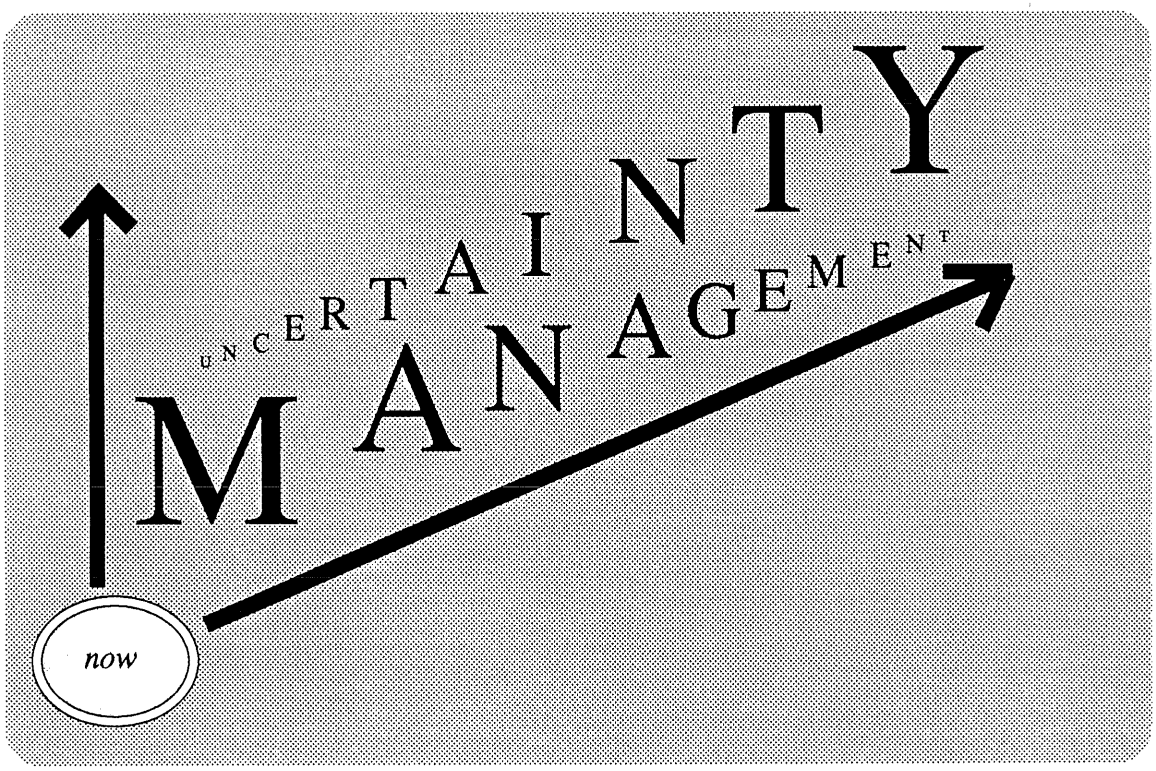
INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
CONSEIL INTERNATIONAL POUR L' EXPLORATION DE LA MER

C.M. 1994/Assess :11

REPORT OF THE

WORKING GROUP ON LONG-TERM MANAGEMENT MEASURES

MIAMI, 18-27 JANUARY,
1994



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1 INTRODUCTION

1.1 Participants

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1.2 Terms of Reference

At the 81st Statutory Meeting in 1993 (C.Res.1993/2:6:15), it was decided that the Working Group on Long-Term Management Measures (Chairman Dr. T.K. Stokes, UK) would meet in Miami, Florida, USA, from 18-27 January 1994 to:

a) develop further strategies for explicitly including spatial effects in multispecies/multifleet assessment models in different fisheries systems, taking account, as appropriate, of:

   i) methods for the incorporation of migration and dispersal rates for use in spatially disaggregated models and advise how such data may be obtained from available data;

   ii) effort reallocation models including socio-economic aspects;

   iii) methods for inferring discard rates from existing data;

b) develop methods for evaluating the performance of long-term management strategies in different fisheries systems, with emphasis on the use of biological reference points in relation to uncertainty, advise how future work on this subject should be structured within ICES and suggest how results can be incorporated in ACFM advice;

c) in relation to the transfer of the STCF database, discuss hardware and software facilities; maintenance requirements; checking procedures; error corrections; updating procedures; extraction procedures; confidentiality protocol; access rights etc.

d) define focus areas for further development of multispecies/multifleet assessment models for future work of the Working Group.

e) consider how collaboration with the Working Group on Fishing Technology and Fish behaviour might be enhanced, especially with regard to gear selectivity modelling and fleet/metier definitions;

f) advise on the data and tools required to address questions associated with the "plaice box" in the North Sea.

The Group will make its report available to the Working Group on Fishing Technology and Fish Behaviour. The meeting should be attended by gear and fish capture experts.

1.3 Acknowledgements

The Working Group would like to thank Joe Powers and all at the Southeast Fisheries Center for the invitation to hold the meeting in Miami, for the excellent facilities and help provided and, last but not least, for the hospitality extended to us.

1.4 Outline and Introductory Remarks on Terms of Reference

The Working Group reviewed and re-asserted the statement made in last year's report : sound fisheries "management procedures" require "objectives" which are to be achieved, "strategies" by which to achieve them, and "tactics" (referred to as "tools" in last year's report) to implement the strategies. The management strategy is the operational definition of the objectives. The tactics are the measures used to translate the strategy into fishery control rules. Also, as stated in last year's report, the Group should be able to formulate useful advice on the likely utility of management "strategies" and "tactics". Though there is the obvious link between strategies and tactics, it is useful to consider each independently.

The "philosophy" of this approach is outlined in section 1.6 whilst more detailed discussion on evaluating management strategies and evaluating management tactics is contained in sections 2 and 3, respectively. These two sections relate directly to terms of reference b) and a).

Section 1.5 is an attempt to clarify and standardise terminology.

The Working Group agreed that work on the evaluation of management strategies and management tactics was inextricably interlinked and that this Group was well placed to serve as a point of integration and should continue to develop the tools necessary for this work (see section 1.7).

Section 2 outlines a framework for the evaluation of management strategies and reports a number of examples either brought to or created during the Working Group. In particular, two sets of calculations for a North Sea cod-like stock were performed during the meeting. The one set is an example of a complete approach to evaluating management strategies, the other is a simpler approach given as an example of what might be done within ICES in the absence of a usable framework for the complete approach. The Working Group has made a number of suggestions and recommendations regarding the elements that should be included in such work. Section 2.5 discusses experiences on the communication of management strategy evaluation.

Section 3 is concerned with issues of fleet movement, fish movement and discarding. Some of the problems facing the Working Group are likely to be matters of estimation rather than of evaluating tactics *per se*. It was agreed that so far as possible, such matters should be referred to the Methods Working Group. Nevertheless, various working documents were considered on migration, fleet definition and on discard inference. It was agreed that work on developing component models (e.g., for migration or effort reallocation) of a framework for evaluating tactics, would need to be carried out on a case specific basis. An example of evaluating the effects of closed areas as a management tactic is given in Section 3.3.6.

The Working Group has been asked to advise on the transfer of the STCF database to ICES (term of reference c)). Discussions on this subject were facilitated by the participation of H. Sparholt of the ICES Secretariat. Specific comments are given in Section 4 of the report. Few technical problems are envisaged but there are potential manpower implications for the ICES Secretariat. If the STCF database is to be of value to this Working Group, it will need to be easily available to members both during and between meetings. It was recognised that a decision as to access to and usage of the disaggregated database needed to be made at the Statutory Meeting or, ideally, even sooner. This may need to be done as a matter of some urgency (see paragraph below on the "Plaice Box"). Specific recommendations are given in Section 4.

Term of reference d) requires the Working Group to define focus areas for further development of multispecies/multifleet assessment models for future work of the Working Group. This term of reference is not addressed in a separate section but is prefaced in Sections 1.5 and 1.6 dealing with terminology and the Working Group's perception of management measures evaluation, together with Section 1.7 which addresses the Working Group's perception of its mandate. Section 5 (Conclusions and Recommendations) draws on these sections and makes recommendations for the structure of future meetings and specific areas of work for the next meeting.

With regard to term of reference e), Ronald Fonteyne, the Chairman of the Fish Capture Committee, presented the work of the Fishing Technology and Fish Behaviour Working Group (FTFB Working Group) towards development of selectivity experimental and analysis procedures. It is noted in Sections 1.7 and 3 that work towards the evaluation of management strategies and tactics will include research and development of techniques for evaluation and application of the methods to specific cases. This Group envisages employing models of gear and vessel characteristics (e.g., selectivity, fishing power, etc.), with associated parameter estimates and measures of uncertainty, which have been studied and developed by the FTFB Working Group. The Working Group agreed that collaboration with the FTFB Working Group would need to be on an *ad hoc* basis with this Working Group seeking advice from the FTFB Working Group on specific gear (and fleet) issues as appropriate.

Term of reference f), regarding the "Plaice Box", was included in order to help the Study Group dealing specifically with this issue. Unfortunately, no participants were present with specific experience of the regulations or models previously used to address related issues. Anon. (1987) and Rijnsdorp and van Beek (1991) have utilised a simple model to investigate the effects of effort redistribution patterns on the level of discarding. The ABC model (now referred to as the 4M model; see Section 3.5) is also available together, potentially, with the spatially disaggregated fleet data for 1989 and 1991 held in the STCF database. Last year, this Working Group (Anon., 1993a) noted the lack of information on discarding and on migration, both of which are considered to be important in assessing any effects of technical measures associated with the plaice box.

It is not clear, however, from the terms of reference for the "Plaice Box" Study Group, precisely what questions are being addressed to that Group. One interpretation is that the Study Group will be considering tactics rather than strategy. Also, it is not clear whether or not that Group would be allowed access to the spatially disaggregated data held in the STCF database (see Section 3.5

and, particularly, 4). A decision on protocols for the use of those data, using the normal ICES procedures, cannot be made before the Study Group meets.

In Section 3.3.3, specific comments are made on evaluating management tactics with particular reference to closed areas. These comments are pertinent to any work that might be conducted by the "Plaice Box" Study Group. This Working Group suggests that the Study Group should take note of the comments on the evaluation of management strategies and tactics in Sections 1.6 and 1.7 and in Sections 2 and 3. The tenor of those comments with respect to the evaluation of tactics is that this can only proceed in the context of defined strategies; that initial conditions, including estimation error, must be taken into account and that, depending on the time-frame of any predictions attempted, the modelling of process noise may also be required. It is also pointed out in Section 1.6.2 that any models used to evaluate tactics must be consistent with those used to evaluate strategies. Ideally, any evaluation of tactics attempted by the Study Group will take account of these comments to the greatest extent possible by incorporating relevant uncertainties into any simulations and by conducting sensitivity analyses to any assumptions concerning eg. effort reallocation or migration. The Working Group suggests that any results or conclusions from that Study Group, should be viewed and interpreted with regard to the comments made in this report.

1.5 Terminology

The Working Group agreed that a common terminology was important and that this should be used consistently. The development of terminology was evolutionary throughout the meeting; it is included here in the introduction to facilitate reading. Additional, relevant terminology can be found in the report of the Working Group on Methods of Fish Stock Assessment (Anon., 1993b). The framework for evaluating management strategies, outlined in Section 2.1.2, and examples included in Section 2.3 demonstrate the usage of this terminology.

RISK ANALYSIS is the evaluation of benefit streams under uncertainty.

RISK is the expected loss of benefits from the resource.

PROBABILITY PROFILES express the cumulative probability of different outcomes from a management scenario resulting from an assessment.

At least five types of uncertainty can be distinguished:

1) **MEASUREMENT ERROR** is the error in the observed quantities such as the catch or biological parameters.
2) **PROCESS NOISE** is the underlying stochasticity in the population dynamics such as the variability in recruitment.
3) **MODEL ERROR** is the misspecification of model structure.
4) **ESTIMATION ERROR** can result from any of the above uncertainties and is the inaccuracy and imprecision in the estimated population parameters such as stock abundance or fishing mortality rate.
5) **IMPLEMENTATION DEVIATION** results from variability in the resulting implementation of a management policy, i.e., inability to exactly achieve a target harvest strategy.

In the simulation the:

UNDERLYING SYSTEM STRUCTURE is the simulated population dynamics and ecological structure of the resource. It is a plausible representation of the dynamics of the resource, possibly including the socio-economics of the fishery in addition to the biological structure. The comparison between any set of alternative approaches to management is conditional upon the underlying system structure simulated. So, robustness to system structure needs to be explored (i.e., the model error should be investigated along with other sources of uncertainty).

MEASUREMENT PROCEDURE is the simulation of sampling from the underlying system to generate observations containing measurement error.

ASSESSMENT PROCEDURE is the estimation of status, reference points and targets from a given set of observations generated in the measurement procedure.

MANAGEMENT PROCEDURE are measures used to manage the resource and include **CONTROL STRATEGIES** such as total allowable catches or size limits, **MONITORING REQUIREMENTS** such as mandatory catch reporting and survey requirements, as well as **IMPLEMENTATION REQUIREMENTS** to operate the control and monitoring.

PERFORMANCE INDICES are measures of the output from the system such as the yield or biomass obtained in a given year in one realization of the underlying system structure with the management approach chosen.

PERFORMANCE STATISTICS are summaries (e.g., means, medians, quartiles, coefficients of variation) of performance indices across simulation realizations and/or projection years.

Additionally:

MANAGEMENT STRATEGY includes all components of the management procedure including monitoring requirements and control.

FISHERY CONTROL is the metric by which the management objectives will be addressed. For example the control might be on fishing mortality or on age at entry

FISHERY CONTROL LAW is the detailed description of how the control will be varied under different stock conditions such as how fishing mortality rate will be varied as a function of stock biomass.

FISHERY TACTICS are the measures that will be taken to implement the control law such as effort restrictions, closed areas, gear regulations or total allowable catch quotas.

1.6 On Strategies and Tactics

1.6.1 Evaluation of strategies

Management strategies define a general approach for achieving objectives. Traditional examples of strategies include target fishing mortality rates (e.g., $F_{0.1}$), minimum spawning biomass and spawning escapement. Ideally, strategies are agreed upon *a priori* and are not modified based on the status of resources at any point in time but they should reflect any predisposition to risk-averse or risk-prone behaviour in relation to uncertainties about resource status. Typically, strategies relate to system-wide characteristics and are not concerned with those temporal, spatial and fleet complexities which do not impact the system state. Strategies may involve time frames such as when the objective is to rebuild a resource. A potential strategy might be reduction of the fishing mortality from $F= 1.0$ to $F=0.5$ over a 5 year period. More frequently, however, strategies do not specify a time frame. Evaluation of alternatives is generally conducted in a manner such that comparisons are not influenced by initial conditions about the state of the system nor are they specific to a certain future point in time. We emphasize that evaluation of strategies is a comparative exercise and not meant to forecast the absolute state of systems. Accordingly, the Group discourages use of the description "long-term" in reference to strategies as this can mislead people into thinking that specific predictions are being made over some long time period. It is understood, however, that evaluation of strategies does involve simulations conducted over a suitable time frame.

The Group agreed that evaluation of management strategies is done most effectively in the context of the entire "management procedure". A framework for evaluation of management procedures was the central theme for one of the workshops at this meeting and is discussed later (see Section 2.1). Essential features are briefly outlined here to contrast with those needed for evaluation of management "tactics". Evaluation of strategies may be conducted by examining historical trajectories. Interpretation using this approach is limited due to difficulties in ascertaining what the true population trajectory was from the perceived trajectory which was estimated. The Group considered that evaluation of strategies through simulation studies promised enhanced insights though it must be recognized that results are dependent on the characteristics of the simulated system. The simulations should not be viewed as providing predictions but as a tool for comparison of relative performance of alternative strategies.

The evaluation framework incorporates two distinct model components, the system model used to generate the underlying population dynamics and ecological structure of the simulated system, and the assessment-prediction model used to evaluate the state of the system from "observations" and to derive the appropriate level of the specified fishery controls. The structural characteristics of these two components may be the same but this is a special case. Permitting the two components to be different allows evaluation of management procedures for a particular system model using various assessment models; eg. for an underlying system which includes multi-species interactions, compare the performance of a single species assessment model to that of a multi-species assessment model. Alternatively we may wish to evaluate the robustness of a particular assessment model, in the context of a management procedure, to a variety of underlying population dynamics models; eg. how sensitive is a management procedure based on a surplus production assessment model to changing the stock-recruitment specification from a Ricker type to a Beverton-Holt type. We refer to the first kind of evaluation as conditioned on the "system" model and to the latter as conditioned on the "assessment" model.

