Advisory Committee on Fishery Management

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REPORT OF THE
COMPREHENSIVE FISHERY EVALUATION WORKING GROUP

ICES Headquarters, Copenhagen

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International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 INTRODUCTION

1.1 Participants

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1.2 Terms of Reference

It was decided at the 83rd Annual Science Conference in 1995 (C.Res.1995/2:13:14) that;

A Comprehensive Fishery Evaluation Working Group will be established under the chairmanship of Dr. G. Stefánsson (Iceland), and will meet at ICES Headquarters from 17-26 June 1996 to:

a) taking into account the future activities of Scientific Committees, define in detail the components required for comprehensive and interdisciplinary evaluations of multispecies and multifleet fisheries in all parts of the ICES area. Such evaluations should *inter alia* include:

i) providing a complete description of available information relevant to the population dynamics of the stock(s),

ii) providing a complete description of the fisheries and fleets currently and historically operating on the stock(s)

iii) suggested improvements for the present assessments and predictions,

iv) describing fully the components required for modelling of the stock(s) including sensitivity analyses, targets and thresholds, as relevant,

v) describing any potential stock-identification problems and associated simulation trials,

vi) consideration of all sources of uncertainty,

vii) the composition of a comprehensive report on the population biology of the stock(s), fisheries, assessment methodology and medium-term projections, with the aim of publication;

b) continue the comprehensive evaluation of North Sea flatfish fisheries with the aim of preparing a final report by 1997;

c) develop an appropriate programme of other case studies reflecting the interests of the whole ICES Area.

1.3 Structure of the Report

This report of the first meeting of the Comprehensive Fishery Evaluation Working Group (COMFIE) sets the stage for comprehensive fishery evaluation by defining some of the most important terms involved, identifying possible international limitations on fishing activities in relation to the biology of fish stocks and initiating case studies to be continued in the future.

Section 2 of the report lists some of the most common biological reference points used in fishery science and relates those to various criteria concerning the sustained utilization of fish stocks. Section 3 of the report describes the process of comprehensive fishery evaluation and lists some international agreements which have been widely endorsed. These agreements imply certain limitations on fishing activities. These limitations are further explored in Section 4, where it is seen that the international agreements imply that certain biological reference points attain high significance and can be used as threshold values both with regard to fishery evaluation and in giving short-term fisheries advice.

Section 5 describes some general considerations concerning medium-term projections whereas Section 6 describes a case study on North Sea plaice and Section 7 describes the current state of affairs concerning other case studies. The future of the working group, including case studies, is discussed in Sections 8 and 9.

2 BIOLOGICAL REFERENCE POINTS

2.1 Background

Biological reference points have been discussed in several reports of the "Methods Working Group" (Anon 1983, 1984, 1993). Caddy and Mahon (1995) review the literature on reference points and provide commentary on various problems related to their implementation. Reference points are most commonly stated in terms of fishing mortality rates or biomass and they may be defined as targets or limits (thresholds). Target reference points represent a desired level of fishing mortality or biomass, while limit reference points represent either an upper bound to the fishing mortality or a lower bound to the biomass.

2.2 Common Reference Points

In this section, we provide a brief overview of the biological reference points which are discussed in later sections of this report. These reference points are commonly derived from analyses of yield per recruit (Y/R) and spawning stock biomass per recruit (SSB/R), and from age-structured production models.

Yield per recruit considers only growth and mortality of a cohort. Input data are weight, natural mortality and exploitation pattern at age. Outputs are reference fishing mortalities which may be used for setting TACs, estimated yield (weight) per unit recruitment (Y/R), and age composition and spawning biomass per unit recruitment (SSB/R) of the cohort throughout its life (Thompson and Bell 1934) (Figure 2.2.1).

$F_{0.1}$: fishing mortality rate at which the slope of the yield per recruit curve as a function of fishing mortality is 10% of its value near the origin.

F_{max}: fishing mortality rate which corresponds to the maximum yield per recruit as a function of fishing mortality.

Spawning stock biomass per recruit analysis combines stock and recruit information with growth characteristics of a cohort (Sissenwine and Shepherd 1987). Inputs include the data used in Y/R analysis plus the observed series of recruitment and the spawning stock biomass that produced it. The analysis is based on various percentiles of R/SSB (e.g. the 90th and 10th percentiles, the median). The F reference point is found by inverting the relevant R/SSB quantile and reading the corresponding F from the SSB/R graph from yield per recruit analysis (Figure 2.2.1, lower panel). A stock-recruitment relationship is not considered. The observed pattern of R/SSB depends on the exploitation history of the stock, environmental effects on recruitment, measurement error, and other factors.

F_{low}: fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the 10th percentile of the observed R/SSB.

F_{med}: fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the median observed R/SSB.

F_{high}: fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the 90th percentile of the observed R/SSB.

F_x: fishing mortality rate on an equilibrium population with a SSB/R of x% of the SSB/R for the corresponding unfished population.

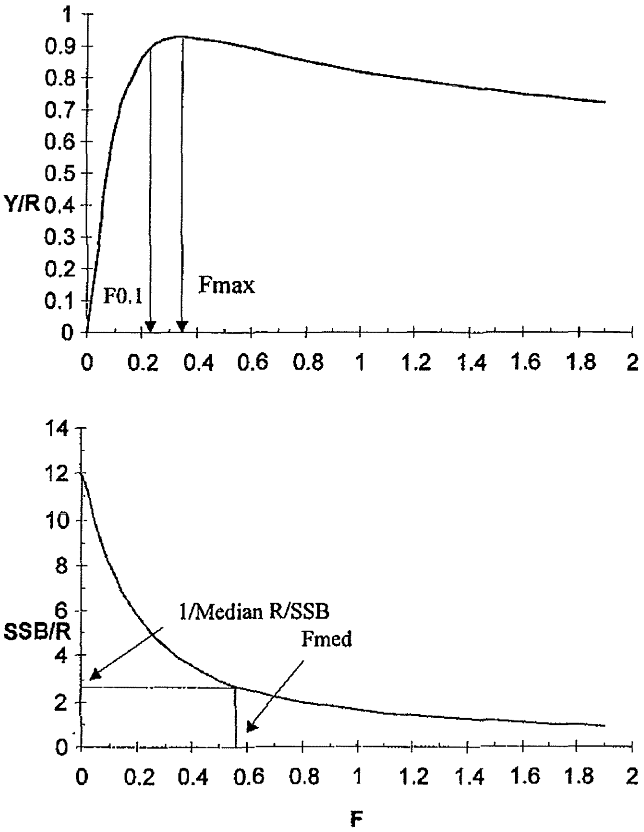

Figure 2.2.1: Y/R and SSB/R curves indicating yield per recruit and spawning biomass per recruit reference fishing mortalities.

Age-structured production models combine a stock-recruitment relationship with Y/R data. For any fishing mortality rate, Y/R and SSB/R are calculated using the Y/R analysis above. The associated equilibrium spawning stock size and recruitment are determined from the respective stock-recruitment equations. (S is substituted for SSB in the following equations.) For a Ricker relationship,

$$R = aSe^{-bS}$$

the equilibrium spawning stock biomass (S_e) is

$$S_e = \frac{\ln(a(S/R))}{b}$$

For the Beverton-Holt relationship

$$R = \frac{aS}{1+\frac{S}{k}}$$

the equilibrium spawning stock biomass is

$$S_e = k\left(a(S/R)-1\right)$$

For a Shepherd stock-recruitment relationship,

$$R = \frac{aS}{1+\left(\frac{S}{k}\right)^c}$$

the equilibrium spawning stock biomass is

$$S_e = k\left(a(S/R)-1\right)^{1/c}$$

Relationships can then be constructed between equilibrium yield and fishing mortality rate (Figure 2.2.2) or between equilibrium yield and spawning stock biomass.

