 826	69 606	17 828	87 434	150 000	30 000
1981	18 061	14 801	32 862	15 571	48 433	150 000	30 000
1982	11 164	1 744	12 908	18 633	31 541	150 000	30 000
1983	5	421	426	11 584	12 010	150 000	30 000
1984	397	318	715	9 919	10 634	150 000	30 000
1985	404	269	673	6 115	6 788	150 000	30 000
1986	1	110	111	7 470	7 581	150 000	30 000
1987	194	372	566	10 102	10 668	150 000	30 000
1988	272	528	800	1 958	2 758	150 000	30 000
1989	3 101	3 899	7 000	6 802	13 802	150 000	30 000
1990	4 440	6 560	11 000	11 670	22 670	150 000	30 000
1991	1 719	2 277	3 996	11 908	15 904	150 000	30 000
1992	924	1 076	2 000	17 827	19 827	150 000	30 000
1993	276	2 398	2 674	18 012	20 686	150 000	30 000
1994	1 954	4 016	5 970	18 350	24 320	150 000	30 000
1995	48	984	1 032	14 058	15 090	150 000	30 000
1996	8 285	445	8 730	16 969	25 699	150 000	21 000
1997	11 652	2 869	14 521	13 629	28 150	150 000	19 000

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[1] Minimal catches in SA 2 in some years are included under SA 3.

[2] TACs during 1974 and 1975 for SA 5+6 included *Loligo pealei* and *Illex illecebrosus.* In addition to SA 3+4 TACs in 1975-1977, countries without allocations were permitted 3 000 tons each.

These landings trends reflect a period of high productivity during 1975-81, followed by a period of lower productivity. There were some signs of recovery during the past 2 years in Subarea 3.

b) Data Available

Relative abundance and biomass indices are shown in Table 6 and Fig. 17b. Stratified mean weight (kg) and number-per-tow from standardized bottom trawl surveys, conducted on the Scotian Shelf (Subarea 4) during July (1970-97), are assumed to represent relative biomass levels at the start of the fishing season. Stratified mean weight-per-tow from standardized research bottom trawl surveys, conducted on the northeastern U.S. continental shelf (Subareas 5+6) during October-November (1967-97), are assumed to represent relative biomass levels at the end of the fishing season. However it is recognized that this multispecies autumn survey does not adequately sample either the aggregated resource along the shelf edge nor any off-shelf portion. A time series, 1982-93, of standardized landings per unit effort (LPUE) also exists for the Subarea 5+6 domestic trawl fishery (Hendrickson *et al.*, 1996). Trends in survey indices are similar among fishery areas but are highly variable, particularly in Subarea 4. Similarity of trends suggests the existence of a single stock throughout Subareas 3-6 with recruitment variability increasing to the north. This high variability in recruitment in Subareas 3-4 is consistent with landings trends.

TABLE 6. Abundance indices from survey and fishery data.

Year	SA 4 July Survey number/tow	kg/tow	SA 5+6 Autumn Survey number/tow	kg/tow	SA 5+6 LPUE tons/day
1967	-	-	1.57	0.242	-
1968	-	-	1.64	0.307	-
1969	-	-	0.59	0.073	-
1970	5.6	0.4	2.26	0.268	-
1971	28.5	2.8	1.68	0.337	-
1972	6.6	0.7	2.19	0.292	-
1973	10.9	1.5	1.47	0.353	-
1974	13.4	1.8	2.82	0.392	-
1975	44.8	5	8.74	1.417	-
1976	231.2	42.7	20.55	7.018	-
1977	50.9	9.5	12.62	3.740	-
1978	16.4	2.3	19.25	4.529	-
1979	91.4	14.2	19.42	6.053	-
1980	23.3	2.2	13.81	3.285	-
1981	35.5	4.9	27.10	9.340	-
1982	26	2.1	3.94	0.602	38.5
1983	76.9	2.1	1.73	0.233	23.6
1984	14.1	1.5	4.54	0.519	56.4
1985	80.2	2.7	2.38	0.355	24.8
1986	7.7	0.4	2.10	0.257	45.2
1987	4.9	0.4	15.83	1.527	67.0
1988	47.3	2.7	23.22	2.997	67.8
1989	26.3	2.7	22.43	3.307	65.8
1990	40.6	4.8	16.61	2.401	31.2
1991	27.1	1.8	5.21	0.691	54.7
1992	121.7	7.3	8.24	0.804	46.2
1993	79	5.4	10.42	1.595	46.2
1994	45.3	4.2	6.83	0.860	-
1995	33.9	2.4	8.01	0.700	-
1996	11.9	0.9	10.76	0.926	-
1997	52	4.8	5.83	0.521	-