The system model should be a plausible representation of the structural dynamics and incorporate appropriate process noise, eg. stochastic recruitment. "Observations" from the system (e.g., simulated survey abundance data) must include suitable error obtained by simulating a measurement procedure which samples the underlying system. The assessment model may misspecify the underlying system as described above. Deviance in implementing the specified controls may occur. Evaluation of the management procedure involves simulating the underlying system and observations from the system, assessing the state of the system based on those observations, making predictions and implementing the controls over a time period while monitoring performance indices and their statistics (see Sections 2.1.1 and 2.1.2). To the extent possible, the Group **recommends** that detailed tactics should be left out of the models used to evaluate strategies. This simplifies the task of evaluating management strategies and makes interpretation easier.

1.6.2 Evaluation of tactics

Many of the detailed measures which managers may invoke from year to year need not be included in evaluation of strategies. Often, however, managers need to know if particular tactics they have in mind for specific situations will translate into meeting a strategy. For example, it may be determined that there is sufficient mixing to consider the resource a unit population, thus allowing evaluation of alternative fishing mortality rates as strategies. The manager may consider implementing the selected strategy through a combination of effort allocation by area and season, perhaps including some closures. A prediction model with multiple areas, a seasonal time scale and suitable migration characteristics must be devised. This example identifies the need for defining a framework which can be used to evaluate if tactics translate into a strategy. It is important to recognize that the strategy is not in question here.

The framework for evaluating tactics involves a "prediction" model. The state of the system is taken to be that perceived through the historic assessment procedure. There is no underlying system to simulate a "true" population, unlike the framework for evaluation of strategies. Thus the initial conditions are very important. The time frame for evaluation is dictated by the management requirements. The measure may be implemented for one year or in perpetuity. The prediction model should take into account the estimation errors of the system state. These may have been estimated analytically or by some Monte Carlo technique. Depending on the time frame of the prediction, it may be necessary to include process noise, eg. stochastic recruitment. In such instances the processes invoked should be consistent with those used in defining the strategy. The structural model for prediction needs to include the necessary species interactions and spatial, temporal and fleet complexity to address the issues posed by the proposed tactics. This complexity can often be more detailed than the model used to evaluate strategies as long as it is consistent with any assumptions made by the models used in defining the strategy. The prediction model must produce a performance measure(s) in the units which the strategy has been defined. Performance of the tactics is based on compliance with the strategy; however, the details of the prediction are also likely to be of interest to the manager. The specifics which are of relevance must be defined in the context of the situation under consideration.

1.7 The Perceived Mandate of the Working Group

Though desirable, the evaluation of management strategies (procedures) and the evaluation of tactics are not always as distinct as has been described here. Though prediction models to evaluate tactics are easier to construct if the strategy is defined first we can imagine situations where the stated strategy cannot be practically satisfied with the suite of tactics at our disposal. In that circumstance, we would offer some feedback from the tactic evaluation and request that alternative strategies be considered. Alternatively, the evaluation of strategies may reveal some approaches which suggest new tactics. In practice, feedback between evaluation of strategies and evaluation of tactics is likely to occur in order to identify suitable practical solutions. The potential for feedback between evaluation of strategies and evaluation of tactics as well as the compelling need to employ consistent models and procedures argues strongly for interaction and collaboration in these two activities. The Working Group is well positioned to serve as a point of integration.

The Working Group perceives its mandate to be the evaluation of management strategies with respect to suitable performance measures and the evaluation of management tactics in relation to identified strategies. The work includes research and development of techniques for evaluation and application of the methods to specific cases (preferably referred by ACFM). This Working Group envisages employing models and associated parameter estimates regarding gear and vessel characteristics (eg. selectivity, fishing power, etc.) which have been studied and developed by the FTFB Working Group, regarding multispecies interactions by the Multispecies Working Group, and regarding fleet and spatial characteristics and population dynamics by the assessment groups. To the extent possible, the Group would refer issues on estimation techniques to the Methods Working Group. A significant degree of co-ordination will be required to ensure that the interactions between this group and others are effective and that their work is complementary.

The Working Group wishes to avoid the liability of having too diffuse a mandate. It would therefore be beneficial to exclude model development and estimation in its terms of reference. No doubt, the Working Group will at times be compelled to develop models and consider estimation for unique problems which are not being studied elsewhere, e.g., multi-area models and migration. The Working Group will also probably have to consider the integration of model components which may be taken from diverse sources. This work would be undertaken, however, in the context of our perceived principal goal, to evaluate strategies and tactics.

Though the Working Group is concerned with both themes (evaluation of strategies and tactics) progress may be facilitated by changing the focus in alternating years rather than trying to cover both topics comprehensively at each meeting. The Working Group **recommends** that the next meeting should focus on further development of a framework for evaluating tactics and suggests that 3 or 4 case studies be identified for analysis. The strategies for the systems to be studied should be identified and a suite of possible tactics to be considered should be described.

The Working Group considers that the expression "long term" is uninformative and potentially misleading in the context of our perceived mandate. We **recommend** that the name be changed to Management Measures Evaluation Working Group.

2 EVALUATING MANAGEMENT STRATEGIES

2.1 Introduction

2.1.1 Outline procedure for evaluating management strategies

This section outlines the major components the Working Group agreed should be included in the evaluation of alternative fisheries management strategies given uncertainty. The terminology used in this description is given in Section 1.5. Although this section outlines a framework for conducting evaluations, the Working Group noted that specific management strategies will need to be analysed for specific fisheries. It is unlikely that general conclusions about the relative performance of a management procedure will apply across a wide range of fisheries beyond those features that are clear from theoretical work (e.g., an $F_{0.1}$ target will be more conservative than F_{max} but will not always perform better for a given fishery). It was noted that the IWC encountered a similar problem in the development of the Revised Management Procedure. That is, a general method for setting catch limits could be developed that was conservative across a wide range of simulated cases, but for specific whale fisheries, it could not be concluded the general procedure would necessarily be conservative without additional detailed simulation studies. Ideally, whilst it is desirable to have defined objectives to help in the evaluation of strategies, this is highly unlikely (see Anon., 1993a, Section 2.1.6) and it will be necessary to evaluate management strategies by considering several indicators relevant to biological, economic, social and other objectives (see Section 2.2). The Working Group **recommends** that ICES work toward adopting the type of management strategy evaluation described below as a regular component of its advice to fisheries managers.

It is important to first note that evaluation of management strategies requires a number of assumptions to be made about how the "true" system works (the stocks and the fisheries). The evaluation of management strategies is conditional on these assumptions. In practice, assumptions about the true system are based on analyses of empirical observations, often made during recent years. It is inevitable that at some point during the evaluations of strategies, extrapolations of the state of the system will be made beyond the range of the observed data, where the assumptions made could be unrealistic. In any case, the performance of management strategies in these previously unobserved states could be examined under different sets of assumptions (i.e., sensitivity of results to model errors). More importantly, the assumptions and methods used to evaluate the strategies should be updated as more empirical observations are accumulated.

There are four major steps for evaluating a set of strategies for a given fishery: 1) calculation of the estimation error in current status; 2) stochastic projections including estimation error and process noise; 3) sensitivity analysis of model errors; and 4) risk analysis. These are briefly described below and illustrated in the examples presented in working documents for the meeting.

1) The estimation error in the assessment of current status is routinely calculated in many stock assessments in North America (e.g., Smith *et al.*, 1993). Delta method, bootstrap and Bayesian methods have been used to obtain a distribution of the estimates of quantities such as the fishable biomass and fully recruited fishing mortality rate. The Working Group noted that the assessment software currently used in ICES does not routinely calculate the estimation error in the assessment, though some estimates of assessment bias are made using retrospective analysis. Only a few studies have used bootstrap or Monte Carlo techniques to evaluate the uncertainty in the biological reference points (e.g., Conser and Gabriel, 1993). Calculation of the estimation error is an essential first step if the effects of measurement error are to be included in the evaluation of management strategies. The Working Group **recommends** that estimates of the estimation error in the assessment be included as a routine part of ICES assessments in future. The Working Group on Methods of Fish Stock Assessment (Anon., 1993b) detailed how these calculations should be carried out; the ICES assessment software needs to be updated to include the facility for estimating uncertainty (including bias) but it is understood that this should be accomplished in the near future (Horwood, *pers comm*).

2) ICES assessment working groups routinely make short-term projections of stock abundance under different exploitation rates as part of their analyses. These projections are made deterministically from the point estimate of current abundance obtained in the assessment. Short-term projections should include the estimation error and therefore result in an interval of stock abundance as the prediction (see Anon., 1993b). For longer term projections for the evalu-

ation of management measures, including stochasticity is essential. There are two components of the stochasticity, estimation error and process noise. The most complete examples of such stochastic projections come from the work done in the southeastern U.S. at the National Marine Fisheries Service Miami Laboratory. The approach is described in Powers and Restrepo (1993), Restrepo *et al.* (1992) and WD 18 for this Working Group meeting. In this work, the process noise is included in the projections in the form of variable recruitment around an estimated stock and recruitment relationship and by randomly varying population parameters such as the rate of natural mortality within a plausible range. The estimation error is included by projecting forward variability in the assessment estimates of current status described above, and updating this estimation error each year by simulating the assessment process forward in time. An alternative, simpler approach would be to assume the variance in the estimates is constant and use a Monte Carlo approach to projecting the estimation error. For each management strategy, a probability distribution of outcomes is obtained including these sources of variability. The comparison of management strategies is through the comparison of these distributions for the quantities important to the managers such as the realised yield and spawning biomass over time.

3) The uncertainty due to possible model error should be explored through sensitivity analysis. In other words, would substantially different results be obtained for a given management procedure, using another plausible underlying system structure, than are predicted given the process noise and estimation error with the original underlying system? For example, if projections have been made using an underlying Beverton and Holt stock and recruitment relationship a sensitivity run may be needed to determine if projections using a Ricker relationship would give a stock trajectory outside the uncertainty intervals obtained from the original model. An example of this sort of sensitivity analysis is given in WD 25. Other sorts of model error that should be investigated are, for example, sensitivity of the results of the projection to migratory behaviour of the stock, the impact of population regulation through multispecies interactions or changes in fishing behaviour. Estimates of stock trajectories obtained with different underlying systems should be compared to the probability distribution of the outcomes of the stochastic projections described above.

4) Risk analysis for decision making can be done with the results of the stochastic projections. The expectation of variables important for conservation (e.g., SSB) or fisheries success (e.g., yield) can be used to calculate expected loss as a measure of risk. In addition, economic measures such as economic rent (see WD 10), producer or consumer surplus may be important variables in developing management advice. A formal risk assessment requires the specification of appropriate utility functions as described by the Methods Working Group in Anon. (1993b) and illustrated in WD 10 and WD 25. In general, however, calculation of long-term expectations, given uncertainty, of important measures of performance should be included as part of the evaluation of a management strategy. Some of these measures are suggested in Section 2.2.

Evaluations of management strategies will need to be carried out on a fishery by fishery basis using the general framework. To do this, ICES Working Groups will need to have available appropriate software for stochastic simulations including the various sources of error. Projections which fully account for the major sources of uncertainty (measurement error, process noise, estimation error, model error and implementation deviation) will require quite complex software such as that described in WD 18 with an additional example described below in Section 2.3.6. Making such software easily usable by the Working Groups will, however, require major additional programming effort. ICES should embark on developing this software as soon as possible. Nevertheless, assessment packages, such as ADAPT and the soon to be released ICES Tuning Package (Version 3.1) including XSA, can produce estimates of estimation errors which should be used when making short-term projections. Additionally, there are simple, easy to use tools such as the commercially available EXCEL add-in program @RISK which can be used for making stochastic forecasts. This is illustrated in WD 25 and in an example described below in Section 2.3.7. The Working Group **recommends** that assessment Working Groups be asked to prepare stochastic forecasts rather than deterministic projections. It should be made clear, however, that these stochastic forecasts measure errors about the perceived population as opposed to the true population.

2.1.2 Simulation framework for evaluating management strategies

It was evident from the presentations made at the meeting that there is common ground among the various approaches used for evaluating the performance of management strategies. Figure 2.1.1 is a flow diagram of the essential components and steps in such a framework. The list below further explains components of the framework and can be referenced to the flow diagram by their numbers:

1. *Underlying System Structure*

This is the "true" system whose dynamics includes process noise. The "true" system is one simplified representation of the real world in which relevant knowledge about reality is incorporated. It is evident that there must exist differences between the behaviour of the "true" system and the real world which, however, cannot be quantified. Important features for the system can be:

- Resolution in space and time: areas with migration between them; monthly or annual time steps.
- Multispecies or single species system. Natural mortality, growth and maturity at age may vary as a function of the abundance of another species.
- Stock recruitment relationships. Various forms (Beverton-Holt, Ricker, etc.) are possible, with or without serial correlation.
- Environmental influences on recruitment, growth, etc.
- Fleet dynamics.
- Market dynamics.

2. *Measurement Procedure*

Here, sampling from the underlying system is simulated so as to emulate the actual observation process and the resulting measurement errors. It may be done by drawing from specified probability density functions or from empirical probability distributions (bootstrap).

3. *Observed Data*

These result from the measurement procedure and are whatever data may be necessary for the assessment procedure, below. Typically, these are:

- Catch (by age, year, size).
- Abundance indices (relative, absolute, CPUE, by age/year).
- Effort.
- Biological parameters (e.g., maturity, growth, sex ratio).
- Fishing Costs.
- Management Costs.
- Prices.

4. *Assessment Procedure*

The assessment procedure uses the observed data in addition to assumptions about the underlying system. Differences between the underlying system and the assessment model are model errors. The assessment procedure may give an estimate of the uncertainty in the results, including estimation error and bias. Examples of assessment procedures are:

- Multispecies or single-species sequential population analyses.
- Acoustic abundance survey estimates.
- Surplus production models.
- Length-based methods.

5. *Perceived System*

The perceived system results from the assessment procedure plus any assumptions made about it plus any subsequent analyses (e.g., a fit to estimated stock/recruitment data). Typically, the perceived system consists of

- Stock size estimates (by age, year, size).
- Exploitation rate estimates (age, year, size).
- Biological and economic reference point estimates (F_{med}, $F_{0.1}$, F_{MEY}).
- Minimum Biologically Acceptable Level.

6. *Fishery Control Laws*

Given estimates of the current stock status (F, SSB, etc.) and management strategy, the target fishing mortality (or catch) is estimated in this step. For instance, F may be set equal to a biological reference point if SSB > MBAL or reduced otherwise. The control law is affected by measurement and estimation error, as these quantities are all estimated. See Figure 2.1.2.

7. *Fishery Tactics*

The control law may be used to specify a TAC or effort regulation or size limits or season/area closures. How these tactics perform in the underlying system may be affected by any of the sources of noise and error in the perceived system.

8. *Updating of Underlying System*

Implementation deviations may take place here. For instance, if the perceived stock size is too large relative to the "true" one, a large TAC may not be obtainable from the underlying system. Also, the fleet dynamics may be such that the tactics selected cannot be fully realized.

2.2 Measures of Performance in Evaluating Management Strategies

Management of fisheries may include definition of one or more objectives often depending on fleet composition, market demands, species composition, population dynamics and present state of involved stocks, etc. A number of policy objectives together with possible strategies are listed below. In many management situations it may not be possible to proceed with a formal optimization of multiple objectives. Rather, a set of performance measures are examined to evaluate a management strategy.

The evaluation of management strategies should be made with performance statistics collected from the underlying system (see Figure 2.1.1). It is also useful, however, to examine the performance statistics from the perceived system and to compare these to the realised performance statistics. These two sets of information, from the underlying and the perceived systems, will not necessarily always lead to the same conclusions. There may be times when a strategy could perform well in reality while this would not be detected from the assessments, and *vice versa*.

Measures of performance might be investigated by considering trajectories, summary statistics such as cumulative yield or time-specific quantities such as continuing yield beyond a certain year. All of these measures would be presented with associated distributions or distributional statistics.