B_{MSY}: biomass corresponding to maximum sustainable yield as estimated from a production model
F_{MSY}: fishing mortality rate which corresponds to the maximum sustainable yield as estimated by a production model.
F_{crash}: fishing mortality which corresponds to the upper intersection of the yield and fishing mortality relationship with the fishing mortality axis as estimated by a production model.
F_{comfie}: fishing mortality rate which corresponds to the minimum of F_{med}, F_{MSY}, and F_{crash} (see Section 4.2).

In addition to these analytical reference points, the Minimum Biologically Acceptable Level (MBAL) refers to a critical value of spawning stock biomass. Issues related to the calculation and interpretation of MBAL have been discussed elsewhere (Anon 1991, Anon 1993).

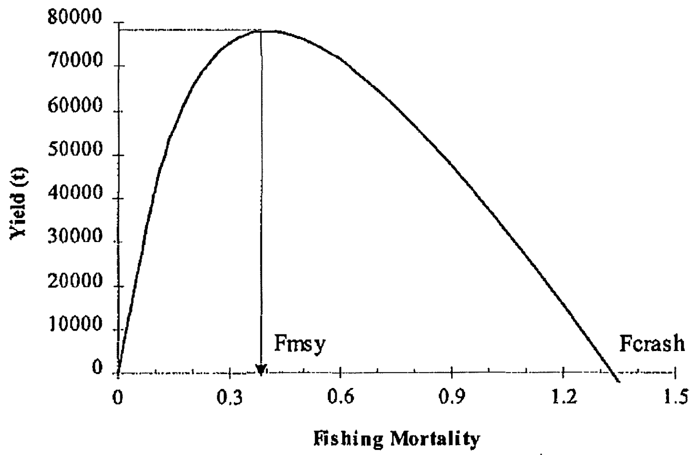

Figure 2.2.2: Equilibrium yield as a function of fishing mortality determined from an age-structured production model.

2.3 Biological Reference Points for Cod in the Southern Gulf of St. Lawrence, a Case Study

In this section we investigate the sensitivity of yield per recruit, spawning stock biomass per recruit, and age-structured production model biological reference points to changes in population parameters. A case study was developed for cod from the southern Gulf of St. Lawrence (Sinclair et al. 1996). Over the past 20 years, there has been a substantial reduction in weight at age in this stock (Fig. 2.3.1). The current weights at ages 6+ are less than half those in the late 1970s, and there has been a downward trend over the period. There have also been changes in the average fishing mortality at age (Fig. 2.3.2). During the late 1970s, F was higher on ages 4-8 than during the 1980-95 period. The average Fs in the following three 5-year periods were similar. However, there was a marked increase in F during 1987-92, followed by a decline to almost 0 in 1993-95 when the cod-directed fishery was closed due to low stock size. These trends do not appear in the averages.

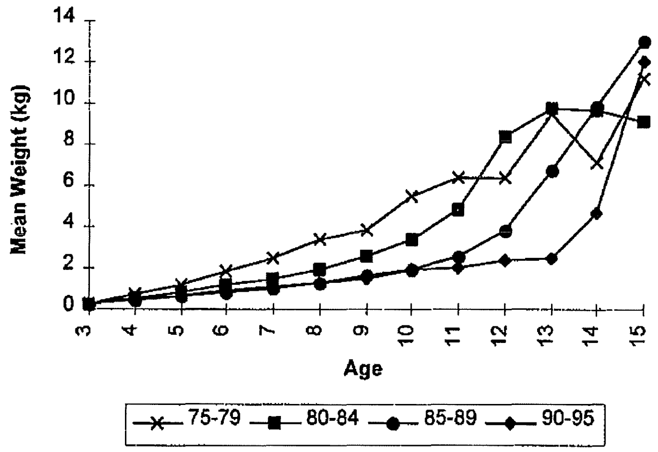

Figure 2.3.1: Mean weight at age for southern Gulf of St. Lawrence cod from four time periods, 1975-79, 1980-84, 1985-89, 1990-95.

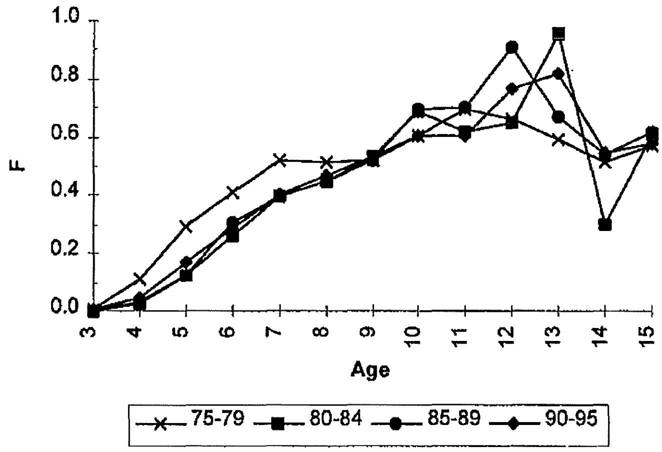

Figure 2.3.2: Mean fishing mortality at age for southern Gulf of St. Lawrence cod from four time periods.

Yield per recruit reference points, $F_{0.1}$ and F_{max}, were estimated using the method described by Thompson and Bell (1934) and Rivard (1982). The respective weights and F at age were used for the four time periods. Natural mortality was assumed to be 0.2 for all ages. The corresponding estimates of $F_{0.1}$ were relatively stable, varying between 0.17-0.21 (Table 2.3.1). Both Y/R and SSB/R at these reference points declined over the time period, from 0.87 to 0.37 kg and from 5.70 to 2.74 kg, respectively. This is expected because of the decline in weights at age. There was a wider range in F_{max} estimates, varying between 0.30 - 0.92. The Y/R curve had a well defined maximum for the first three time periods, but was flat topped in the last time period. This caused a large difference between the estimates of $F_{0.1}$ and F_{max}. Yield per recruit at $F_{0.1}$ was estimated to be between 88-95% that at F_{max}, while the fishing mortality at $F_{0.1}$ was approximately 60% F_{max} in the first three time periods and 23% F_{max} in the last time period. Spawning biomass per recruit at $F_{0.1}$ was about 1.5 times higher than at F_{max} in the first three periods and 2.3 times higher than at F_{max} in the last period.

Percentiles of R/SSB used in spawning biomass per recruit analysis depend on the conditions faced by the stock during the period for which data are available. The variability of the inverse of R/SSB for southern Gulf of St. Lawrence cod was examined using three types of running medians, based on 10 and 20 year class moving windows, and cumulative medians beginning with the 1950-60 year classes. The 10 year class median varied between 1.0 - 4.1, reflecting a strong temporal trend in the data (Fig. 2.3.3). The range of the 20 year-class median was 1.6 - 3.6. When the median was calculated on the cumulative data set, the range was between 2.6 - 4.0. Clearly, any spawning stock biomass per recruit reference points calculated for this stock will be influenced by the time period of data available for analysis.