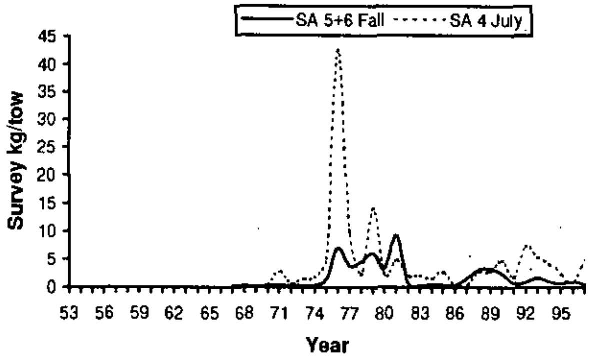

Fig. 17b. Squid in Subareas 3 to 6: trends in landings and survey biomass indices by fishery data.

Attempts were made to apply a stock production model including covariates (ASPIC) to this annual species. The input parameters used were the Subareas 3-6 landings, Subareas 5+6 standardized LPUE and autumn survey kg/tow, as well as Subarea 4 July survey kg/tow. However model runs resulted in unrealistic estimates of various population parameters which may reflect unsuitability of the model for an annual species with dynamic migrations and a high growth rate.

c) **Stock Identification**

This species is assumed to constitute a unit stock throughout its range from Newfoundland to central Florida. Although conclusive genetic stock identification studies have not been conducted, several factors lend support to the unit stock concept. The distribution and timing of the occurrence of larval and juvenile stages between Newfoundland and south of Cape Hatteras suggest a spawning site south of Cape Hatteras, with a Gulf Stream dispersal mechanism which transports larvae and juveniles as far north as Newfoundland (Dawe and Beck, 1985; Rowell and Trites, 1985; Rowell *et al.*, 1985; Hatanaka *et al.*, 1985). In all Subareas, the first occurrence on the shelf is along the shelf-edge during spring (Lange and Sissenwine, 1983; Dawe and Warren, 1992). This distribution pattern suggests a single stock which recruits to all fishery areas simultaneously from offshore. As well, biomass indices from July surveys in Subarea 4 are positively correlated with biomass indices from Subarea 5+6 autumn surveys ($r = 0.567$).

d) **Reference Points**

It was not possible to calculate RPs because of unclear recruitment patterns and data limitations. Particularly problematic is the lack of adequate data on age and growth, and of an abundance index for the entire stock area.

A qualitative approach proposed by Caddy (SCR Doc. 98/8) was viewed positively as a first step to applying the PA to stocks such as short-finned squid which can be described as data poor.

e) **Decision Rules**

The fishery in Subareas 3+4 is regulated by TAC. The analyses on which this TAC is based were last conducted in 1980 and were predicated on population parameters, biomass estimates, and target exploitation rates which have since been shown to be invalid or unsupported. At that time, short-finned squid was assumed to have a low natural mortality rate and exhibit asymptotic (von Bertalanffy) growth. Also, the likely existence of a single stock was not considered.