2.2.1 Examples

Policy objectives: High Yield

Possible Strategies: Target F: $F_{\text{Maximum Sustainable Yield}}$

Performance Statistics: Expected yield over the planning horizon, the trajectory of yield, expected variability in yield

The objective of biological fishery models is often maximization of long-term yield in terms of biomass. If biological and/or economic interdependence occur this should be included in the underlying system in order to evaluate the management approaches.

Policy objectives: High Economic Return

Possible Strategies: Target F: $F_{\text{Maximum Economic Yield}}$

Performance Statistics: Expected economic rent, Expected producer and consumer surpluses

Application of bio-economic models allows evaluation of management approaches implemented to maximize the economic profit. The Maximum Economic yield, the resource rent, is often estimated as the net present value of the total revenue subtracted from the net present value of the total costs. Apart from knowledge about the underlying biological dynamics, maximization of economic yield also ideally requires full knowledge about costs of the fishery, e.g., capital costs, operation costs and labour cost, and price formation dynamics. Usually $F_{\text{Maximum Economic Yield}}$ is smaller than $F_{\text{Maximum Sustainable Yield}}$.

Policy objectives: High employment

Possible Strategies: Target F: $F_{\text{Maximum Sustainable Revenue}}$

Performance Statistics: Expected number of full time or part time fishermen, Expected revenue

In some fisheries high employment may be more important than high profit. In that case the costs of the fishery may be ignored estimating the target F alone focusing on the revenue. Usually $F_{\text{Maximum Sustainable Revenue}}$ is somewhere between $F_{\text{Maximum Economic Yield}}$ and $F_{\text{Maximum Sustainable Yield}}$.

Policy objectives: Conservation of stocks

Possible Strategies: Control laws such as shown in Figures 2.1.2b and 2.1.2c

Performance Statistics: Trajectory of spawning biomass, Stock size relative to MBAL, Spawning biomass per recruit ratios.

Stability in yield may be obtained through stability in biomass. Maintaining SSB > MBAL will facilitate conservation and stability. For already depleted stocks, reducing F may be required for rebuilding and long-term sustainability.

2.3 Examples

The examples in this section illustrate current efforts in the evaluation of management strategies. All of these represent different levels of sophistication and of completeness in terms of the evaluation steps outlined in Section 2.1.1. Some examples are based on actual stocks, while others are hypothetical. Section 2.3.1 studies the impact of improved precision on the short-term performance of an $F_{30\%SSBR}$ strategy for Gulf of Mexico king mackerel. The objective for this stock is maximum sustainable yield as modified by relevant socio-economic considerations. This is the only example here that has actually been used for decision-making. Section 2.3.2 exemplifies a more formal risk analysis which has some coverage of all the evaluation steps in section 2.1.1. For this Icelandic cod fishery, the primary objective is to avoid a stock collapse. The strategy examined aims at avoiding a collapse while optimizing profits with a penalty on instability. Section 2.3.3 involves a sophisticated multispecies model as the underlying system in the Barents Sea. Several strategies are examined in a system whose objectives are changing as management moves from a single to multispecies basis. Section 2.3.4 illustrates the use of a much simpler underlying system in evaluating a constant effort policy in terms of resource rent. The objective of management for this shrimp stock is economic efficiency. Section 2.3.5 demonstrates the use of a simulation framework such as that in Figure 2.1.1. It uses hypothetical stocks in varying degrees of exploitation with undefined objectives and various management strategies. Sections 2.3.6 and 2.3.7 were run during this meeting and are loosely based on the North Sea cod stock, whose management objective is unspecified.

2.3.1 Gulf of Mexico king mackerel

An example in which the interaction between research and short-term management strategies were evaluated using stochastic methods was presented by Powers and Restrepo (1993 and WD 27). In this example, the process of assessment, determination of target fishing mortality rate and selection of total allowable catch (TAC) was stochastically modeled for the Gulf of Mexico king mackerel. Then the efficacy of alternative research programs in reducing the uncertainty in the TAC selection was examined using decision analysis. Expected outcomes of yield, cost, yield per cost and opportunity losses of these quantities were computed.

The simulation model is the technique used by a southeastern United States scientific panel to assess the Gulf of Mexico king mackerel stock and to generate scientific advice presented to a regional management council for their decision on TAC. The base assessment model in the simulation is the ADAPT methodology in which indices of abundance were fit to the standard catch equations (catch-at-age) with a VPA. Terminal year parameters were estimated from an SVPA to obtain selectivity and then minimization of the weighted sum of squares of the fit between the indices of abundance and the appropriate stock sizes at age. The allowable biological catch (ABC) was determined by projecting stock size using the target F (F at 30% spawning stock biomass per recruit) with ABC being the associated yield.

Monte Carlo simulations of the SVPA and ADAPT fitting procedure were conducted in order to incorporate measurement error of the indices of abundance, catch (including by-catch), catch-at-age and natural mortality. The measurement procedure included variation in catches, catch-at-age and indices of abundance which were generated using means and coefficients of variation and probability distributions from the sampling procedures used to collect the data. Natural mortality rates were assumed to be uniformly distributed around the input value used in the assessment. Process noise was incorporated by modelling recruitment in the projection years as a lognormal distribution, the mean and variance of which was determined from the observed recruitment estimates from each of the Monte Carlo simulations of the assessment.

The probability profiles of ABC which result from the Monte Carlo simulations are presented to the decision-makers. Using this they choose a TAC which incorporates their perceptions of cautiousness relative to the status of the stock and other socioeconomic inputs.

In the example study presented to the Working Group the above simulations were utilized to evaluate the effects of research programs which reduce the measurement error. Several research scenarios were defined in which it was assumed that the coefficients of variation of the input variables were reduced. Then the simulation was repeated for each of these scenarios. The resulting reduction in the uncertainty in the ABC distribution was examined in terms of the implications of TAC decisions being optimistic or cautious as to the status of the resource.

The distribution of estimates of ABC from the scenarios indicated that realistic improvements in research could substantially reduce the uncertainty in ABC estimates from a 40% to a 20% coefficient of variation. Expected yield for cautious strategies increased with enhanced research programs. Opportunity losses of foregone yield and lost surplus were diminished as well. Benefits of research combined with cautious management strategies to the fishery and the economy can substantially exceed the costs of the research.

2.3.2 Icelandic cod

The paper by Baldursson, Stefánsson and Danielsson (WD 25) considers management of the Icelandic cod stock. The biological model is a cohort model but the economic model is based on the National Economic Institute's macro-economic model.

Economic performance indices are defined and an attempt made to maximize them. There are two types of performance indix that are looked at: present value of profit and present value of utilization. Utilization is basically profit with a penalty on oscillations. These are later used as benefit streams in formal risk analysis using the @risk add-in to Microsoft Excel.

The model is initially run deterministically to look at the steady state characteristics of the system and find the optimal control law.

The uncertainty taken into account in the analysis is process noise in the form of stochastic recruitment, weight and maturity at age. Measurement error in the assessment is represented by a lognormal distribution of error around the current fully recruited F with constant C.V. of 15%.

The probability profiles of the utility and the spawning stock are shown in the WD 25 for three different control laws that set different levels of allowable catch depending upon the estimated level of spawning biomass.

Extensions now under development involve:

- Consumption of capelin and shrimp by cod.
- Effects of the size of the capelin stock on the growth of cod.

Both shrimp and capelin are valuable commercial species in Iceland. It is expected that optimal stock sizes of cod will be lower than in the single species model and the present value of the utility higher.

The interactions are in relatively simple functional form and are based on data from the last decade.

Additions to the risk analysis involve:

- process noise: Recruitment of capelin.
- measurement error: Estimation of the spawning stock of capelin.
- implementation deviance
- model errors.

The optimal control law will be based on maximising the combined utility of all three species. Implementation deviance can occur in all three species. Sometimes it is biased. Biases in the implementation are equivalent to changing the control law in the risk analysis.

Managing the simulated stock using a feedback control law can result in the underlying system moving to states not previously observed in recent history. In effect, the simulation extrapolates the underlying system dynamics. However, such extrapolation is tentative and will require updating if the management strategy is used in practice. This is likely to be a more critical concern in systems governed by multispecies dynamics.

2.3.3 Barents Sea multispecies system

In Norway, a framework for evaluating management approaches for the fisheries in the Barents Sea is under development (WD 21). This work is conducted by the Norwegian Computing Center (NCC), which has also been involved in the development of management procedures for whale stocks carried out by the Scientific Committee of the International Whaling Commission (IWC).

The underlying system presently contains the species cod, capelin and herring. There are strong biological interactions between these three species. All the species are divided into age and length groups, and recruitment, maturation, growth, predation mortality and spawning mortality is modelled. Fishing by various fleets (but no technological interactions) and research surveys are also modelled. Some environmental factors like sea temperature and primary production are also included. Measurement error (on survey indices) and process noise (stochastic recruitment) is taken into account.

Various control laws (single- and multi-species) are currently being tested, and the choice of performance indices and statistics is also currently under discussion. The underlying system will be extended also to contain economic considerations in the near future. This project will become a forum for discussion between biologists, managers and economists.

2.3.4 Davis Strait shrimp

WD 10 simulates the expected yield and resource rent obtained by applying constant fishing effort on a varying shrimp stock.

The underlying system includes an age structured population subject to random recruitment within a fixed range around a mean value at each age class. Growth according to von Bertalanffy is assumed and weights are estimated as a function of length.

By applying three different recruitment ranges the sensitivity of the results to process noise was investigated. Also, the robustness of the results to the choice of distribution pattern of the recruitment at each age class is investigated applying both uniform and a lognormal distribution.

The effect of changing fishing tactic was investigated by increasing the mesh size from 43 mm to 55 mm.

For each recruitment range, recruitment distribution, and mesh size the performance statistics, including average yield, discard level, and revenue with the respective CVs based on 1,000 simulations, is given.

2.3.5 A hypothetical stock

WD 18 and WD 20 explore the comparative performance of management strategies by simulating a single species underlying system governed by Beverton and Holt stock and recruitment dynamics with lognormal process noise. The measurement procedure incorporated lognormal errors in catch and survey indices which are then assessed using the ADAPT methodology. Each simulation year the stock is projected forward one year and then re-assessed. Both the perceived stock abundance and fishing mortality rates and the underlying system are kept track of in order to evaluate the impacts of estimation error and process noise on the performance of the management strategy. The basic performance statistics calculated are the yield, spawning biomass, recruitment and fishing mortality rate. In addition, the power of the test that the stock biomass is greater than a threshold (MBAL) level defined by the point on the stock recruitment curve where recruitment is expected to be 50% of the maximum is computed. Both the trajectories over time as well as the expected value of each of these measures over the 15 years of the simulation are kept track of as measures of performance.

In WD 20, simple constant F strategies are evaluated for a stock in an overexploited condition at the start of the projections. In WD 18, control laws which incorporate a minimum biomass level below which F is reduced are explored. Some of these control laws directly utilize the uncertainty in the estimates of current status. The results in all of the simulations indicate that the initial condition of the underlying system is of major importance in determining the performance of a management strategy. It is clear that strategy evaluation can only be done on a fishery specific basis. The control laws incorporating uncertainty and utilizing a minimum biomass level in general perform better than the constant F strategies for the examples examined in these papers. However, because of the difficulty of estimating the minimum biomass level relative to the underlying system, the resource may not rebuild to near the level that would yield MSY if it was overexploited in the first place. To accomplish rebuilding, a cautious F strategy even at biomass levels above the perceived minimum would be required.

These Working Documents along with the published work of Powers and Restrepo (1993) and Restrepo *et al.* (1992) illustrate the use of stochastic simulations incorporating measurement errors, estimation errors and process noise for the evaluation of management strategies. This method can be applied to a wide variety of fisheries to produce scientific advice incorporating uncertainty.

2.3.6 North Sea cod-like example

The simulation framework of WD 18 and WD 20 was used for an example loosely based on North Sea cod. Results from the 1993 assessment (Anon., 1993c) were used to set up the basic underlying system as follows: A Beverton-Holt stock recruitment relationship was fitted assuming lognormally distributed recruitment. The mean squared error from this fit was used to parameterize the process noise in the underlying population. Natural mortality was set equal to 0.2 per year for all ages (a difference from that assumed in the assessment) and the selectivity pattern, weights at age and maturity ogive were assumed to be time-invariant and equal to those estimated for 1993 in the assessment.

Two management strategies were examined: constant F_{med}, and an F_{med} strategy modified by a probability/linear control as described in WD 18 and Section 2.3.5 (in this control, F_{med} is multiplied by the perceived probability that the stock is above an MBAL, in this case estimated from a stock-recruitment fit to the assessment results). The management strategies did not enter into effect until the 21st simulation year. For the initial 20-year simulation of the underlying system, the estimated F-trajectory in the assessment was assumed and recruitment was allowed to vary stochastically according to the estimated relationship. The simulations were made for 100 populations such that 100 plausible initial fishery trajectories were obtained with process noise. From then on, the underlying system was sampled for catch and relative abundance data assuming 20% CVs and the assessments were made using a single-species VPA (ADAPT). The assessment procedure resulted in estimates of estimation error in SSB. For each population, each year, a TAC was set in accordance with the estimated stock size and the management strategy being examined. These TACs were taken from the underlying population without implementation error, unless the underlying stock size was too small to support such TACs; in such cases, a maximum constraint of $F=10.0$ was set. This measurement-assessment-projection-implementation sequence was repeated for 16 simulation years.

Figures 2.3.6.1a and 2.3.6.1b show the median trajectories in yield and 90% confidence bands for the two management strategies. Note the high variability in years 1 to 20, which is due to process noise. After year 20, the variability increases as the F trajectory for each population is not the same. Figure 2.3.6.1 c illustrates how the probability/linear control law strategy performed relative to the constant F_{med} strategy. The random number sequences used to generate process noise over time in each simulated population is kept unchanged across experiments. Thus, the underlying recruitment time series in population 13 for the F_{med} case draws from the same sequence of random deviates as the 13th population with the control law. The relative yield in Figure 2.3.6.1c was obtained by dividing the yield obtained with the control law strategy for a given simulated population by that obtained for the corresponding population with the F_{med} strategy. In this case it is apparent that the control law could substantially increase yield after a drastic reduction in the first year of implementation.

Figures 2.3.6.2 (a to c) show similar performance statistics in SSB. By the end of the 16-year projection time period (year 36 in the figure), SSB resulting from the control law could be 1 to 14 times greater than that obtained with the constant F_{med} strategy. Figure 2.3.6.3b is a probability profile of relative SSB in year 35, illustrating the skewness of this performance statistic.

Figure 2.3.6.3a illustrates how the perceived assessment error may be affected by the management strategy: In this case, the precision in estimated SSB is greater for the control law than it is for the F_{med} strategy.

2.3.7 Evaluation of a North Sea cod-like stock using the risk spreadsheet

Stochastic projections for management strategy evaluation can be performed in a spreadsheet format using a software package called @Risk as an add on to Lotus 123 or Microsoft Excel. This software has the advantage of simplicity and ease of use, though estimation errors can not be as fully explored as with the more complicated simulations described in Section 2.3.6 and in WD 18 and WD 20. Essentially, the @Risk package provides spreadsheet functions for generating random numbers from a wide range of distributions in any spreadsheet cell formula, and the macros for performing, storing and summarizing a set of iterations of the spreadsheet calculations. The summarization of performance statistics can be done easily.

An example was run by the Working Group to illustrate the method for possible application by the assessment working groups. The underlying system was a fully age structured population with Beverton-Holt stock and recruitment dynamics with lognormal process noise. The Beverton-Holt function, with parameters estimated from the most recent assessment on North Sea cod, was used to give the mean recruitment over a range of stock sizes. A constant coefficient of variation of recruitment of 65% estimated from the fitted stock recruitment relationship gave the variance at any given stock size. Other biological parameters and starting stock abundance at age was taken from the North Sea cod assessment (Anon., 1993c). Estimation error was introduced into the model in two ways, through lognormal variation on the exploitation pattern at age vector, and in variability around the target fishing mortality rate specified as a triangular distribution with a range of 0.2. Projections were made for 15 years into the future and 100 iterations were performed. Note that while the simulations were based on North Sea cod, the model and parameters would need to be reviewed in detail before these results could be applied in the context of advice on this stock. <u>This example was performed for illustration only</u>.