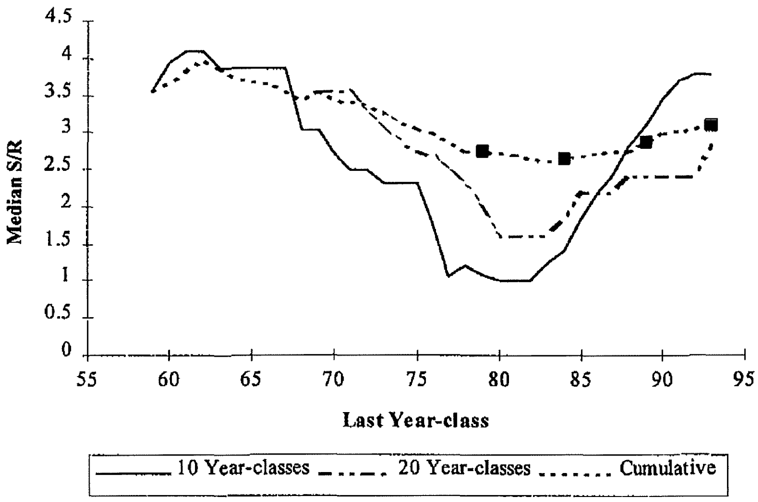

Figure 2.3.3: Trend in the inverse of median R/SSB for southern Gulf of St. Lawrence cod. The medians were determined over 10 and 20 year class moving windows, and on the cumulative data-set. The last year class in the respective series is shown on the x-axis. Median values used to calculate F_{med} for the four time periods are indicated with the solid squares.

Median R/SSB was determined for the four cumulative periods 1950-79, 1950-84, 1950-89, 1950-93, and F_{med} was estimated using the 1975-79, 1980-84, 1985-89, and 1990-95 mean weights and F at age data, respectively (Table 2.3.2). The medians were relatively stable, varying between 2.7 - 3.1. However, the associated values of F_{med} were much more variable, declining from 0.55 for the initial period when weights at age were the highest, to 0.16 when the weights were lowest.

A Ricker stock-recruit curve was fit to the entire dataset, assuming lognormal errors, in order to calculate age-structured production reference points (Fig. 2.3.4). Estimated values of F_{MSY} declined from 0.40 for the 1975-79 period, to 0.23 for the 1990-95 period (Table 2.3.3). Maximum sustainable yields also declined, from 78,000 to 31,000 t. When weights at age were relatively high (in the first two periods), F_{crash} was above 1.3. However, F_{crash} declined as the weights at age declined, to a low of 0.79 in the last period.

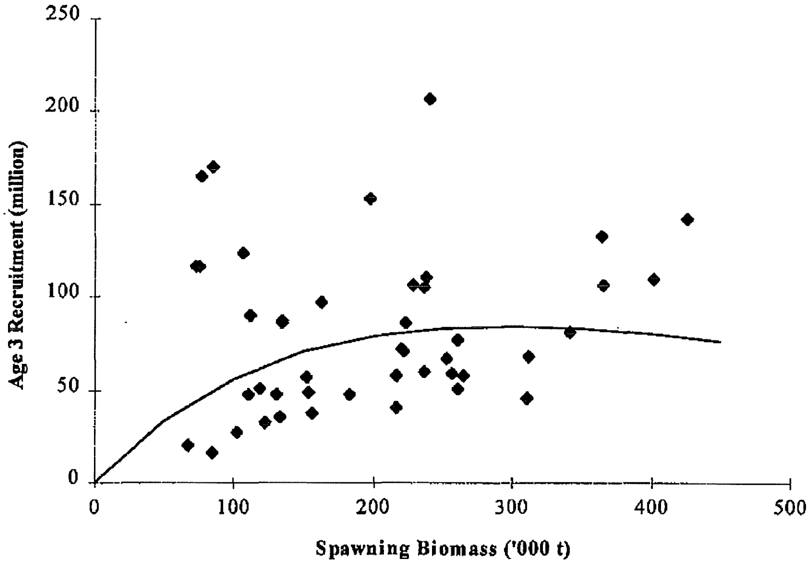

Figure 2.3.4: Stock and recruitment data for southern Gulf of St. Lawrence cod.

The lowest reference fishing mortality in all but the last time period was associated with $F_{0.1}$. Values of F_{MSY} and F_{max} were similar in the first three time periods. However, F_{max} increased in the last time period, and it was estimated to be higher than F_{crash}. In 1975-79 and 1980-84, F_{med} was the highest reference point, but it was the lowest reference F in the last period. Estimates of Y/R were similar in all time periods, and these declined as the weights at age declined. Estimates of equilibrium SSB/R corresponding to $F_{0.1}$ F_{max}, and F_{MSY} also declined with weights at age.

The lowest % maximum SSB/R was 21% associated with F_{max} in the 1990-95 period (Table 2.3.4). As noted above, this fishing mortality was not sustainable in the age-structured production analysis. The highest value was 56% associated with F_{med}, again in the last time period. The estimated % maximum SSB/R was stable in the case of $F_{0.1}$ at between 47 - 51%. The largest range in % maximum SSB/R was associated with F_{med}.

2.4 Comparison of Biological Reference Points for Several Stocks

The working group examined the F-based biological reference points for several fish stocks in the ICES area (Table 2.4.1). There was little variation in $F_{0.1}$ among stocks; the values ranged from 0.18 to 0.22. Estimates of F_{max} were generally below 0.46, except for a high value for southern Gulf cod in a period of low growth rate. Estimates of F_{med} varied between 0.16 for southern Gulf cod in 1990-95 to a high of 0.83 for North Sea cod. Estimates of F_{MSY} also showed a large range, from 0.23 - 0.72. Estimates of F_{high} were above F_{crash} in eight of 10 cases investigated, confirming that F_{high} is a dangerously high fishing mortality. The F_{comfie} (see Sections 2.2 and 4.2) reference point ranged between 0.16 - 0.40 in the cases examined. It also declined as weight at age declined for southern Gulf of St. Lawrence cod. This is a desirable quality since the target fishing mortality would decrease as the productivity of the stock decreased.

3 THE COMPREHENSIVE FISHERY EVALUATION WORKING GROUP WITHIN ICES AND INTERNATIONAL AGREEMENTS

The role of the Comprehensive Fisheries Evaluation Working Group (COMFIE) is perceived to be:

1. to develop and apply comprehensive fisheries evaluation (CFE) techniques;
2. to provide the basis for giving advice on strategic fisheries issues, including the appropriate use of methodologies by Assessment Working Groups;
3. to undertake CFEs for specified fisheries (case studies) as required.

The role of COMFIE would not extend to the development of other methodologies in response to short-term needs. If needed, that role would be filled by the Working Group on Methods of Fish Stock Assessment, convened on an *ad hoc* basis.

The comprehensive fishery evaluations will usually be complex and to a large extent inter-disciplinary, requiring input from experts in different fields. A CFE will therefore be a process which will be carried out in steps (see below) with a considerable amount of work done intersessionally, in co-operation with the relevant assessment working groups. Direct communication between COMFIE and assessment working groups, particularly on biological problems, is desirable and key persons from assessment working groups should attend COMFIE meetings. CFEs are intended to provide the basis for management advice for several years and updating of assessments according to the recommended procedure will be undertaken by the regular assessment working groups. Normally, new CFEs for a given fishery would be done every 5-10 years. Justification for earlier reviews could be, for example, an unexpected development in the fishery, changes in management objectives or improvement in methodology or data. COMFIE would probably have a capacity for having three CFEs in progress at each meeting. However, this will require a large attendance and therefore will influence the choice of venue for the meetings. COMFIE should meet annually.