Given that our understanding of the life history and population dynamics of this species significantly differs from that of two decades ago, harvest control options for this species should be reconsidered.

f) **Research Requirements**

Indices of stock biomass and recruitment should be developed which represent the entire stock area.

Data on age and growth should be collected from all fishery areas, to attempt to clarify recruitment patterns and provide input data for estimating stock biomass.

Stock composition and extent of interchange among fishery areas should be clarified through application of mark recapture and genetic techniques.

V. FUTURE DEVELOPMENT AND FUNDING

Scientific Council considered that the Workshop was the starting point of developing limit and target RPs in the PA to the management of NAFO fish stocks. It was agreed that work should be continued, particularly by the Designated Experts during the intersessional periods between Scientific Council Meetings.

Scientific Council noted that continuation on work on the PA would have financial impacts. While some funding requirements will be needed for intersessional or specific meetings that the Scientific Council may call, significant financial commitments may also be needed for research (additional scientific surveys in the NAFO Area) and further developments of the PA for NAFO fisheries.

As noted there is an identified significant need to reduce the levels of uncertainty around developing RPs for all of the NAFO stocks, and in many cases the levels of uncertainty are broad. These uncertainties, unless narrowed down in a short time frame, may have considerable economic impacts resulting from inappropriate management decisions. Scientific Council believes that investment toward those research initiatives is an essential commitment in the development of the Precautionary Approach to Management of NAFO Stocks.

It was generally noted some Contracting Parties have valuable fishery databases. Scientific investigations of these historic data series could likely provide good insight to many of the NAFO stocks. In particular the USSR research data were thought to possibly be of value.

ANNEX 1. METHODS APPLIED

	Methods				
Stocks	ASPIC	Y/R and/ or SSB/R	Evans and Rice[1]	Mohn and Black[2]	Others
Under the Responsibility of Fisheries Commission					
Cod in Div. 3M	X	X	-	-	G_{loss}[3], Age Based Prod. Model[4]
Cod in Div. 3NO	X	X	X	-	G_{loss}[3], Traffic Light[5]
Redfish in Div. 3LN	X	X	-	-	-
Redfish Div. 3M	X	X	-	-	Z Length of Entry to Fishery[6]
American plaice in Div. 3LNO	X	X	X	X	Age Based Prod. Model[4]
American plaice in Div. 3M	X	X	X	-	-
Witch flounder in Div. 3NO	-	X	-	-	Catch Effort Data Analysis[7] Y/R Model
Yellowtail flounder Div. 3LNO	X	X	X	-	Traffic Light[5], ASSFM model[9], Thompson Bell[10]
Capelin in Div. 3NO	-	-	-	-	Review of data and assessments
Greenland halibut in SA 2+3	X	X	-	-	
Shrimp in Div. 3M	X	X	-	-	Traffic Light[5], Z Length of Entry to Fishery[6]
Squid in SA 3+4	X	-	-	-	Review of data and assessment.
Not Under the Responsibility of Fisheries Commission					
Greenland halibut in SA 0+1	X	X	-	-	Traffic Light[5], Age Based Prod. Model[8]
Roundnose grenadier in SA 0+1	-	-	-	-	Traffic Light[5]
Shrimp in SA 0+1	X	-	-	-	Prod. model under development, Traffic Light[5]
Redfish in SA 1	X	-	-	-	Lowest observed biomass from surveys
Other Finfish in SA1	-	-	-	-	Lowest observed biomass from surveys

[1] Evans and Rice, 1988.
[2] Mohn and Black (SCR Doc. 98/10).
[3] Cook (SCR Doc. 98/9).
[4] Sissenwine and Shepherd, 1987.
[5] Caddy (SCR Doc. 98/8).
[6] Caddy, 1996.
[7] CEDA, 1995.
[8] Ricker, 1975.
[9] Cook, 1997.
[10] Thompson and Bell, 1934.