Three management strategies were evaluated and three performance indices examined. The strategies were F at the *status quo* level taken to be 0.86, F reduced in the first projection year to 0.5 and a hybrid strategy proposed by Shepherd (WD 22) which set F at the average of the *status quo* level, the target level of 0.5 and the average of the most recent 3 years. The latter strategy was intended to improve the stability of the landings whilst moving toward the management target (note: Shepherd proposed using the average of the recent catches which would require iteratively calculating F, but this was too difficult to be implemented during the meeting so average of recent Fs was used. These will not in general be the same). The performance indices were the yield, spawning biomass and the coefficient of variation in yield (Figures 2.3.7.1 - 2.3.7.3).

The results indicate the effect of reducing F on rebuilding of this stock. The immediate reduction to F = 0.5 reduces the landings in the first few years but more rapid rebuilding soon more than compensates. Note the uncertainty means that the range of results for the 100 simulations increases through time as expected.

2.4 Management Based on MBAL

The Working Group on Methods of Fish Stock Assessment described procedures for choosing minimum biologically acceptable biomass levels (MBAL) to be used as biological reference points in the development of scientific advice by ACFM (Anon., 1993b). This reference point is a stock biomass level below which ACFM would recommend a strong conservation strategy be adopted such as major reductions in the rate of fishing mortality. As discussed by the Methods Working Group, the choice of MBAL is related to stock productivity because it is estimated from stock and recruitment data as a spawning biomass below which recruitment is more likely to be poor.

When a stock is above MBAL the policy objectives are likely to focus more on yield and economic considerations than conservation *per se*. Above MBAL, other management strategies are appropriate, for example, to obtain a high but stable yield. In the extreme case, the management strategy could be to maintain the stock at the MBAL. This constant biomass strategy was explored using a deterministic model in WD 23 for the Northeast Arctic, Icelandic and North Sea cod stocks using the observed patterns of recruitment without relating this recruitment to spawning biomass. The results indicate that a large variation in catches can be expected if management aims at a fixed SSB level. This variability is a direct result of the variability in recruitment.

Stability in the fisheries is frequently expressed by fishermen and the fishing industry as being highly desirable. The simulations of the three cod stocks show that a fixed SSB strategy will tend to create very unstable fisheries for these stocks and with respect to stability a fixed F strategy performs clearly better.

The approach of specifying a control law using MBAL as a precautionary level with a constant F strategy when the stock is above that level was analysed in WD 18. For a northwest Atlantic cod-like stock the use of an MBAL in combination with a constant F strategy performed better than a strategy without MBAL. However, even better performance statistics were obtained when the MBAL plus F control law explicitly incorporated uncertainty in current stock status. For currently depleted stocks short-term yield will be reduced but long-term yield will recover short-term losses.

As noted in previous sections, the evaluation of a management strategy needs to be done on a stock by stock basis. A full evaluation of the efficacy of a strategy including an MBAL as part of the control law needs to include the several sources of uncertainty described. Because of the importance of the stock and recruitment relationship to the application of a strategy including MBAL, sensitivity analysis to model error in the underlying system will be essential in the strategy evaluation. In addition, it is clear that the estimate of MBAL and its subsequent performance will depend on the range of historical data available. The Working Group **recommends** that a full strategy evaluation be done for one or more example stocks where MBAL is likely to be important. This should give ACFM a better picture of the relevance of MBAL concept for developing management advice.

2.5 Communication

The Working Group recognizes that communication of probability profiles to fisheries managers, and the interpretation of that information by the managers in making their decisions, is a difficult process. Therefore, it was felt that the experiences in other management institutions could provide useful insight. Two such experiences are briefly reviewed below from the southeastern United States and from the International Waling Commission. The implications of these experiences to ICES are discussed.

2.5.1 Southeastern United States

Fisheries in the southeastern United States are characterized by time series data that are of relatively short duration, fisheries for which the recreational component composes a large proportion (and in many cases the majority) of the catch, biological and logistic difficulties in traditional data collection. To address these difficulties, a high priority has been placed on the determination and communication of the risks and uncertainties in stock assessments for stocks such as Gulf of Mexico king Mackerel (see Section 2.3.1). Initially (in the early 1980s), uncertainties in the assessment were addressed through sensitivity analyses which resulted in a range of yield values within which TAC was selected. At first the managers interpreted the range of allowable catch within which they could pick TAC as a uniformly distributed range, i.e., that each yield level within the range was equally likely to reach the target F. Quite naturally their tendencies under these interpretations were to pick TAC above the upper end of the range. Subsequently, legal rulings limited the choices to those less than or equal to the upper end of the range. After that ruling the initial decision of the managers was to choose the upper end of the range.

At that point the assessment research was developed to try to characterize the probability profile of allowable catch. This was done with discrete decision tree approaches and then Monte Carlo and bootstrap methods (See Section 2.3.1). For these stocks, the selection of TAC by the managers was then limited to be within a probability range from the probability profile. The probability range was specified by the scientists to be within the 17th and 83th percentiles approximately corresponding to plus or minus one standard error.

Over the following few years the managers responded by recognizing that the probability profile represented risk to the resource and to the resource users. Selecting a low TAC will protect the stock with a short term cost to the fishers; conversely, selecting a TAC high on the probability profile will increase risk to the resource but with short-term benefits to the fishery. The managers tended to select TACs which were within the range (often slightly above the median). They also had a tendency to "keep last year's TAC", i.e., a stability objective.

Now, probabilistic multiple year strategies are being examined by managers to achieve stock recoveries within a specified time horizon. In these instances, the managers are being presented with and are reacting to allowable catch information in the form of probability density and cumulative distribution functions. This experience has shown that the managers can and do interpret the probability profiles as a mechanism to balance trade offs. The education process has been lengthy, but results are promising.

2.5.2 International Whaling Commission

Anon. (1993a, Section 2.2.3) described the development of a management procedure for the International Whaling Commission (IWC). The Scientific Committee (SC) of the IWC asked the Commission for objectives to aid in this development but eventually received these only after making its own suggestions. As stated, the agreed objectives were not very precise and contained terms that could not be operationally defined. The SC therefore had to interpret for itself, what performance measures might be appropriate in developing a management procedure. The SC used the framework to evaluate management strategies outlined in this report (Sections 1.6.1 and 2.1.1). The SC itself considered hugely detailed performance measures and related statistics including probability profiles and individual trajectories. The measures of performance presented to the full Commission, however, were a considerably reduced set, directly related to the agreed objectives and necessary for the Commission to reach a decision and adopt a procedure. In reaching that decision, the Commission had to consider not just the underlying science but also the multinational political objectives which had to be traded-off or neglected dependent on negotiation and/or voting strength.

2.5.3 Implications

Experience within the IWC and the southeastern US demonstrates the need only to present a set of performance statistics directly related to the stated or perceived objectives, to help managers reach a decision. Even so, the scientists often had to communicate directly and intensively with small groups of managers in order to explain the development process and the implications results. The performance statistics will vary according to the need of the managers and the particular structure of the management system in place. Clearly, for example, a management body that incorporates economic considerations into its decision making will require quite different measures to a body neglecting such matters.

It is not easy, therefore, to advise on how to incorporate results from risk analyses into the advice of ACFM. It is important in the development of such advice for a close dialogue between ACFM and this Working Group in order to clarify how ACFM would seek to use the results and how the ACFM "customers" might react to certain approaches. As an initial effort this Working Group **recommends** that ACFM select a "pilot" stock for which the management advice is expanded to include risk analysis results. It is suggested that the stock be one with single-species management concerns and one for which strategy options can be elucidated.

3 MANAGEMENT TACTICS AND FISH MOVEMENT, FLEET MOVEMENTS, AND DISCARDING

3.1 Introduction

One of the terms of reference of the meeting called for the development of methods for including spatial effects in multispecies/multifleet assessment models taking into account migration and dispersal rates, effort reallocation and discarding data. Several working papers were presented on these topics and a summary of discussions follows. It is difficult to evaluate methods for determining and describing these in the absence of specific management strategies and/or tactics to evaluate. In order to facilitate future work and reduce the possibility of duplication of effort, it may be more appropriate to forward certain questions on estimation to the Working Group on Methods of Fish Stock Assessment. For example, the development of methods for estimating the rate of discarding or migrations and incorporating these into stock assessments may best be addressed by the Methods Working Group. The evaluation of management tactics possibly to control the rate of discarding or incorporating migration rates into an evaluation of box closures may be reviewed by this Working Group.

The Group focused its discussion on how consideration of fish movement, effort reallocation, fleet definition, and discarding may be incorporated into the evaluation of management measures. It has been generally agreed that this should be carried out within a system-specific framework which address individual situations.

3.2 Movement

Assessment of box models or management of trans-boundary stocks requires knowledge of the movement of fish between sub-areas or mixing between stocks. Conceptually, it seems that fish movement rates can be estimated from observed changes in distribution of the fish or from mark-recapture data. Methods for such movement estimation face several important obstacles and are still in relatively early development. Two major obstacles were discussed by the Group: the problem of model specification and the problem of dimensionality. Model specification refers to the assumptions that are made regarding the dynamics of the population and observation processes. The problem of dimensionality relates to the ability to resolve the parameters of the model from the data. Obviously the dimensions of the problem depend upon the assumptions that are made.

The dimensionality problem was discussed by Webb (WD 9). The inverse method was applied to estimate the movement parameters for a box model solely from information on the relative density in each of the boxes. Webb's model assumes that mortality and movement take place instantaneously at the end of each time step in proportion to the population density at that time. He considered simple box models where movement from one area (box) to another is proportional to population densities. In one such model, he postulated a closed system in which fish can move freely among N boxes. If the movement rates are different each year (or other time period), the number of movement parameters to be estimated is $N(N-1)$ per time period, but there are only N population equations per time period; thus the movement parameters can never be estimated. The problem can be simplified by dividing each time period into s seasons and assuming that the movement rate varies between seasons but not between time periods. (Note that s could be 1.) Then the number of movement parameters to be estimated becomes $sN(N-1)$, and there are sN population equations per time period. In this seasonal framework, estimation is possible with at least N-1 time periods' worth of data on area-specific densities. However, to estimate standard errors along with the parameters, a longer data series is required. The dimension of the problem can be reduced further by adopting additional assumptions, but it remains of the order of N^2 unless many movement parameters are assumed zero. It might, for example, be reasonable to set movement between non-adjacent boxes to zero, given an appropriate time scale. There is also the possibility that movements may be cyclical, such as seasonal spawning migrations. It then becomes necessary to resolve the parameters over much shorter time scales. However, as the time scale decreases, the indices of density can become less precise; in some cases, indices of density may not be available except on an annual basis or a few times each year.

Two general approaches to estimating movement parameters can be taken: they can be estimated simultaneously with traditional parameters of stock status (e.g., fishing mortality) in an integrated assessment model or they can be estimated independently of the other parameters using auxiliary data. An example of an integrated movement and assessment model was given by Prager (WD 26, see below).

The estimation methods examined by the Group can be conveniently divided according to the types of data they employ. The Group considered three general categories: methods based on indices of density, methods based on mark-recapture information, and methods that incorporate indirect measures of density inferred from a more detailed understanding of the biology of the stock.

3.2.1 Fish movement and migration: estimation from abundance indices

The Group examined several methods for estimating movement parameters from area-specific indices of abundance (density). At least in principle the area-specific densities can be indexed by research surveys, fishery CPUE, or even indirect measures such as area-specific data on stomach contents.

Prager (WD 26) described the implementation of a production model (due to Fox, 1975) of N stocks characterized by independent population parameters and also by movement parameters. The estimated movement from any stock to any other is determined by the corresponding movement parameter and the size of the stock of origin relative to its maximum size (carrying capacity). This model is characterized by N(N-1) movement parameters that are to be estimated, along with 4N population parameters, from catch and CPUE data. The implementation, for two stocks, was tested on simulated data following the underlying model with added noise. It was found that, even with a very small amount of noise, it was impossible to estimate the movement parameters. A tentative conclusion is that catch and CPUE data are insufficient to estimate one transfer coefficient per stock. It is conjectured that restructuring the population model to estimate only net movement (one coefficient per *pair* of stocks) might allow the parameters to be estimated.

An application to Georges Bank (Van Eeckhaute *et al.*, WD 5) demonstrates the use of additional assumptions and data to arrive at estimates of movement. In this paper, movement of cod across the US-Canada line was the topic of study. Based on prior biological observation, such movement was considered to occur towards the US from October through April, and towards Canada from May through September; thus, two movement parameters could describe the dynamics. A sequential population analysis on the combined US and Canadian catch data (at six-month intervals) was used to estimate total stock size by age on April 1 and October 1 of each year. Survey data, available around these same dates each year, provided estimates of the proportion of fish (by age) on each side of the line on the same dates. Combining these data provided area-specific population estimates by age. Estimates of movement were then made by a simple bookkeeping technique. For example, the net number of fish moving to the US side was obtained by subtracting the number of fish dying from fishing and natural mortality on the Canadian side from the difference in population abundances on that side in the beginning of subsequent six-month periods. In a second paper, (Gavarisl *et al.*, WD 6), the movement estimates were used to analyze the effects of possible Canadian management measures in the presence of a US fishery at different levels of intensity. To do this, a deterministic simulation using constant recruitment was used to conduct yield per recruit type evaluation of fishing the strategy. It is suggested that the framework described in Section 2.1.2 be applied to this problem.

3.2.2 Fish movement and migration: estimation from tagging data

Fish movements should be estimable from mark-recapture data provided the marked fish are representative of the unmarked population and there are enough observations to describe movement from one area to another with time intervals sufficiently small to preclude more than one movement between areas. Several studies have attempted to do just that, many of which are reviewed in the paper by Hilborn (1990).

Hilborn (1990) developed a method for estimating movement proportions from tagging data. The population model used differs from Webb's box model (WD 9) only in that natural mortality and movement are included in the same term - Webb's model includes a separate parameter for natural mortality. The Hilborn model, however, adds a tag-return component in which tag returns are considered Poisson events. The solution is found by nonlinear minimization based on simulation of fish movement. The set of parameters that provides the simulation most closely matching the observed tag returns is the set of estimates. Webb notes that Hilborn's method can easily be incorporated into his framework, but does not give specific details on how this could be accomplished.

Butterworth and Punt proposed an estimation procedure for two boxes that combines tagging data with VPAs at the 1993 meeting of ICCAT's SCRS (Standing Committee on Research and Statistics). Mortality is assumed to occur continuously whilst migration is assumed to occur at the end of each time period. The procedure involves running the VPA with fixed values for the movement proportions and selecting the values which most nearly reproduce the observed ratios of tag recoveries between areas. The Group considered that a useful modification might be to automate the procedure by explicitly including movement parameters in the objective function of the VPA. There was some concern, however, regarding the proper way to do this.

Porch (WD 37) suggested the possibility of developing an alternative to the 'box' approach that would include spatial dimensions explicitly and model the movement of animals more realistically. Porch developed a method for estimating the velocity and diffusion of tagged fish in anticipation of such a model.

3.2.3 Alternative estimation approaches

An area-based multispecies simulation model (MULTSPEC) has been developed in Norway (Bogstad *et al.*, 1992) and a similar model (BORMICON) is under development in Iceland. These models combine all available information (Stock estimates from surveys and VPA, catch data, stomach content data, stomach evacuation rate models etc.) in a single framework. This has already proven to be very useful in revealing biases and inconsistencies in the data.

These models can be used for estimating migration and other parameters in several ways, depending on the data available. So far, however, only Bogstad and Tjelmeland (1992) have estimated migration rates, using the MULTSPEC model. In that work, measures of density and suitability of prey in each area are used to calculate consumption. Predation and migration parameters are then estimated by comparing this level of consumption with the level of consumption calculated directly from stomach content data using a stomach evacuation rate model. Other data, such as survey indices and catch data by area can be used as an aid in the estimation. It was found that a yearly migration pattern had to be estimated in order to fit the model to the data.

3.2.4 Conclusions

Based on the papers presented at the Working Group meeting and the remarks of the participants, a few general remarks are possible, even at this relatively early stage of work:

1. Movement and migration are common and often poorly described properties of fish stocks, and they are important to assessing stock status. The movement models required vary considerably with the resources involved and the types of questions being asked. The importance of understanding fish movement is accentuated by the common heavy exploitation or overexploitation of stocks that cross jurisdictional boundaries. Further research in this area is to be encouraged.