3.1 Relationships with International Agreements

Several recent initiatives by the United Nations and its organisations will influence future approaches to fisheries management. The main ones are 1) the Code of Conduct for Responsible Fisheries adopted by the FAO Committee on Fisheries in November 1995 (Anon, 1995b) and 2) the Agreement for the Implementation of the Provisions of the United Nations Convention of the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks adopted by the UN General Assembly in August 1995 (Anon, 1995a,c). The application of the Code of Conduct is voluntary while the Agreement on the Management of Straddling Fish Stocks and Highly Migratory Fish Stocks is not. In the absence of information to the contrary, the Comprehensive Fishery Evaluation Working Group assumes that States which signed the Agreement for straddling and highly migratory fish stocks will be as conservative with shared stocks or those under their jurisdiction as with straddling and highly migratory ones. Articles 5 and 6 of the Agreement are of most interest and they are given below:

PART II

CONSERVATION AND MANAGEMENT OF STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS

Article 5

General Principles

In order to conserve and manage straddling fish stocks and highly migratory fish stocks, coastal States and States fishing on the high seas shall, in giving effect to their duty to cooperate in accordance with the Convention:

a) adopt measures to ensure long-term sustainability of straddling fish stocks and highly migratory fish stocks and promote the objective of their optimum utilization;

b) ensure that such measures are based on the best scientific evidence available and are designed to maintain or restore stocks at levels capable of producing maximum sustainable yield, as qualified by relevant environmental and economic factors, including the special requirements of developing States, and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global,

c) apply the precautionary approach in accordance with article 6;

d) assess the impacts of fishing, other human activities and environmental factors on target stocks and species belonging to the same ecosystem or associated with or dependent upon the target stocks;

e) adopt, where necessary, conservation and management measures for species belonging to the same ecosystem or associated with or dependent upon the target stocks, with a view to maintaining or restoring populations of such species above levels at which their reproduction may become seriously threatened;

f) minimize pollution, waste, discards, catch by lost or abandoned gear, catch of non-target species, both fish and non-fish species (hereinafter referred to as non-target species) and impacts on associated or dependent species, in particular endangered species, through measures including, to the extent practicable, the development and use of selective, environmentally safe and cost-effective fishing gear and techniques;

g) protect biodiversity in the marine environment;

h) take measures to prevent or eliminate overfishing and excess fishing capacity and to ensure that levels of fishing effort do not exceed those commensurate with the sustainable use of fishery resources;

i) take into account the interests of artisanal and subsistence fishers;

j) collect and share, in a timely manner, complete and accurate data concerning fishing activities on, inter alia, vessel position, catch of target and non-target species and fishing effort, as set out in Annex I, as well as information from national and international research programmes;

k) promote and conduct scientific research and develop appropriate technologies in support of fishery conservation and management; and

l) implement and enforce conservation and management measures through effective monitoring, control and surveillance.

<u>*Article 6*</u>

<u>*Application of the precautionary approach*</u>

1. States shall apply the precautionary approach widely to conservation, management and exploitation of straddling fish stocks and highly migratory fish stocks in order to protect the living marine resources and preserve the marine environment.

2. States shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures.

3. In implementing the precautionary approach, States shall:

a) improve decision-making for fishery resource conservation and management by obtaining and sharing the best scientific information available and implementing improved techniques for dealing with risk and uncertainty;

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

c) take into account, <u>inter alia</u>, uncertainties relating to the size and productivity of the stocks, reference points, stock condition in relation to such reference points, levels and distribution of fishing mortality and the impact of fishing activities on non-target and associated or dependent species, as well as existing and predicted oceanic, environmental and socio-economic conditions; and

d) develop data collection and research programmes to assess the impact of fishing on non-target and associated or dependent species and their environment, and adopt plans which are necessary to ensure the conservation of such species and to protect habitats of special concern.

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

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

6. *For new or exploratory fisheries, States shall adopt as soon as possible cautious conservation and management measures, including, inter alia, catch limits and effort limits. Such measures shall remain in force until there are sufficient data to allow assessment of the impact of the fisheries on the long-term sustainability of the stocks, whereupon conservation and management measures based on that assessment shall be implemented. The latter measures shall, if appropriate, allow for the gradual development of the fisheries.*

7. *If a natural phenomenon has a significant adverse impact on the status of straddling fish stocks or highly migratory fish stocks, States shall adopt conservation and management measures on an emergency basis to ensure that fishing activity does not exacerbate such adverse impact. States shall also adopt such measures on an emergency basis where fishing activity presents a serious threat to the sustainability of such stocks. Measures taken on an emergency basis shall be temporary and shall be based on the best scientific evidence available.*

Annex II of the Agreement provides guidelines for the application of precautionary reference points. Its relevance to the work of the COMFIE warrants reproducing the 7 points here:

ANNEX II

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

A precautionary reference point is an estimated value derived through an agreed scientific procedure, which corresponds to the state of the resource and of the fishery, and which can be used as a guide for fisheries management.

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

Precautionary reference points should be stock-specific to account, inter-alia, for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and major sources of uncertainty.

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

Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low. If a stock falls below a limit reference points or is at risk of falling below such a reference points, conservation and management action should be initiated to facilitate stock recovery. Fishery management strategies shall ensure that target reference points are not exceeded on average.

When information for determining reference points for a fishery is poor or absent, provisional reference points shall be set. Provisional reference points may be established by analogy to similar and better-known stocks. In *such situations, the fishery shall be subject to enhanced monitoring so as to enable revision of provisional reference points as improved information becomes available.*

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

3.2 Acceptable Harvest Control Laws

These agreements limit the space of acceptable harvest control laws[1] and how this may be reflected in annual advice.

The various conventions lead to the conclusion that

- fishing should be limited to sustainable levels[2]
- uncertainty should not be a reason to maintain high fishing mortality
- the stock biomass should be kept above B_{MSY} (see Section 2.2)
- fishing mortality should be kept below F_{MSY} (see Section 2.2)
- in the absence of other information, F_{MSY} may be taken as a limit reference point
- in the absence of other information, B_{MSY} may also be taken as a limit reference point
- there should be only low probability that limit reference points are exceeded

All of these statements are made explicitly in the conventions and there is little room for misinterpretation. In order to use these statements in advisory work, some further implications must be considered.

The main implication of these statements is that fishing mortality should remain below measures of F_{MSY} (with high probability) and the biomass should be above B_{MSY}. In cases when only rudimentary estimates of F_{MSY} are available, fishing mortality should remain below conservative estimates unless it can be shown that higher mortalities are sustainable.

For many ICES stocks, especially demersal ones, this would probably imply substantially reduced fishing mortalities and increased biomasses, in most cases probably by a factor of 2 or more. For stocks such as Icelandic cod, Northeast Arctic cod, and North Sea cod, where long series of spawning stock biomass and fishing mortality are available, biomass appears to be cascading down slowly from high values in the 1940s as average fishing mortalities increase. This suggests that the strong management actions implied by the international agreements may indeed be needed. On the other hand, multispecies considerations indicate that decreasing fishing mortality and rebuilding the biomass of apparently overexploited stocks of predators might result in a decrease in the overall fish production due to increased predation. Article 6.2 of the Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks states that "The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures". In this context, the multispecies considerations create uncertainty about the need to reduce fishing mortality and rebuild biomass, but article 6.2 says that this is not a reason not to act. Therefore, specific research should be undertaken to clarify the influence of multispecies considerations with respect to overall fishery conservation.

MSY, F_{MSY} and B_{MSY} are not usually available for most of the stocks in the ICES area. It is therefore recommended that quantified estimates of those quantities be obtained on a priority basis for the major stocks.

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[1] A harvest control law (HCL) is a rule for quantifying management measures based on all available knowledge

[2] "Sustainable Use" means the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations. (From "Article 2. Use of Terms" of the Convention on Biological Diversity, Rio de Janeiro, 1992).

3.3 CFEs and Fisheries Management

The dynamics of exploitation are such that fish stocks are likely to eventually become overexploited and collapse if effective fishery management is not implemented.

The development of the fishery management process would generally consist of the following steps:

A) Identify interested parties[3] which have a legitimate interest in the use and management of fishery resources.
B) Agree, with the interested parties, on the social, economic and biological objectives to be pursued.
C) Identify viable/feasible management actions.
D) Evaluate management procedures to achieve the management objectives.
E) Agree on a management procedure.
F) Develop a fishery management plan.
G) Implement the fishery management plan.
H) Monitor and evaluate the fishery management plan.
I) Go back to D when necessary.