APPENDIX I. STATEMENT FROM 4-19 JUNE 1997 SCIENTIFIC COUNCIL MEETING REPORT

(*NAFO Sci. Coun. Rep.*, 1997, p. 40-41)

Endorsement of the Precautionary Approach by the Scientific Council

After reviewing the development, evolution and application of the precautionary approach in fisheries management, the Scientific Council **endorsed** the precautionary approach as described in Article 6 and Annex II of the UN Agreement of the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. In addition, the Council intends to use the practical guidance given in FAO 1995a on how to exercise such precaution.

The Council recognizes that implementation of the precautionary approach will be a challenging and ongoing process. To address this challenge in a rigorous and objective fashion, the Council has initiated development of a framework and action plan, and arranged for a *Scientific Council Workshop on the Precautionary Approach to Fisheries Management*. This Workshop, to be chaired by the Chairman of the Scientific Council, will meet during 17-27 March 1998 in Dartmouth, Nova Scotia, to address the following terms of reference:

1. Describe procedures for determining limit and target reference points under various levels of stock-specific information,
2. determine the limit and target precautionary reference points for all stocks under the responsibility of the NAFO Fisheries Commission (i.e. cod in Div. 3M and Div. 3NO, American plaice in Div. 3M and Div. 3LNO, yellowtail flounder in Div. 3LNO, witch flounder in Div. 3NO, redfish in Div. 3M and Div. 3LN, Greenland halibut in SA 2+3, capelin in Div. 3NO, shrimp in Div. 3M and squid in SA 3+4),
3. specify decision rules (e.g. courses of action to achieve target reference points and to avoid exceeding limit reference points,
4. develop criteria to be used in consideration of possible fisheries re-openings,
5. identify data collection and monitoring activities required to reliably evaluate resource status with respect to reference points,
6. define research requirements to improve the quantification and evaluation of uncertainty (i.e. risk analysis) as well as methodological developments required to reduce uncertainty, and
7. indicate time frames and funding required to successfully implement the precautionary approach.

APPENDIX II. LIST OF SCIENTIFIC COUNCIL DOCUMENTS

RESEARCH DOCUMENTS (SCR)

SCR No.	Ser. No.	Name and Title
98/2	N2975	RIKHTER, V. A. Problems of fishery management: precautionary approach and some others.
98/3	N2977	CADRIN, S. X., and U. SKÚLADÓTTIR. Surplus production analysis of shrimp in the Denmark Strait.
98/4	N2978	RÄTZ, H. J., and J. LLORET. Checking of some conventional management reference points for the cod stock off Greenland.
98/5	N2979	MYERS, R. A., K. G. BOWEN, N. J. BARROWMAN, and G. MERTZ. The maximum reproductive rate of fish at low populations sizes.
98/6	N2980	VAZQUEZ, A., and S. CERVIÑO. Covariance among survey indices of abundance at age.
98/7	N2981	BELL, E. D., and G. STEFANSSON. Performance of some harvest control rules.
98/8	N2983	CADDY, J. F. Deciding on precautionary management measures for a stock and appropriate limit reference points (LRPs) as a basis for a multi-LRP Harvest Law.
98/9	N2984	COOK, L. M. Application of gloss methodology to 3NO cod.
98/10	N2985	MOHN, R., and G. BLACK. Illustrations of the precautionary approach using 4RVW haddock and 4VsW cod.
98/11	N2986	RIVARD, D. Elements of a non-parametric precautionary approach.
98/12	N2988	BELL, E. D., and G. STEFÁNSSON. In search of stability: how to halt the decline of fish stocks.
98/76	N3069	NAFO. Report of Scientific Council Workshop on the Precautionary Approach to Fisheries Management.

SUMMARY DOCUMENTS (SCS)

SCS No.	Ser. No.	Name and Title
97/12	N2911	SERCHUK, F. M., D. RIVARD, J. CASEY, and R. MAYO. 1997. Report of the *Ad hoc* Working Group of the NAFO Scientific Council on the precautionary approach.

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