2. The simultaneous estimation of movement and stock status parameters would facilitate computation of precision measures of movement estimates, as well as sensitivity analyses of assessment results with respect to input information. Furthermore, movement and mortality are basic forces that often affect the dynamics of a population simultaneously, and thus can be naturally combined in a population-dynamics model. However, certain types of data on fish stocks (e.g., catch-effort data) may not contain enough information to allow simultaneous estimation. The question arises as to whether a general statement can be made about the relative utility of combining tagging data with catch-effort data in new models compared to using separately the existing and well-known models for analysis of each data type. It appears that separate modelling is probably the most productive first step and that combined modelling should be attempted once the problem is sufficiently determined.

3. Reduction in dimensionality is usually best achieved by adopting assumptions specific to the stock(s) being considered. Biological knowledge will generally form the basis for assumptions that can lead to improved estimability and precision. As stated in Webb (WD 9) and exemplified by Van Eeckhaute *et al.* (WD 5), a model that follows specific cohorts can facilitate the estimation of migration rates.

4. The problem of dimensionality is markedly reduced, and computations consequently become easier, when the number of boxes is reduced to two. The increased number of parameters required for models using more than two boxes can present major problems of estimation. As the two-box scenario probably accommodates many management issues it is worthy of continued study.

5. Estimates of movement rates should be accompanied by estimates of precision. Because the estimates of precision usually do not encompass all forms of error (e.g., model specification error), the assumptions underlying the estimates and the precision estimates should be clearly stated when estimates are provided. However, the task of distinguishing the estimation error from process noise will be very difficult when there is considerable variation in the movement patterns from year to year.

6. Even incremental progress in the study of fish movement can be of practical use. For example, the production model with movement, even though it cannot (at least in the form given) estimate movement rates, could be used with hypothesized rates for testing robustness of assessments that assume no movement. Similarly, simulation models that portray fish movements more realistically might be used to test the ability of the simpler box models to capture the essential dynamics of a moving population. Movement models can also be used in management strategy evaluation sensitivity analyses of model error to various movement rates.

3.3 Fleet Definition and Effort Reallocation

Fleet definition is an aggregation process to reduce model dimensions and resolution from a vessel-by-vessel basis to a more analytically tractable one, with minimal loss of realism.

Appropriate levels of aggregation and realism will vary with management tactics and questions of local interest. When regional managers must evaluate alternative tactics in terms of local winners and losers, fleet definition that allows evaluation of port-specific impacts will be of interest. When local management tactics include individual transferable quotas, responses may be highly variable from vessel to vessel depending on vessel strategies; under those circumstances, important information is conveyed by the degree of inter-vessel variability rather than a statistic of central tendency. When fleet definitions are made for purposes of allocation, definitions tend to become more and more fine-scale as the allocation process evolves.

3.3.1 Application of multivariate techniques

A paper was presented that showed how it was possible to investigate the variation in species catchability (at age) and effort allocation by fishing trips by multivariate methods using as an example the English North Sea demersal fleet (Kell, WD 13). Techniques such as principal component and factor analysis are able to summarize the variation within the data and provide a reduced number of variables to model both exploitation pattern and effort distribution. Species mixes were identified using catchability and then related to the activity of fishing boats and the distribution of their trips. This is a flexible approach as the data can be summarized according to the main patterns in the data rather than to *a priori* classification.

Once the main patterns in exploitation and effort have been identified it will be possible to investigate the effect of management on these using historical data and also hopefully to model the effects of management.

A second example of fleet definition in the context of evaluation of management tactics was based on Northwest Atlantic Mid-Atlantic Bight groundfish fisheries (Gabriel, 1993 MS). The relationship between target species initially stated by vessel skipper and heterogeneity of species composition of resulting catches was investigated. The results were designed eventually to be used in the evaluation of the impact of single-species management tactics on co-occurring species in a specified subregion. The results indicated that for some target species, resulting catch composition was relatively fixed and well-characterized. In other cases, catch composition was more highly variable. This indicated that for this particular system, fleet definition (and resulting dynamic models) should reflect variability in catch composition; and the initial definition of fleets based on target species could now be simplified, because variability in species catch composition within some fleets was larger than between fleets. Other potential model mechanisms such as individual species migration patterns would not be required, as seasonal and interannual variability in species composition based on empirical data would be adequate to meet the emerging model's objectives.

For determination of variability or heterogeneity in fishery operations, initial analyses should be based on the most highly disaggregated data available, ideally vessel-by-vessel and tow-by-tow (or other appropriate unit).

An analysis of the seasonal variation in technical interactions in Gulf of St. Lawrence groundfish fisheries was presented (Sinclair, WD 1). The analysis was performed to investigate the importance of annual migrations on the species composition of catches and the associated by-catch implications. Cod fisheries in this area have recently been closed and managers are interested in how the by-catch of cod may be limited during fisheries for other species such as redfish, American plaice, witch flounder and white hake.

Fisheries were defined using cluster analysis of monthly catch compositions in rectangles of 10' latitude and longitude. The spatial and seasonal distribution of the clusters was examined by colour-coding the rectangles, and assembling monthly maps into an animation movie.

This allowed visualization of the movements of the fisheries and comparison with published information on stock distributions.

A specific area of considerable seasonal variation in catch composition was identified and monthly catch rates of the species of interest were calculated. A linear programming approach was used to examine how fishing effort might be allocated on a monthly basis to attain target catches of cod and the other species. Such an approach may be useful in identifying potential closed areas and seasons when the objective is to limit catches of a particular species.

3.3.2 Factors influencing catchability

When modelling the interactions between fishers and fish resources, consideration must be given to variations in catchability due to changes in fish stock distribution and vessel fishing power. The former, defined as the fishing mortality per unit of standard effort, is a characteristic of the fish stock. Seasonal migrations may affect catchability with fish being more spatially concentrated during migrations and spawning and less aggregated during feeding periods. Fishing power is related to the physical characteristics of the vessels such as horsepower, overall length, and gross tonnage. It is often difficult to discern between fishing power and differences in species distribution but this will be important when modelling changes in the exploitation of a stock in response to area or seasonal closures or change in fishing effort by fleets.

A multiplicative framework was used to estimate variations in commercial catch rate in relation to area, season, and vessel characteristics (WD 33). Data for a cod stock in the gulf of St. Lawrence were presented. This stock undertakes substantial seasonal migrations, exiting the Gulf to the east with the onset of winter and re-entering when the ice leaves in the spring. Three main gear types are used in the fishery, side otter trawls, stern otter trawls, and seines. The multiplicative model used was:

$$\ln C/E = Y + M + A + M{*}A + G + S + G{*}S + e$$

where
- C = catch
- E = effort
- Y = year
- M = month
- A = area
- G = gear
- S = vessel size class

Observations were grouped by vessel, year, month, and area. Least square mean estimates of CPUE by area and month, and gear and vessel size class were compared as indicators of relative differences in catchability and fishing power.

The parameter estimates indicated that catch rates were highest in the eastern portion of the area in the spring and fall during the migration period. The lowest catch rates were in the summer period following spawning. There was a significant interaction between month and area. Catch rates were higher in larger vessels for each gear type. The increase in catch rate was more pronounced for trawlers than seiners.

It was noted that the annual trend in catch rates declined over the period of the study. At the same time, nominal fishing effort increased during the spring and fall in the eastern area where catch rates were the highest. The net result was a greater increase in standardized effort than nominal effort and a potentially greater increase in fishing mortality than if effort increased proportionally.

A potential drawback for this approach is that the data were taken from existing logbooks and the experimental design is highly unbalanced. Even though a general linear model was used to estimate least square means, some of the parameter estimates may be confounded. This may be overcome if the data are further aggregated or by specific experiments.

Generalized additive models (GAMs) (e.g., Chambers and Hastie [ed.], 1992) should be investigated to analyze the types of spatial effects described above. Traditional approaches employing linear models often require area effects to be modelled as discrete variable. GAMs model area effects as continuous non-linear functions.

3.3.3 Behaviour

Behaviour of fleets (e.g., effort reallocation) may be motivated by management tactics: species quotas associated with individual vessels will define vessel behaviour. In other cases, fleets may be managed by weekly quotas, and rotate through several directed fisheries seasonally. There will be differential effects of economic and social factors on behaviour among and within fleets.

In the case of both fleet definition and effort reallocation, appropriate levels of scale and resolution are dependent on model objectives and institutional perspectives. For example, meaningful definitions of fishery areas in the Northwest Atlantic differed significantly between fishery managers, fishery biologists, and fishermen (Clay, 1993 MS).

3.3.4 Evaluating management tactics: a closed area example

Approaches to evaluating tactics are less developed than those for evaluating strategies. Evaluation of tactics need not model an underlying system if a strategy is robust to the types of models being examined and if the perceived performance statistics adequately approximate the realized performance statistics. In the following section an outline of a protocol is presented for evaluating closed areas as management tactics. In this case it was considered important to include model error regarding fish movements and effort allocation as well as initial population state uncertainty in the evaluation framework.

Closed areas may be used as tactics to: a) modify exploitation patterns on a stock; b) reduce overall fishing mortality ; and/or c) change the distribution of fishing mortality on a mixture of species.

Summarization of the characteristics of vessels or fleets historically involved in the affected fishery is straightforward. Evaluation of the impact of a closed area on fishing mortality rate may only be qualitative or comparative with respect to achieving targets.

An initial approach to evaluating the effects of a proposed closed area could consist of:

1. System identification

- Identification of fleets based on: a) exploitation pattern; b) fishing power; and c) species composition of catch (as related to tactics listed above).

- Estimate of patterns of migration of species and patterns of mobility of effort (e.g., vessel range, fisheries with habitual components, differential mobility between large and small vessels) and the associated variability.

- Initial abundance of affected fish populations including variance

2. Construct a simulation model reflecting the underlying system components relative to the closed and surrounding areas. This may be used to generate "True" fish distribution patterns, fleet partial fishing mortalities, and population histories. Process noise in the underlying population (e.g., interannual variability in fish distribution) and fleet dynamics would be included.

3. Simulate "Observed" data including estimation error (e.g., estimation of fleet partial fishing mortality), compliance (e.g., ability to exclude fishing from closed area), and model error (e.g., effort allocation follows different rule than "true").

4. Calculate and compare "True" and "Observed" performance statistics which may be population exploitation patterns and fishing mortality rates, catches by fleet, and other quantities of interest to managers.

Models which compared performance of management strategies evaluated by the Group assume perfect implementation of fishing mortality controls (no implementation deviance) (see Section 2.3.5). Uncertainty in the effectiveness of those controls may eventually be described from the results of tactical models where the source and degree of implementation deviance may be identified. It is very important to include stochastic components reflecting uncertainty in key elements of tactical evaluation, e.g., uncertainty in exploitation pattern, effort reallocation/reduction, estimation of population size, fishing power.

One of the model components is effort reallocation. It may be possible to simulate effort reallocation by a form of bootstrap analysis. Catch or a reparameterized form of it (e.g., CPUE, partial F or catchability) may be related to the abundance and distribution of the stocks in the fishery as well as to various measures of effort and fishing activity by the use of linear or general additive models. The distribution of the errors following the fitting of the model can then be used in simulation along with estimates of variability for the independent variables, obtainable from trip data. Alternatively, within-area effort could be redistributed stochastically, based on historical distribution of effort over regions outside the area by vessels with similar fishing characteristics e.g. vessel size, distance from home port,.

3.3.5 Additional approaches to effort reallocation

Characteristic historical patterns of variability in fleet behaviour may provide some indication of potential range of future responses. Those patterns could be identified by inspecting time series of e.g., monthly or areal catch per unit effort or effort for correlations of patterns from year to year. This would indicate if historical patterns were repeatable from year to year, and would indicate which components in the patterns were most variable.

Such an analysis was presented for cod in the Gulf of St. Lawrence in WD 34. The spatial distributions of commercial CPUE, fishing effort, and research survey catches were compared on a 10' grid of latitude and longitude. There was little correlation between commercial CPUE and research vessel catches on the 10' grid. This may be due to an inappropriate spatial or temporal scale of measure. Interannual correlations of effort by grid were the highest, followed by the correlations of research survey catches, followed by the correlations of commercial CPUE. The distribution of fishing effort may be more predictable than the distribution of the fish. Further investigation on a vessel by vessel basis may indicate differences in behaviour among fishers who search for concentrations as opposed to those with a more traditional fishing pattern.

Effort reallocation models in addition to the probabilistic simulation approach described above may apply by analogy and by specific model objectives. From a biological perspective, models of migration, where fishermen were modelled as migrators, may be considered. Models from optimal foraging theory, where fishermen were modelled as predators, could also be considered. For example, switching between potential prey (target species or species groups) could be modelled as a function of the relative availability of those alternative prey (with associated implications for system stability); and the appearance of "habitual" components of effort allocation may reflect "bet-hedging" (Murawski, 1993 MS). Models from economic theory, where fishermen were modelled as part of a rational economic system, could also be evaluated. From a social anthropological perspective, models of human behaviour apply. Behavioral reactions to changes in management measures may be inferred by analogy to reactions of fishery systems in other regions (e.g., from works referenced in Clay, WD 36 given in Appendix 1).

Although potential alternative model structures based on economic and social science can be identified, further specification and development of those approaches will require participation by individuals familiar with these economic or behaviorally-based models. The expertise is significantly different from that required for stock assessment and multispecies modelling to date.

Expansion into the areas of economic and social science likewise requires alternative data (e.g. cost data, and changes therein as changes in regulations occur); and data collection systems for economic and social assessments are not well-developed relative to those for stock assessment. Retrospective evaluation of the impacts of regulations on economic and social behaviour will be difficult: Specific effects of individual regulations on behaviour cannot be easily decomposed given complex regulatory histories.

3.3.6 Conclusions

1. Fleet definition and reallocation models should be developed from data at the lowest possible level of aggregation to represent adequately the operational levels of the fishery in question. If area closures are to be considered then fine scale spatial resolution will be required. If variability in species composition and catchability are important, then trip-by-trip data may be required.

2. Fleet definitions should reflect both the mean and distributional properties of the variables.

3. If management tactics are oriented toward age specific effects then fleet definition should include consideration of catchability at age. This may reduce the number of observations available to define fleets to those trips that were sampled directly for age or length composition. If management tactics are oriented toward changes in exploitation of different species then catch composition or CPUE data may be used.

4. Defining fishing fleets and effort allocation models for the evaluation of management tactics is developmental at present. It would be prudent to focus future studies on relatively simple fisheries (few species) with rich data sets (commercial and research) and where specific management strategies are clearly defined.

3.4 Discard Inference

Accounting for the discards is a necessary part of the management measures evaluation process as well as the stock assessment. This becomes more important when management tactics change the number, size or species composition of the fish discarded. Methods for estimating discard rates include using data from direct observation by at sea observers or developing models based on variables such as population parameters and gear selectivity. Two papers were presented which explored these approaches.

(1) Data collected by observers on commercial vessels were analyzed using general linear models. The effects of spatial, temporal, and operational variables on the magnitude and composition of discarding were analyzed. (Murawski, WD 16).

(2) A model was developed to estimate catch at age using length at age distributions, gear species specific selection factors, and fisheries discarding practices. Discards at age were then estimated by subtracting the landings at age from the catch at age (Casey, WD 17).

It was noted that estimated selectivity ogives may have high variances since relatively slight variations in gear or operation of gear may have significant effects on performance. When inferring discards from selectivity ogives this estimation error should be included. Care should be taken to obtain up to date gear selectivity estimates for the appropriate fleets. Video camera and image analysis of discarding was suggested as another means of direct observation (Strachan, 1993). Another suggestion was to require that all catch be landed.

The Group suggested that comparison of parameters estimated by population models (such as Casey's) with direct observation would be useful for calibration purposes.

3.5 Examples

3.5.1 The 4M software package including Multi-species, Multi-area and Multi-fleet Models

3.5.1.1 General description

A software package was presented, which includes effects of migration and effort reallocation in case of box closures (WD 1 in last year's Working Group report and Vinther *et al.*, 1994).

The aim of the new assessment package was to combine elements of the ICES multispecies VPA (MSVPA), the multispecies forecast program (MSFOR), the STCF prediction program (ABC) and data for these models into one integrated modular user-friendly software package.