Conflicts in fisheries management can often be linked to either the absence of objectives or to the objectives not being shared by interested parties. Without clearly defined and quantified objectives, it is difficult to assess the effectiveness of fishery management. Investing time and energy in the identification and adoption of common mutually agreed management objectives could be one of the most productive initiatives to increase the effectiveness of fishery management. When objectives are clearly defined and quantified, decision-making is simplified.

The nine steps outlined above fit broadly into the five components of a "classic" Decision Analysis paradigm, as outlined by Keeney and Raiffa (1976). WD18 suggests how fisheries management decision making fits into that paradigm and notes, in particular, that given the specification of objectives and viable management actions, scientific input is usually restricted to the provision of support material sufficient to permit decision makers to make rational, credible decisions.

Fisheries scientists' main inputs are at step D (to evaluate management procedures and the associated probability of achieving management objectives) and in a support role at step E, during which results from step D need to be effectively communicated.

3.4 Steps Involved in a Comprehensive Assessment

Given identified management objectives and viable management actions, a CFE of a fisheries system would consist of the following steps:

1. interpret management objectives and viable management actions;
2. identify existing data;
3. conduct exploratory analyses;
4. determine the feasibility of management procedure evaluation;
5. construct appropriate models of the fishery system;
6. evaluate and compare the performance of alternative management procedures;
7. recommend steps that would lead to improvements in the CFE;
8. produce full documentation of the CFE;
9. produce information required for decision making.

Each of these steps potentially involves a large number of components. The paragraphs below describe some of the key points associated with each step:

1) interpret management objectives and viable management actions

[3] In the English speaking world, "stakeholders" is sometimes used instead of "interested parties". "Stakeholders" may imply having a financial interest in the fishery and it may therefore have a more restrictive meaning. "Interested parties" could include both harvesting and non-harvesting interests.

This step requires that management objectives be translated into quantifiable terms so that they can be evaluated. These quantifiable terms determine the metrics to be used for later analyses. For example, units could be weight or value for analyses based on yield, or fleet characteristics for analyses based on employment or allowable fishing mortality. In many cases, the management objectives do not translate directly to such terms. A component of Step 1 would then be to suggest possible metrics for evaluation. Feedback on these metrics may be required from the management body.

2) identify existing data

A list should be compiled which includes all existing data for the fishery evaluation, whether or not the data are readily available. A CFE would normally encompass a wider range of data than those considered in a typical stock assessment. For example, environmental data and economic and sociological data may be required to represent the objectives from Step 1. Similarly, multi-species and technical interactions could be important in many cases. Typical assessment data include fishery catch and effort by species, time, area, gear type and fleet and biological characteristics (length, age, sex, maturity, growth, natural mortality) of the species in the catch. In addition, data on similar fisheries and stocks may be useful in developing appropriate models.

The data list should also include an indication of the reliability and scale of the data (e.g. time, area coverage). Uncertainty would normally be related to the conditions under which the data were collected and some data which are deemed to be important may have low reliability. For example, misreporting and discarding could lead to low reliability in catch data.

3) conduct exploratory analyses

Exploratory analyses involve both graphical and analytical approaches to initial data examination. These analyses help to identify basic patterns and relationships in the data which could guide the construction of system and assessment models in Step 5. Exploratory analyses could also establish sensible temporal and spatial scales and initial bounds for the formal analysis and consequent advice. For example, initial decisions could be made on which relationships to exclude from the formal analysis as well as the most important relationships to include. Any major gaps in the data required could also be identified here.

4) determine the feasibility of management procedure evaluation

Essentially, Step 3 should provide sufficient insight to assess the feasibility of the evaluation required. Serious problems encountered in Step 3 (if any) would lead COMFIE to advise ACFM that it is unable to deliver the output requested, and make suggestions for remedial action (Step 7).

5) construct appropriate models of the fishery system

Models that mimic the system of interest would be constructed using a combination of simulation and estimation procedures. Estimation procedures may include a variety of assessment tools. These models would maximise the information gain from the available data and assess the plausibility of alternative hypotheses about the underlying system. The scope and complexity of the modelling task follows from Step 3. Thus, this activity would focus primarily on the development of models and analytical approaches.

6) evaluate and compare the performance of alternative management procedures

Unless specified otherwise in Step 1, alternative assessment procedures and HCLs would be compared and evaluated by reference to (i) the degree to which they meet identified management objectives, and (ii) the degree to which they meet case-specific objectives and internationally agreed objectives related to sustainability.

7) recommend steps that would lead to improvement in the CFE

Recommendations might relate to the need for new data collection, calibration of data collection procedures by different nations, methods to improve data precision, development of analytical tools, or additional

Such recommendations could be based on a cost-benefit analysis following from the management procedure evaluation.

8) produce full documentation of the CFE

Documentation should include the main report, referenced working documents, computer programs, descriptions of code and usage, model equations and parameterizations, and other relevant information. Sufficient detail should be provided so that analyses could be repeated by individuals who did not participate in the CFE. This requires that rationales for all decisions be carefully documented.

Documentation of the CFE should be made available through electronic media (e.g. CD-ROM, World Wide Web).

9) produce information required for decision making

Methods of communicating with decision makers would depend on their objectives and expertise. Methods may vary from simple decision tables and summary graphics to complex outputs. Decision makers must communicate the rationale for their decisions to a broader audience. The need for simple but effective means of communicating the scientific basis for decision making, including uncertainties, is therefore imperative.

Managers should be involved in the interpretation of the CFE output and provide feedback on implementation of the suggested measures.

3.5 Overview of the Contents of a CFE

Comprehensive fishery evaluations should include in-depth examination of the socio-economic and biological basis for the management of the fisheries under consideration. The review of the biological basis would normally cover the following non-exhaustive list:

- management procedures currently in place, and their consequences
- scope of feasible management actions available for the fishery
- stock structure of the species involved
- main predator-prey relationships
- main environmental relationships as they affect recruitment and growth
- distribution of the stock with respect to the distribution of the fishery
- spawning areas
- juvenile areas and rearing areas
- migration patterns by size/age-groups
- influence of density on growth and/or distribution
- variability in recruitment and its main causes
- stock-recruitment relationship
- fleet composition, the fisheries in which they are involved, their interactions and their selectivities
- robustness of various stock assessment approaches (including statistical catch at age analysis)
- possibility of a catastrophe (e.g. what happened for these stocks in the past, or for stocks with similar characteristics elsewhere).

The assessment working groups would normally either provide these reviews or be closely involved in them.

4 HARVESTING STRATEGIES

4.1 Background

Section 2 above describes various biological reference points based on fishing mortality and biomass levels. Section 3 above describes various international agreements, some of which relate to maximum sustainable yield and other biological reference points. The following subsections describe in some detail how the agreements imply fairly strict limitations on fishing mortality and biomass levels.

In order to compare the agreements and the harvest control laws, it is convenient to separate HCLs into three types. The distinction may not always apply since in some cases the HCL can be very complicated, but this distinction provides a useful point of reference.

a) Harvesting in the central ICES area is usually compared to fishing mortality rates and advice is often framed in terms of reductions in fishing mortality. Thus it is most natural to consider catch control laws which are F-based, e.g. the F *status quo* (F_{sq}) - rule which allocates catches corresponding to a constant fishing mortality as earlier observed.

b) In other areas TACs are sometimes based on relationships with biomass. In this case is natural to consider HCLs which are simple functions of biomass. One example is to use a constant proportion of biomass.