The 4M package has included data for the North Sea. It is planned to transfer data for the Baltic Sea to the 4M package such that it may be the main tool for the Working Group on Multispecies Assessment of Baltic Fish. In principle, the package may be used for other areas. The data management benefits of 4M increase with the complexity of available data and the planned use of the built in features.

The system consists of three basic parts:

- **Databases**, i.e., data organized in groups for processing.
- **Operations** on these data.
- **Options** for these operation.

The database system includes features for storage and flexible extraction of data used in both single and multispecies assessment. The system gives possibilities to handle spatial catch and effort information by fleet, survey data and stomach content data.

The operations and the corresponding options implemented are:

VPA:

The VPA can operate in single or multispecies modes. The package does not yet include tuning of VPA. Given terminal F's and stomach content data the VPA calculates food suitabilities in the same way as the ICES MSVPA program does.

It is possible to perform the VPA by separate sub-areas including migration. Migration coefficients are assumed to be known. Local Fs, suitability and stock numbers may be estimated for each sub-area. To do this requires spatial and temporal disaggregated catch, stock distribution and stomach content data for a range of years. However, for the North Sea such catch data only exist for 1989 and 1991 (STCF data).

As spatial data on stomach content and stock distribution (from IBTS surveys) are available for 1991 the model include the possibility to estimate local Fs, suitabilities and stock size for this year. This may be used as input for area based predictions from that point.

STATUS QUO PREDICTIONS:

Input data for the predictions can be extracted from historic data (VPA). Partial Fs by fleet, management box and sub-area can be calculated using the STCF and survey data. The sub-areas and boxes to be closed can be defined by the user. Alternatively, predictions may be made for the total area only.

Single species as well as multispecies approaches may be selected for predictions. Suitabilities estimated in the VPA is assumed to be constant and is used to calculate future predation mortality. In case of several sub-areas migration between sub-areas may be included. Migration coefficients are assumed to be known.

PRICE CHANGES:

The price by fleet, quarter, species and age is available in the STCF database. The package contains a model, which estimates future prices using elasticity parameters by country also available in the STCF database.

TACTICS:

The following management tactics may be evaluated in the predictions:

- Box-closures by fleet and quarter. The following option for reallocation of effort is included:

  The fraction of effort within a box reallocated outside the box could be selected by the user. The spatial distribution of effort reallocated is assumed to correspond with the historic effort distribution outside the box. This model is not based on any kind of analyses, but should only be considered as a preliminary alternative to doing nothing.

- Mesh size changes by fleet and box given the selection parameters and gear specification.

- Effort by fleet can be changed by the user.

- Overall change of Fs by quarter.

STATUS:

The 4M package has been tested and compared with the ICES MSVPA, MSFOR and ABC programs. The 4M package can reproduce the results of the latter programs using North Sea multispecies data for 1974-1992 and the STCF database for 1991.

Complete sets of stomach content data are available for 1981 and 1991. In the intermediate period limited data are sampled for some years.

Quarterly survey data for 1991 are kept in ICES and will be transferred to the database.

The STCF data for 1989 have been checked by STCF Working Groups in 1991-92. The Working Groups concluded that aggregated catch data for the species cod, haddock, whiting, saithe, plaice and sole were in agreement with corresponding data from relevant ICES Working Groups.

The data set for 1991 has been checked by DIFMAR and aggregated data were found to be in agreement with catch data from ICES Working Groups for the species cod, haddock, whiting, saithe, plaice, sole, mackerel, sandeel, norway pout and sprat. Regarding herring the spring spawners from Division IIIa have been included in the database in order to correspond with catch data from the Herring Assessment Working Group for the Area South of 62°N.

3.5.1.2 Use of 4M in the Working Group on Long-Term Management Measures

The 4M system was designed to combine the existing MSVPA, MSFOR, and ABC models with information on spatial and temporal variation in prey suitability and fishing effort into an integrated deterministic system. The system provides considerable flexibility for calculating, storing and retrieving assessment, STCF, and research survey data. Population abundance is obtained either from existing single species or multispecies assessments; in either case there is currently no capability to use information on parameter uncertainty. Fish migration rates are input and effort reallocation processes are calculated deterministically from historical data.

The 4M system was not designed to evaluate management tactics within a stochastic framework. This requires that the prediction model accounts for estimation error of the system state (see Section 1.6.2) and to introduce process noise for the system dynamics (possibilities for stochastic recruitment already are implemented). It should be noted that estimation error of system state parameters needed for the temporal/spatial resolution of the model are often not available due to a lack of suitable information.

While techniques are being developed to incorporate measurement, process, model, and estimation errors into single species management procedures (see Sections 2.3.6 - 2.3.7), to extend this to include multispecies effects in MSVPA would require extensive additional modelling and data collection. Existing ICES assessment working groups may need to incorporate these techniques, when developed, into the regular assessment process. The addition of spatial effects which require statistical estimation of migration rates is also challenging (see Section 3.2). The study of factors influencing fishing effort distribution is currently developmental.

Users may use the 4M system to simulate possible management scenarios by altering selectivity and effort distribution parameters. The sensitivity of the results to variations in inputs such as migration and predation rates may also be investigated. Evaluation of tactics including error simulation of all parameters would probably not be possible even on very fast computers. Therefore, it will be necessary to identify the most important parameters and reduce the number of simulations to make the evaluations feasible. Results from ICES Multispecies Working Group and risk assessments could be used for this. Furthermore sensitivity analyses of factors in the 4M prediction program could be carried out using factorial design of simulations. Further work on problems of reduced spatial and temporal complexity may also contribute further insight. The Group suggests that a factorial sensitivity experiment be conducted for a more aggregated version of the North Sea model. More consideration should be given to the statistical properties of the parameters being used in these predictions and caution used in interpreting the results.

4 THE TRANSFER OF THE STCF DATABASE TO ICES

4.1 Introduction

According to a general agreement between the EU (formerly called the EC) and ICES (see ICES, Doc. C.M.1991/Del:13*), ICES will take over the responsibility for handling the STCF data base (Report on Administration for the Year 1 November 1991 to 31 October 1992, ICES Annual Report, January 1993).

The new program package (4M) made by DIFMAR is a modular assessment and projection package including the STCF database. The package combines the latest versions of the ICES multispecies VPA and forecast (formerly called MSVPA/MSFOR) programs, the STCF prediction program (ABC), and data for the programs into one integrated, modular, user-friendly package, which is called 4M. A common menu-oriented SAS program is the users interface to the database and programs in the DIFMAR package, which facilitates use of the STCF database in the assessment and projection programs.

Strictly speaking, only the STCF database part of the DIFMAR package is dealt with in the agreement between EU and ICES. However, it might be sensible to transfer the whole package from DIFMAR to ICES for practicality reasons.

4.2 Hardware and Software

The hardware available at ICES, i.e., a network of HP work stations running under UNIX and PCs running under DOS and Windows is sufficient. The disk capacity needed would be about 100 MB for keeping the data and for running the programs. One year's data are about 15 MB. It might be necessary for ICES to increase the storage capacity on their computers.

The DIFMAR package can easily be transferred to ICES. The software used is developed in SAS Windows version 6.08 and this should be directly applicable to UNIX SAS version 6.09. Several SAS modules are used: SAS AF, SAS Graphic and FSP, which all are available at the ICES Secretariat. The new multi-species, multi-fleet VPA and forecasts programs are written in ANSI C.

The STCF database and assessment programs could be transferred to the ICES Secretariat immediately following agreement with the EU.

4.3 Maintenance Requirements, Checking Procedures, Errors Corrections

All known errors in the DIFMAR package have been corrected. It is, however, almost certain that errors will be discovered in the future as the package starts to be used. It will demand a significant amount of manpower at the ICES Secretariat to learn the programs in order to be able to correct discovered errors and to maintain it. Likewise, data inconsistencies and general improvements of the programs are another field of work where manpower will be needed by the Secretariat. It is not possible accurately to predict the manpower requirements associated with the database but a rough estimate is about 3 months per year in years when data are supplied.

4.4 Updating

It has not yet been decided how often the database should be updated. The frequency of updating, however, has implications for ICES manpower commitments and for the use to which the database might be put. It is stated in section 1.6.2 of this report that management tactic evaluation requires projection from the current system state taking account of estimation errors and process noise. If the STCF database is to be used for evaluating tactics, it is therefore necessary to have current data with associated errors. Thus far, data supplied for the database has been about two years "late". Also, it is apparent already that there are substantial differences between the 1989 and 1991 datasets.

4.5 Confidentiality Protocol and Access Rights

The STCF database contains very detailed information about national fleets fishing in the North Sea. These data are confidential and usually only highly aggregated parts are made available for public use as ICES papers and reports. More detailed data may have commercial value or be politically sensitive. Therefore, the STCF Working Group made very strict rules for the access right and use of the data (see Appendix 2). Only Working Group members were allowed access to the data and only under certain circumstances. As these data are now to be transferred to ICES and as the STCF Working Group is dissolved new rules have to be implemented.

The Working Group would like to make the following points regarding the rules on access rights and confidentiality protocol:

a) The full, disaggregated database should only be used by relevant ICES Working Groups, Study Groups, Workshops etc. A difficulty arises in the need to prepare for such groups and in completing relevant work intersessionally. It is desirable to permit such work. Strict guidelines on the distribution and use of the database need to be established as a matter of urgency. The Working Group suggests that in the ICES context, a useful procedure might be that the ICES General Secretary or Fishery Secretary and the Chairman of the present Working Group, would have to approve access to the database on a given request from a member of a Working Group, Study Group etc. If that member wants to publish her/his work the General Secretary/Fishery Secretary and the Chairman would have to approve.

b) National institutes providing data to the database should have access to data restricted to a level of aggregation where national data cannot be traced, e.g. total international landing-at-age by rectangle but **not** by fleet. Such data might be useful in relation to estimating migration of fish or in relation to ecosystem effects of fisheries.

c) National institutes not providing data to the database, other organizations, commercial enterprises, NGOs, individuals, etc. should only have access to highly aggregated data published in ICES papers and reports.

d) It should be made clear to scientists gaining access to the detailed database that data should not be made available to others. It may be necessary to establish a formal procedure where receivers of data agree to conditions relating to use, publication and distribution of data.

e) Data from the database should in principle be free of charge. The ICES Secretariat will, however, incur expenses in terms of manpower, computer costs, postage costs and overheads due to a given request. These costs may have to be covered by the recipient.

The present Working Group recognises that the questions about confidentiality protocols and access rights probably have to be considered and agreed upon at the national institute/delegate level. The Working Group would like this to happen as soon as possible.

5 CONCLUSIONS AND RECOMMENDATIONS

The Working Group deliberations regarding definitions of a framework for the evaluation of management measures (both strategies and tactics) entailed the development and agreement of a suitable terminology. Much of the model development needed will be case specific with inputs drawn from other Working Groups. It is clear that considerable work still needs to be done before ICES can be confident in the tools at its disposal.

The Working Group considered descriptions of fish movement, fleet definition and effort reallocation. It is clear that the high dimensionality of some fisheries systems is a problem. As far as possible, answers to questions concerning those systems should be addressed with relatively simple models incorporating stochastic elements and with suitable sensitivity analyses performed.

Evaluating tactics requires a recent, preferably current, estimate of the system state. The timeliness of data supply and assessment outputs for use in tactic evaluation models is therefore important. Also, it is noted that the evaluation of management tactics must involve stochastic projections including estimation errors of the current system state. Data or estimates supplied for use in such models must therefore include error estimates of the various elements.

5.1 General Recommendations

1. The Working Group agreed that work on the evaluation of management strategies and management tactics was inextricably interlinked and **recommends** that this Group should be the focus for such work within ICES.

2. The Working Group **recommends** that its name be changed to the Management Measures Evaluation Working Group.

3. The Working Group **recommends** that, to the extent possible, issues on parameter estimation techniques should be referred to the Methods Working Group.

4. The Working Group **recommends** the adoption of a standard terminology within ICES as specified in Section 1.5 of this report.

5. The Working Group **recommends** that ICES work towards adopting management strategy evaluation, as described in this report, as a component of its advice on fisheries.

6. To the extent possible, the Working Group **recommends** that detailed tactics should be left out of the models used to evaluate strategies. This simplifies the task of evaluating management strategies and makes interpretation easier.

7. The Working Group **recommends** that prediction models used to evaluate tactics be constructed so as to take into account the estimation error of the system state.

8. The Working Group **recommends** that estimates of the estimation error in assessments be included as a routine part of those assessments in the future.

9. The Working Group **recommends** that assessment Working Groups prepare stochastic rather than deterministic projections, including both estimation error and process noise.

5.2 Recommendations for the Next Meeting

Regarding its own future, the Working Group **recommends** that the next meeting should primarily focus on further development of a framework for evaluating tactics and suggests that 3 or 4 case studies be identified for analysis. The strategies for the systems to be studied should be identified and a suite of possible tactics to be considered should be described. The Working Group also **recommends** that, at its next meeting, it consider a particular stock (possibilities might be North Sea plaice or herring) to demonstrate the framework for evaluating management strategies (including the use of MBAL) and to suggest specific ways that the results might be incorporated into the advice given by ACFM. This would entail a dialogue between ACFM and the Working Group in the development of suitable terms of reference.

Suggestions for tactic evaluation case histories that might be considered included The Georges Bank Transboundary stocks of cod and haddock, The Gulf of St. Lawrence cod subject to differential fishing effort reduction, the Scotian Shelf haddock, North Sea cod and the problem of differential effort reduction in the mixed fisheries, one Boreal multispecies system and Barents Sea cod.

6 REFERENCES AND WORKING DOCUMENTS

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6.2 Working Documents

The list of working documents available at the meeting is given below. Some are also included in the Reference list under their authorship. WD 36 is given as Appendix 1.

WD 1 Sinclair, A. 1993. Seasonal Components in Technological Interactions in Gulf of St. Lawrence Shrimp and Groundfish Fisheries.

WD 2 Sinclair, A. 1993. Estimating Fleet Specific F Given Catch Quotas.

WD 3 Sinclair, A. 1994. DRAFT. Gulf Sustainable Fishery Project: a multi-disciplinary experiment. A proposal, January 13, 1994.

WD 4 Horwood, J. 1994. Application of a (very) simple model to evaluate the quantitative effects of closed areas when the age composition of the catch in the box is unknown.

WD 5 Van Eeckhaute, L., E.A. Trippel, and S. Gavaris. 1994. Distribution and Migration of Haddock Across the Canada/USA Boundary on Eastern Georges Bank.

WD 6 Gavaris, S., L. Van Eeckhaute, M.I. Buzeta, and J. Hunt. 1994. Yield Projections for the Transboundary Cod and Haddock Resources on Eastern Georges Bank.

WD 7 Draft Report of the Multispecies Assessment Working Group. ICES, Doc. C.M.1994/Assess:9.

WD 8 Report of the Working Group on Multispecies Assessment of Baltic Fish. ICES, Doc. C.M.1994/Assess:1.

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WD 12 Hassager, T. Kjær and H. Lassen. Why Skippers Skip Grounds: A probabilistic decision model for whether a skipper continues fishing on the same or change to some other ground, based on data from the West Greenland Shrimp fishery.

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WD 17 Casey, J. 1993. Estimating Discards Using Selectivity Data: the Effects of Mesh Size Changes in the Mixed Demersal Fisheries in the Irish Sea.

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WD 21 Hagen, G., E. Hatlebakk, T. Schweder, and B. Bogstad. 1994. Scenario Barents Sea: A tool for evaluating fisheries management regimes.

WD 22 Shepherd, J.G. 1994. A Possibly Not Completely Stupid Procedure for Setting TACs.

WD 23 Jakobsen, T. 1994. Some Aspects of Management Based on MBAL.

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WD 26 Prager, M.H. 1994. An Implementation of Fox's Production Model With Mixing: Initial Results.

WD 27 Powers, J.E. and V.R. Restrepo. 1993. Evaluation of Stock Assessment Research for Gulf of Mexico King Mackerel: Benefits and Costs to Management.

WD 28 Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, Resource Exploitation, and Conservation: Lessons From History.

WD 29 Rosenberg, S.A., M.J. Fogarty, M.P. Sissenwine, J.R. Beddington, and J.G. Shepherd. 1993. Achieving Sustainable Use of Renewable Resources.

WD 30 Clay, P.M. 1993. Management Regions, Statistical Areas and Fishing Grounds: Criteria for Dividing up the Sea.

WD 31 Report of the Working Group on Long-Term Management Measures. ICES, Doc. C.M.1993/Assess:7.

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WD 36 Clay, P. 1994. Selected Bibliography on Social Science & Fleet Definition/Dynamics.

WD 37 Porch, C.E. 1994. A New Approach to Estimating Dispersion Parameters From Mark-Recapture Data.

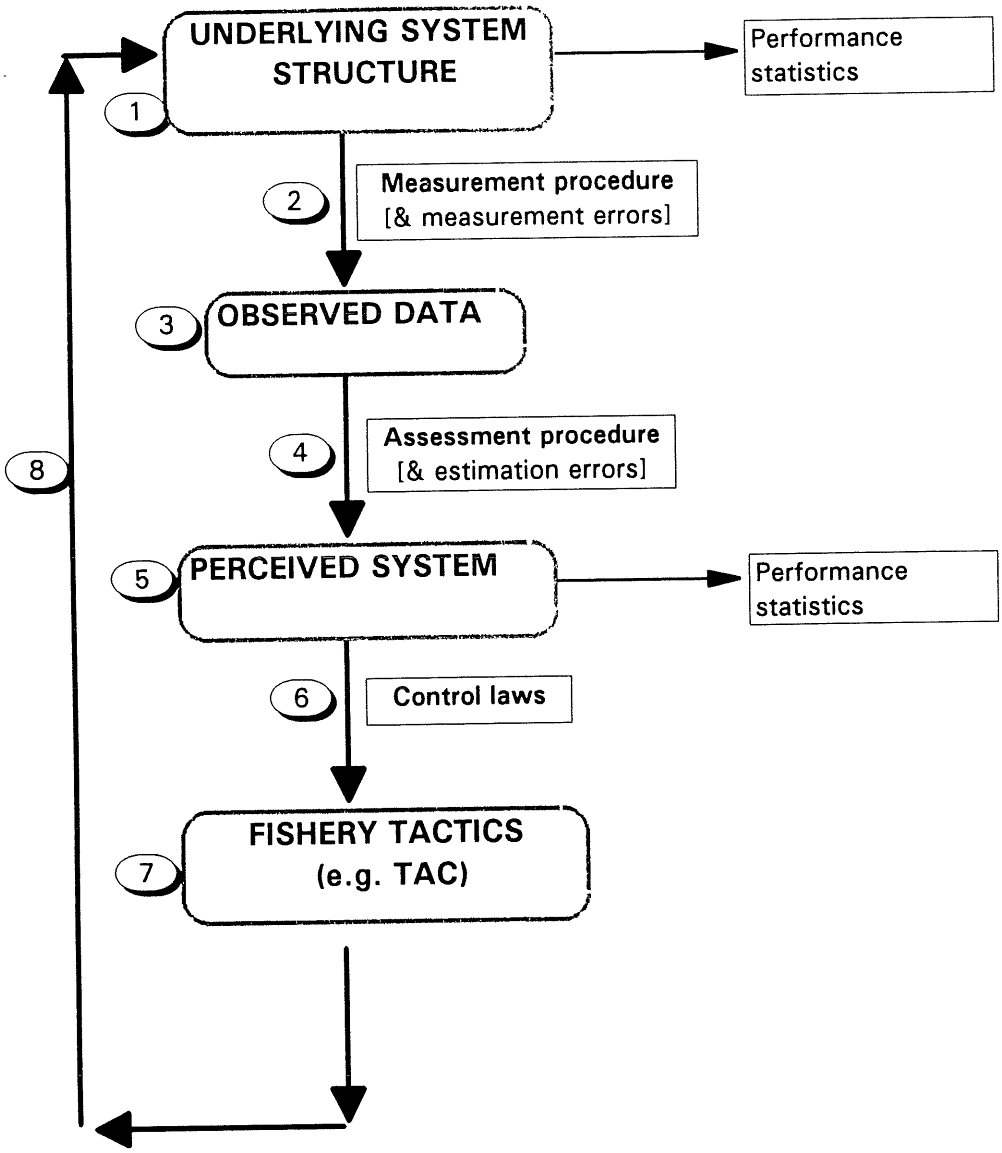
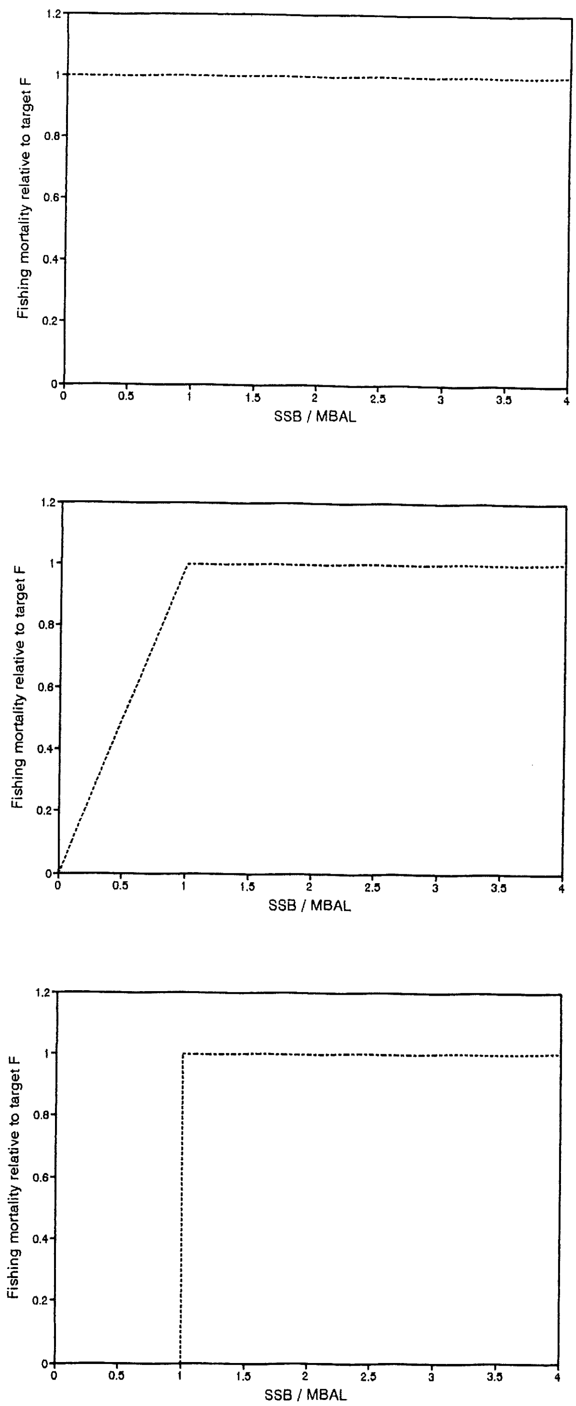


Figure 2.1.1 Flow chart for simulations used in evaluation framework. (The numbers refer to Section 2.1.2).



a)

b)

c)

Figure 2.1.2 Example control laws. Top: F is set to a constant target, regardless of the estimate of spawning stock biomass. Middle: Below a threshold (MBAL), F is reduced in proportion to the estimate SSB/MBAL. Bottom: F is reduced to 0 when SSB falls below the threshold.

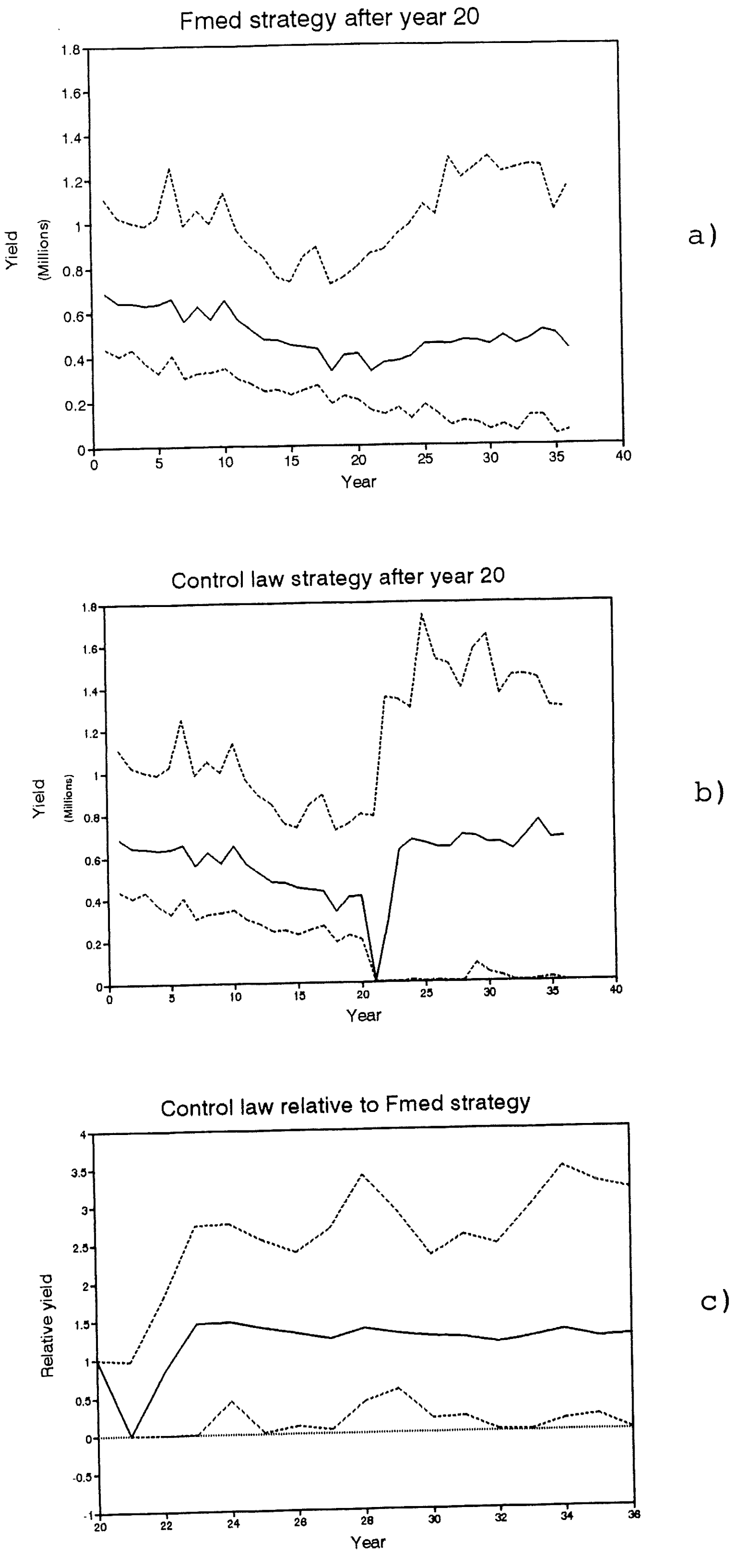


Figure 2.3.6.1 North Sea cod-like example. The median trajectories in yield and 90% confidence bands for the two management strategies (a) and b)); c) is the yield for the control law strategy relative to the F_{med} strategy.

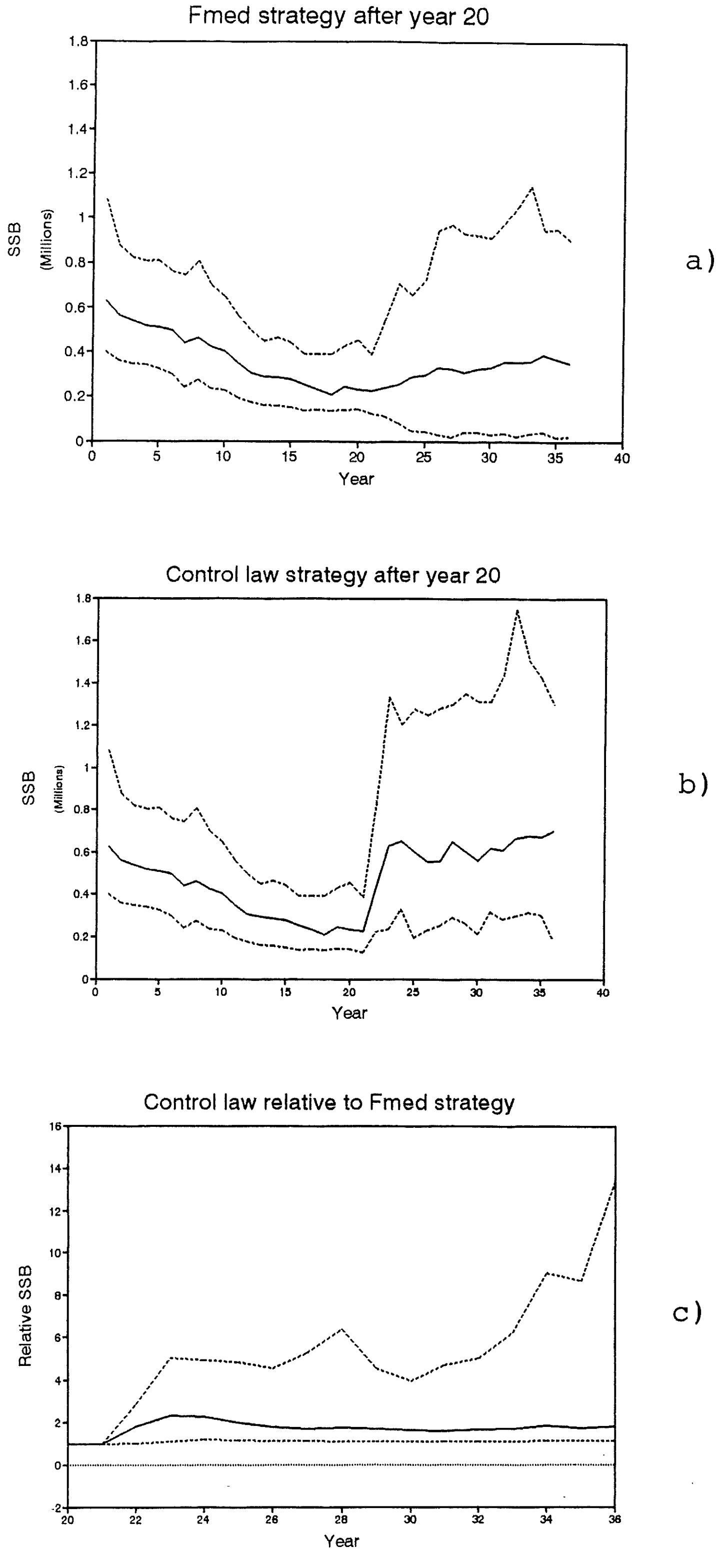
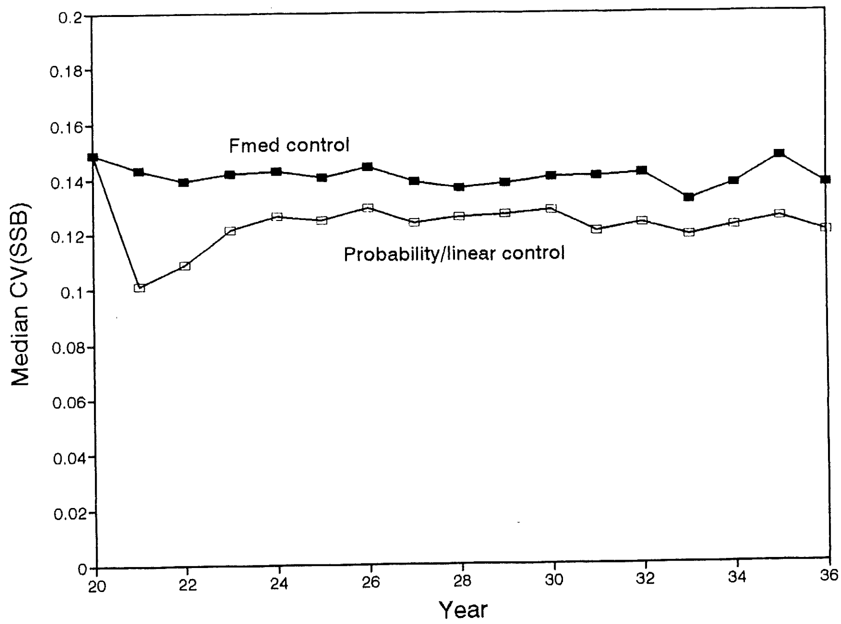
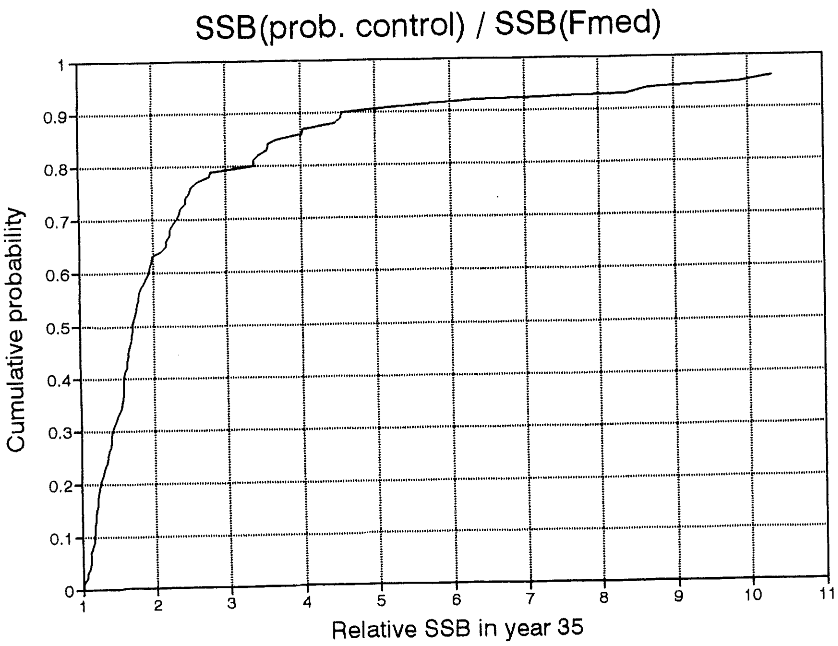


Figure 2.3.6.2 North Sea cod-like example. The median trajectories in SSB and 90% confidence bands for the two management strategies (a) and b)); c) is the SSB for the control law strategy relative to the F_{med} strategy.



a)



b)

Figure 2.3.6.3 North Sea cod-like example. a) shows the median CV of SSB for the two management strategies; b) is the probability profile of relative SSB in year 35.