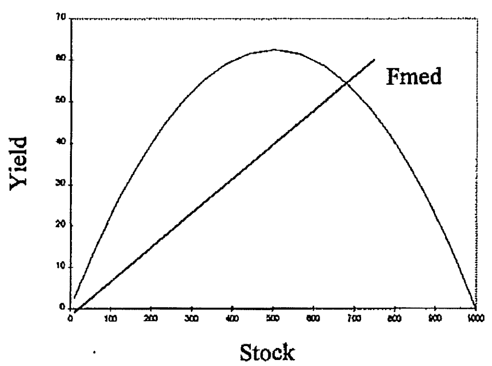
c) Finally, some strategies are more adaptive and try, for example, to move halfway to a target fishing mortality.

Of these, the first two allow fairly easy comparison to long-term prediction methods. In particular, a constant-F rule will correspond to an ordinary replacement line in the stock-recruitment plot, as given for F_{med} in most ICES working group reports. A HCL which is a linear function of biomass can be added as a straight line in a figure describing equilibrium catch as a function of SSB.

The relationship between the stock-recruitment plot, F-rules and fishing mortality-based reference points is given in Section 2.

Figure 4.1.1. shows an example of how an F-rule appears in the catch-SSB plane.

Fig. 4.1.1. An F_{med}-based harvesting strategy and equilibrium catch *vs* SSB.



4.2 Relationship between Harvesting Strategies and International Agreements

The following describes how the various agreements limit the space of acceptable harvest control laws[4] and how this may be reflected in annual advice.

The various conventions lead to the conclusion that

- fishing should be limited to sustainable levels
- uncertainty should not be a reason to maintain high fishing mortality
- the stock biomass should be kept above B_{MSY} (see Section 2.2)
- fishing should be at a fishing mortality below F_{MSY} (see Section 2.2)

[4] A harvest control law (HCL) is a rule for quantifying a management measure based on all available knowledge

- in the absence of other information, F_{MSY} may be taken as a limit reference point
- in the absence of other information, B_{MSY} may also be taken as a limit reference point
- there should be only low probability that limit reference points are exceeded

All of these statements are made explicitly in the conventions and there is little room for misinterpretation. In order to use these statements in advisory work, some further implications must be considered.

The main implication of these statements is that there should be a high probability that fishing mortality remains below measures of F_{MSY} and that the biomass should remain above B_{MSY}. In cases when only rudimentary estimates of F_{MSY} are available, fishing mortality should remain below conservative estimates unless it can be shown that higher mortalities are sustainable. The reasoning below is in terms of fishing mortality, but for each of the fishing mortality reference points considered, there are corresponding equilibrium biomass reference points. Equilibrium conditions are rarely met and both F-based and the corresponding biomass-based limit reference points should be used as constraints.

Sustainability implies that the probability of exceeding the fishing mortality at which the stock crashes (F_{crash}) should be very low.

F_{med} is one potential estimate of a sustainable fishing mortality. This estimate may in some cases be as high as the fishing mortality at which the stock crashes (F_{crash}) but, in general, one would expect that $F_{med}<F_{crash}$ and therefore that fishing at F_{med} would be sustainable. In the case of populations with a history of recruitment overfishing, F_{med} estimates the fishing mortality at which the stock crashes. Because of measurement errors and process error in the stock-recruitment relationship, observed values of F_{med} may sometimes exceed this theoretical upper bound. Conversely, F_{med} may be a conservative estimate of fishing mortality (low F). This is only the case in lightly exploited populations which have maintained a high spawning biomass throughout the period of exploitation.

However, F_{med} is one of the few available estimates of sustainable fishing mortality. Because F_{med} may be as high as F_{crash}, it must be taken as an upper bound on an acceptable fishing mortality unless better estimates are available.

An estimate of F_{MSY}, on the other hand, is rarely available, and even when it is, it tends to be highly uncertain. Even in those cases where F_{MSY} exists, it cannot be taken as a target fishing mortality, since various agreements explicitly state that F_{MSY} is an upper bound (limit reference point) which should not be exceeded.

In the absence of any stock and recruitment information, F_{max} is often used in place of F_{MSY}, but F_{MSY} is commonly less than F_{max} and hence F_{max} must also be considered an upper bound on a fishing mortality satisfying the most common international requirements. If F_{max} is ill-defined, then $F_{0.1}$ instead of F_{max} could be used in the decision process below.

The above implies that in the absence of more detailed and accurate information, any target fishing mortality F_{target} must be such that the realized fishing mortality, F, satisfies

$$\mathbf{F < F_{comfie}}$$

with high probability, where

$$\mathbf{F_{comfie} = \min\{F_{med}, F_{MSY}, F_{max}\}.}$$

This conclusion indicates that there are certain limitations on catch control laws if they are to satisfy the international agreements. During the testing of management procedures including catch control laws, the probability of exceeding limit reference points must be evaluated.

In particular it would seem that a TAC decision rule (or catch control law) which determines the quota in year t, Q_t as a function of e.g. the stock size would have to satisfy

$$\mathbf{P\{\ Q_t \leq Y_{sust}(t)\ \}\ \text{is high}}$$

where $Y_{sust}(t)$ is a catch corresponding to a fishing mortality of F_{comfie}. This probability can be determined from simulating the HCL using different models.

In the simplest case, the simulation would involve uncertainty in the estimate of the current state and a forward projection of recruitment under various conditions. The probability that the population biomass or the fishing mortality rate meets the specified criteria could then be estimated from the uncertainty associated with the projected stock size. These simulations must also account for uncertainty in the implementation and measurement of the target biomass or fishing mortality rate, for example, the typical difference between target values of F and the value which is actually achieved. Examples of these types of projections are provided in later sections of this report.

The relationship between the above considerations and annual advice may not be one-to-one but, in the absence of a better measure of sustainable fishing mortality than F_{med} for the stock, the following is quite clear:

Annual advice which implies repeatedly exceeding F_{med} is not consistent with the international agreements.

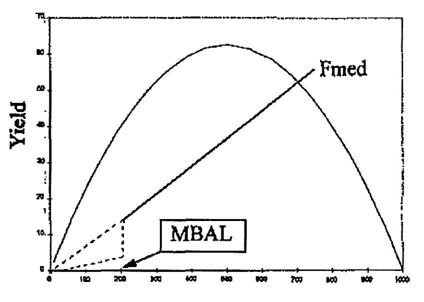
4.3 Notes on Acceptable Catch Control Laws

The international agreements refer to B_{msy} to be taken as a biomass limit reference point in the absence of other knowledge. ACFM uses a limit reference point called MBAL (Figure 4.3.1). In both cases the intent is that the biomass should remain above the limit reference point and this implies a very low fishing mortality in cases where the stock approaches or goes below the limit reference point.

It follows from considerations in previous subsections that the space of acceptable catch control laws is quite restricted. In particular, it is seen that such a CCL must lie below certain curves in the stock-catch plane.

These types of bounds (Figure 4.3.1) are used in various simulations given in Section 6.6.

Fig 4.3.1. Bounds on harvesting strategy and equilibrium catch *vs* SSB.



4.4 Non-sustainable Fishing Activities

4.4.1 Introduction

Three cases of non-sustainable fishing practices are described in this section.

4.4.2 Non-Sustainable Fishing of Southern Gulf of St. Lawrence Cod

Changes in weights at age of cod in the Southern Gulf of St. Lawrence, and the effects of this on biological reference points, Y/R, SSB/R, and MSY are described in Section 2.4. There has been a considerable reduction in weights at age of this stock, and this leads to reduced estimates of MSY, F_{msy}, and F_{crash}. Here, the observed trajectories of yield and SSB, and yield and F are compared to the equilibrium curves estimated for the different time periods.