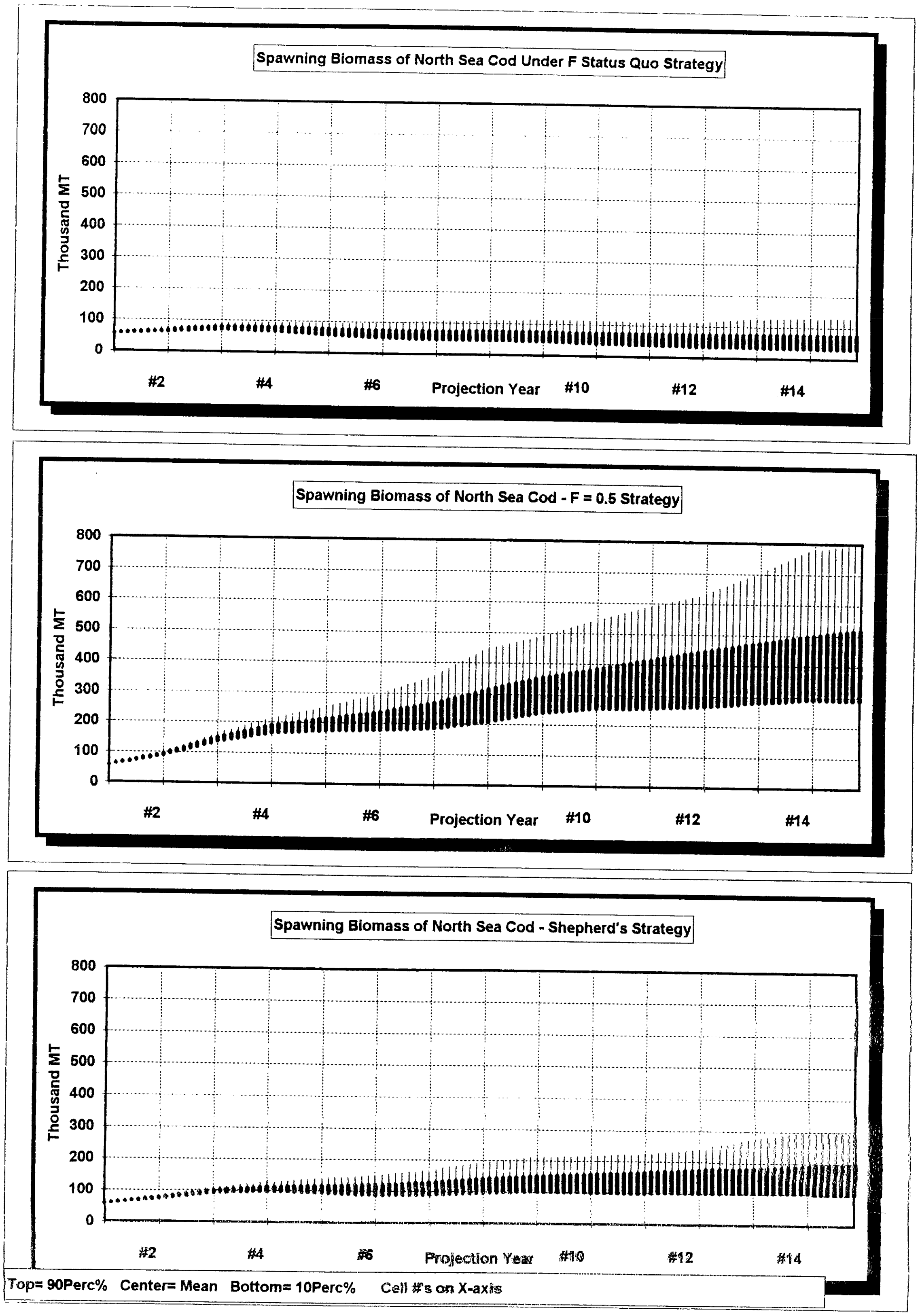


Figure 2.3.7.1. Spawning Biomass at different management strategies.

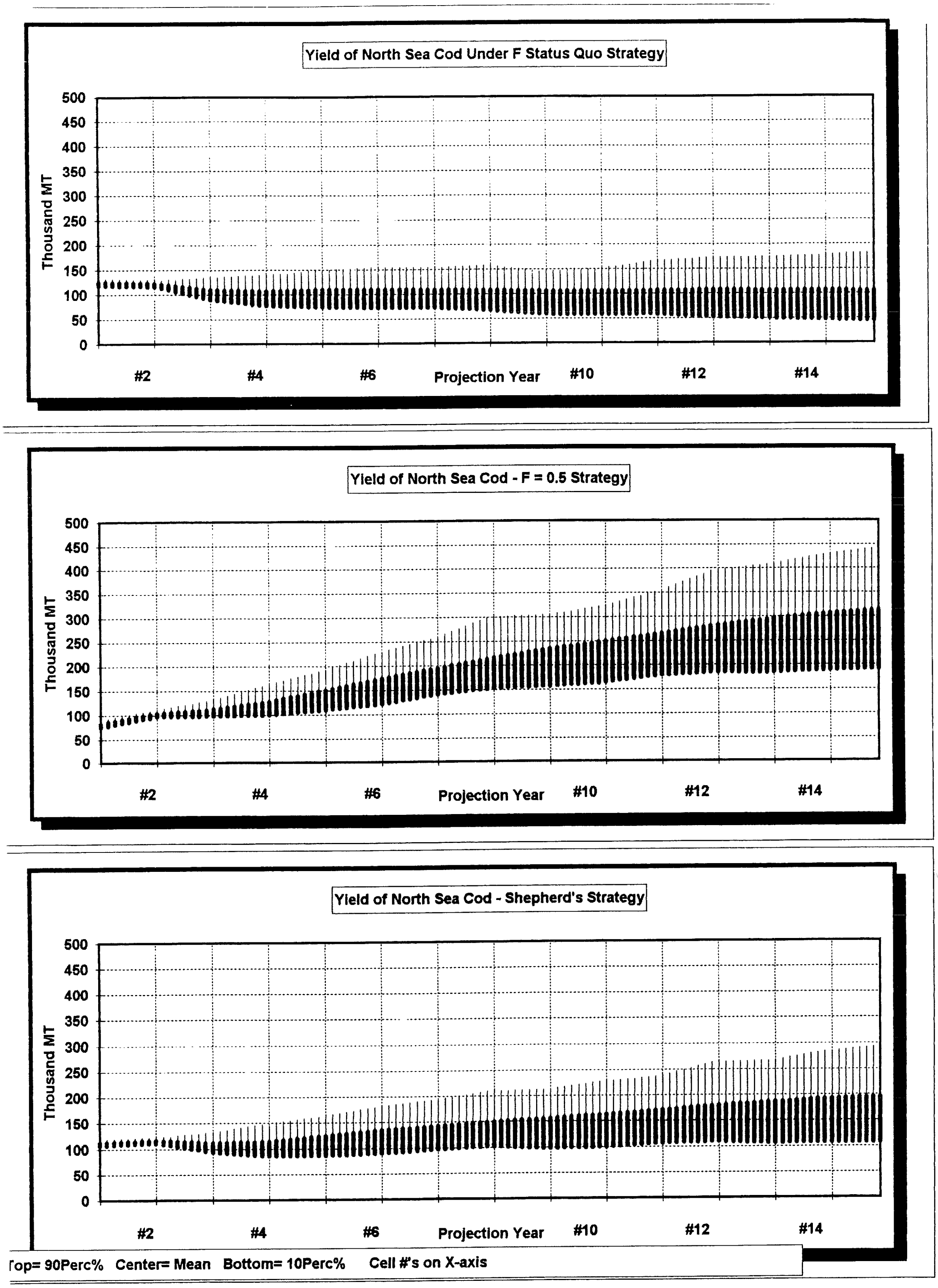


Figure 2.3.7.2 Yield at different management strategies.

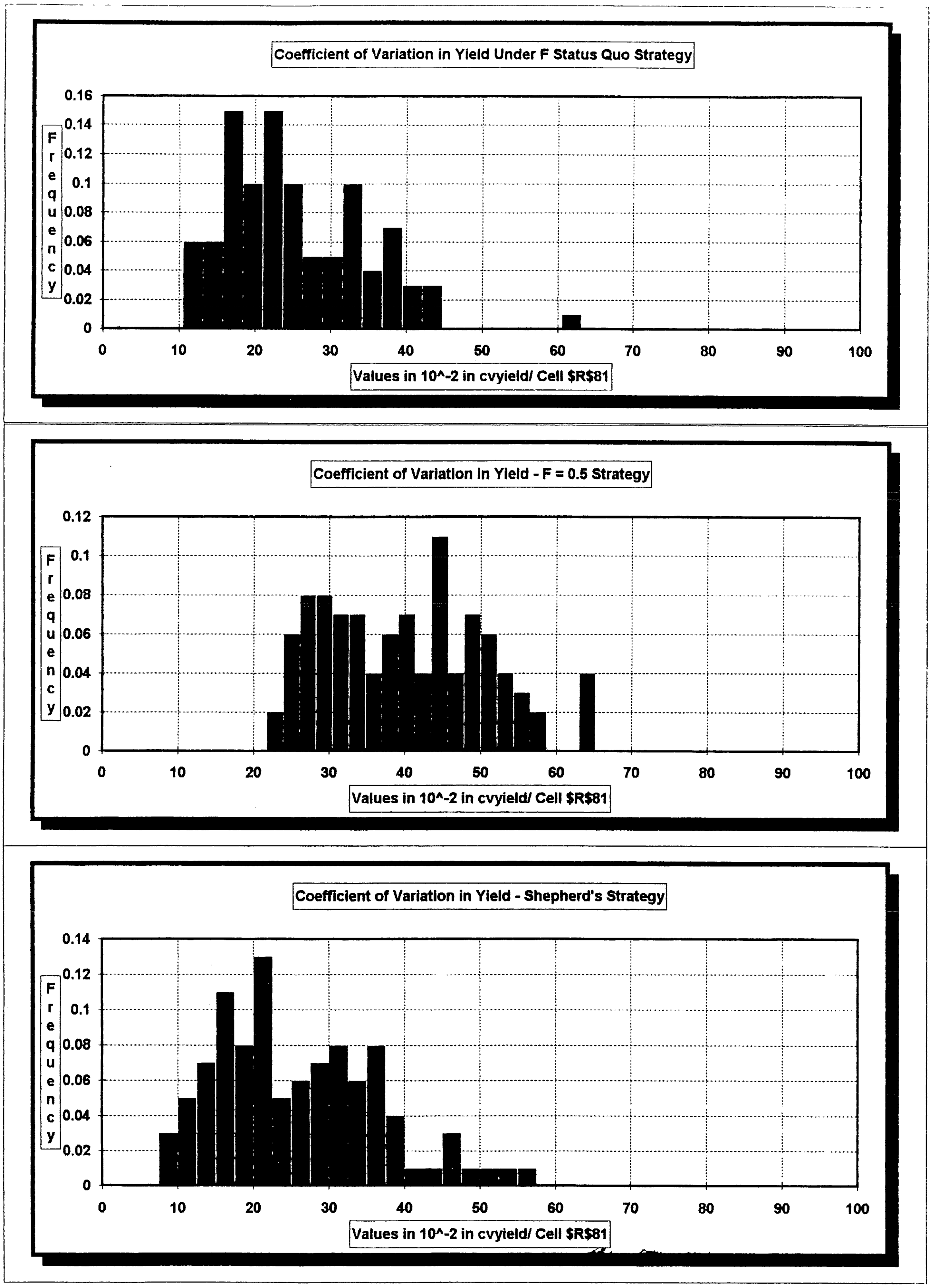


Figure2.3.7.3. C.V. of Yield at different management strategies.

APPENDIX 1

SELECTED BIBLIOGRAPHY ON SOCIAL SCIENCE & FLEET DEFINITION/DYNAMICS

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- Human Ecology
- Human Organization
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- Journal of the Fisheries Research Board of Canada
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- North American Journal of Fisheries Management
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- Policy Studies Review
- Practicing Anthropology
- Society and Natural Resources
- Sociology and Social Research

APPENDIX 2

SECTION 2.5 FROM THE "REPORT OF THE MEETING OF THE STCF WORKING GROUP ON IMPROVEMENTS OF THE EXPLOITATION PATTERN OF THE NORTH SEA FISH STOCKS"

Lowestoft, 28 March - 6 April 1990

Confidentiality

The national laboratories providing the data have through their annual sampling programmes spent substantial funds to collect the data. The data are collected for scientific purposes and are usually made available to ICES assessment working group in a more aggregated form.

Because of a recent tendency of the national laboratories to undertake study contracts the data are of commercial value and should, therefore, be protected. The data base also enables detailed analyses of the economic importance of various sectors of national fleets and it is expected that national governments will reserve their rights to approve such analysis.

The terms of reference of the Working Group include bioeconomic modelling of the fishery in the North Sea and this objective cannot be met unless disaggregated biological and ecological data are available to the Working Group. The evaluation of technical measures for certain areas (box closures and derogations) cannot be dealt with unless data are available on a disaggregated area basis. Similarly, the consequences of any management measure on each fleet cannot be calculated unless data are available for each fleet component.

Data of the specified disaggregated form must, therefore, be available to the Working Group during its meeting. It is envisaged that substantial amounts of preparation in terms of development of programmes and models must take place outside the Working Group meetings. For this reason, it is preferable that all Working Group members have access to a realistic data set.

To accommodate the requirement for confidentiality of the data and to allow checking of data and development of the model outside formal Working Group meetings, the Working Group agreed the following:

i) Data supplied by each national are the sole property of that nation. Dissemination of any nation's data to any part other than this Working Group will be carried out only by the national authority supplying the data. Members of this Working Group are not at liberty to provide data, other than that which they have personally supplied, to any other party.

ii) The definitive data base will be held in the Danish Institute of Fisheries and Marine Research (DIFMAR) on behalf of DGXIV. A copy of this data base can be sought, by Working Group members only, by submitting written application to the Working Group Chairman stating the purpose for which the data are required. The Chairman, after consultation with other Working Group members, will be responsible for granting or denying access to the data.

iii) Any Working Group member in possession of a copy of the data base is responsible for its security and confidentiality.

iv) Results of any analysis of the data supplied by other countries and conclusions drawn from these results may only be published in reports of this Working Group.