During 1959 to 1992, most of the observed annual values of yield and SSB were between the equilibrium yield curves for the 1975-79 and 1980-84 time periods (Figure 4.4.1). Spawning biomass was always less than that associated with MSY. Only the 1993-95 annual values were below the curves for the latter two time periods.

A similar pattern is seen in the relationship between yield and F (Figure 4.4.2). In this case, only the 1975-95 annual values are shown. Fishing mortality was greater than F_{msy} in all years except 1977-78 and 1993-95. There was an increase in F during 1987-92 to levels in excess of F_{crash}. Only since the closure of the fishery in 1993 have the observed values been below the equilibrium curves. Continued high F in the mid-1990s could have had disastrous effects on the stock.

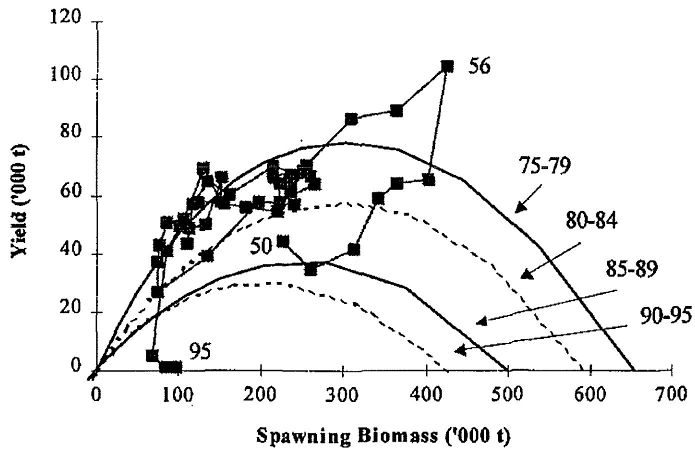


Figure 4.4.1: Comparison of estimated equilibrium conditions of yield and spawning biomass with observed annual values for southern Gulf of St. Lawrence cod. Four equilibrium curves are shown which correspond to conditions in the years indicated.

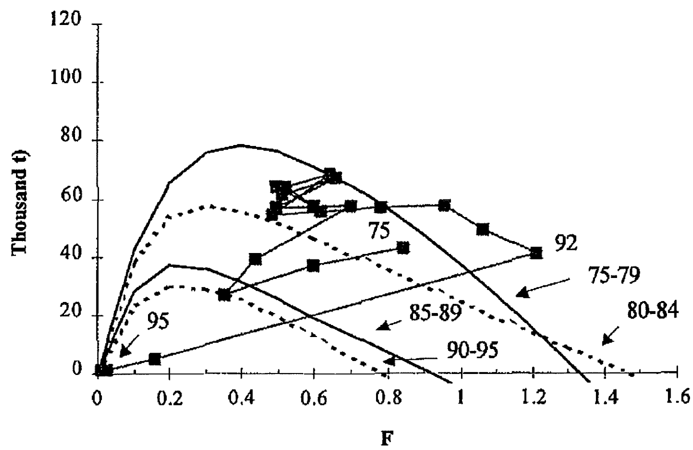


Figure 4.4.2: Comparison of estimated equilibrium conditions of yield and F with observed annual values for southern Gulf of St. Lawrence cod. Four equilibrium curves are shown which correspond to conditions in the years indicated.

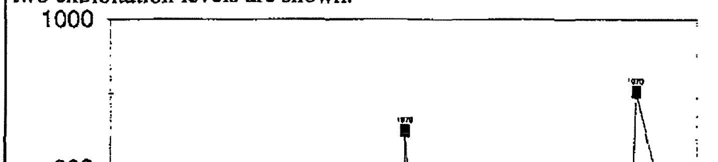
4.4.3 Non-sustainable Fishing of North Sea Cod

Data from the most recent assessment of North Sea cod (Anon, 1996) were used to evaluate yield per recruit, spawning stock biomass per recruit, and age-structured production biological reference points. For the latter analysis, a Shepherd stock-recruitment curve was fit to the SPA age 1 numbers of recruits and spawning biomass for the 1963-94 year-classes (Figure 4.4.3). The respective biological reference points and the associated performance measures (S/R, Y/R, and equilibrium S, R, and Y) are listed in Table 4.4.1. The fishing mortality at $F_{0.1}$ (0.18) and F_{max} (0.28) were considerably lower than F_{msy} (0.72) and F_{med} (0.83). The unsustainable fishing mortality (F_{crash} = 0.91) was close to both F_{msy} and F_{med}, and lower than F_{high} (1.10). The % maximum S/R was 6% or less for F_{med}, F_{msy}, F_{high}, and F_{crash}. The estimated yields at $F_{0.1}$ and F_{max} are likely to be poorly determined given the lack of stock and recruitment observations at the higher levels of S associated with these levels of fishing.

The equilibrium spawning biomass and yield curves from the age-structured production analysis indicate potentially dangerous production dynamics for this stock (Figure 4.4.4). The peak in the yield vs. F curve is well to the right, and F_{msy} is very close to F_{crash}. Using F_{msy} as a target fishing mortality appears risk prone, given that a small error in estimation or implementation could result in an unsustainable F.

Comparing the observed levels of F, S, and Y to those from the equilibrium curves suggests that the stock may be on the verge of collapse. The observed values are close to the equilibrium lines suggesting that the production analysis is providing a reasonable fit. During the past 10 years, the observed Y and S have declined steadily, with current values getting close to the origin (Figure 4.4.5). Over the same period, the annual estimated F has been close to F_{crash} (Figure 4.4.6). Yields have been declining while F has been relatively constant. Continued high levels of F are likely to reduce the stock even further. If the estimated stock production dynamics are close to the real situation, the stock could be on an irreversible road to collapse unless very drastic measures are taken.

Figure 4.4.3. North Sea cod. Stock recruit data. Replacement lines for two exploitation levels are shown.



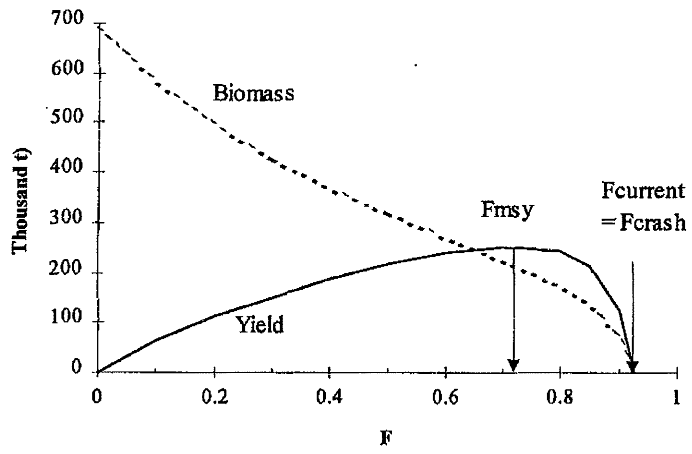


Figure 4.4.4: Equilibrium biomass and yield vs. F for North Sea cod, estimated using an age-structured production analysis.

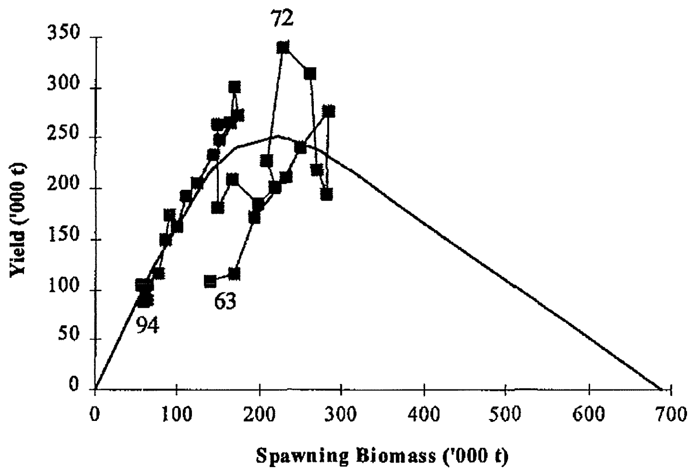


Figure 4.4.5: Comparison of estimated equilibrium conditions of yield and spawning biomass with observed values for North Sea cod.

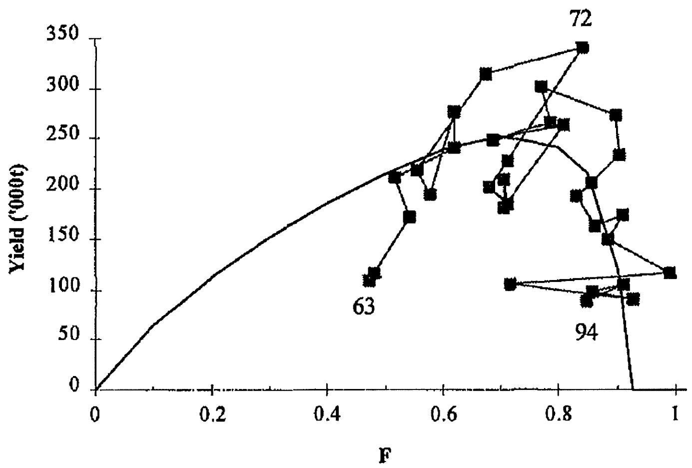


Figure 4.4.6: Comparison of estimated equilibrium conditions of yield and F with observed values for North Sea cod.

4.4.4 Iceland Cod

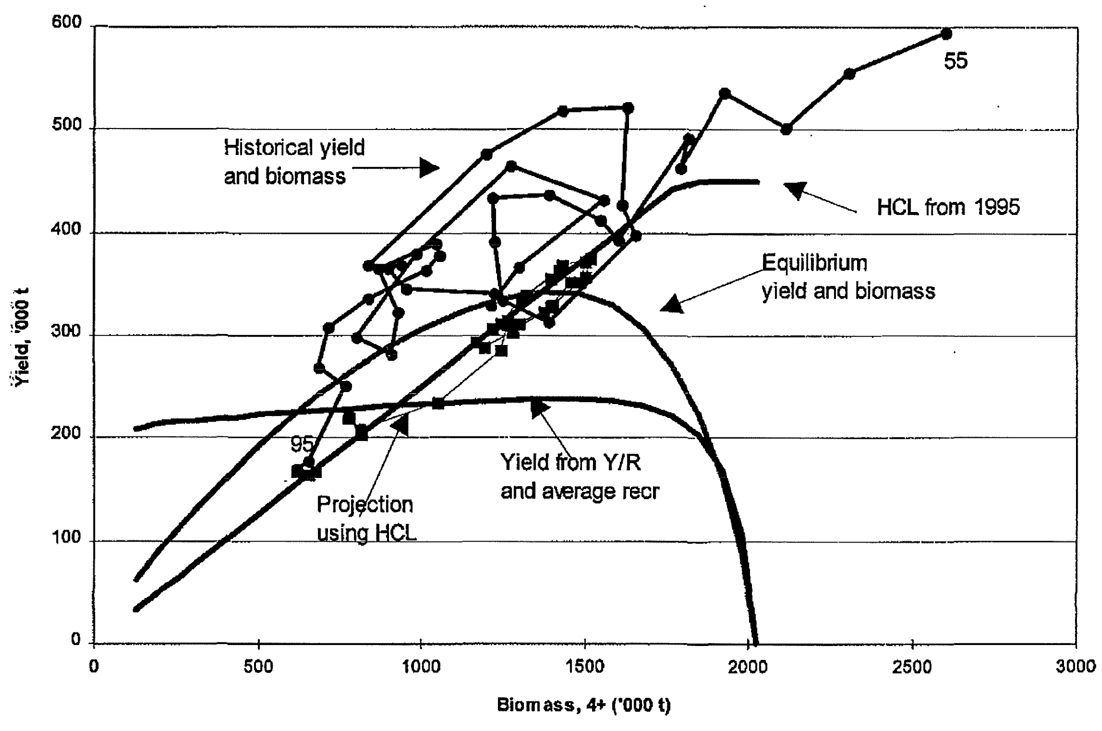
Fig. 4.4.7 depicts some theoretical and observed relationships between yield and 4+ biomass for Iceland cod. The solid curve shows the estimated equilibrium yield for a given stock size, based on predicting with a fixed fishing mortality forward in time and using the average catch and SSB at the end of the period along the lines described in Stefánsson *et al.* (1994).

Since this includes the assumption of a stock-recruitment relationship, the computations are repeated using simply yield per recruit and average recruitment computed from recent years.

The figure also shows the historical time trajectory of catch and biomass. In most cases, the observed values are above the equilibrium curves, spiralling towards the origin, indicating non-sustainable harvesting.

The last few years in the plot correspond to restricted fisheries aimed at conforming to a harvest control law taking 25% of the biomass (straight line). Also shown is the projected trajectory of stock and yield if the catch control law is followed into the future.

Fig. 4.4.7. Iceland cod. Yield and biomass. See text.



5 MEDIUM-TERM PROJECTIONS – GENERAL CONSIDERATIONS

5.1 Introduction

A number of factors must be considered in the calculation of medium-term projections. As discussed in Section 4.2, the simplest projections would include uncertainties in the estimate of stock size for the initial year and in the projected recruitment. Sections 5.2 and 5.3 discuss possible approaches for addressing uncertainties in initial stock size. Such approaches may acknowledge measurement error in the data and estimation error associated with the parameters, but assume that the underlying model provides a perfect representation of the stock dynamics. Section 5.4 discusses various issues related to the selection of a stock-recruitment relationship required for the forward projection.

5.2 Variance Estimates for Catch Forecasts

ADAPT (Gavaris, 1988; Gavaris and Maguire 1996) was used to assess North Sea cod, North Sea plaice and North Sea sole using the same data as the 1995 North Sea Demersal Working Group (ICES, Doc. C.M.1996/Assess:6). The survivors were estimated using a non-linear least square minimization of the differences between observed series of indices of stock sizes and predicted indices of stock size from VPA using a Marquart algorithm. The survivors in 1995, and their CVs (Gavaris, 1993) are compared with those calculated by the North Sea Demersal Working Group using XSA.

CVs	**North Sea cod**		**North Sea Plaice**		**North Sea sole**	
AGE	**ADAPT**	**XSA**	**ADAPT**	**XSA**	**ADAPT**	**XSA**
2	0.20	0.14	0.28	0.22	0.48	0.35
3	0.21	0.10	0.20	0.15	0.38	0.17
4	0.22	0.08	0.20	0.11	0.50	0.13
5	0.24	0.09	0.24	0.10	0.52	0.13
6	0.24	0.09	0.28	0.10	0.51	0.11
7	0.23	0.09	0.30	0.11	0.44	0.12
8	0.33	0.13	0.27	0.10	0.65	0.12
9	0.33	0.15	0.24	0.10	0.55	0.15
10	0.48	0.21	0.23	0.10	0.72	0.14
11		0.24	0.27	0.10	0.96	0.17
12			0.29	0.11	1.12	0.23
13			0.32	0.12	0.88	0.24
14			0.32	0.13	1.05	0.26

Most of the CVs calculated from the ADAPT assessment are at least twice as high as those derived from XSA. Although they are probably closer to reality than those from XSA, they are nevertheless likely to underestimate actual uncertainties because of model errors. They, or similar statistically-based estimates of uncertainties, should be used to describe the variance of the initial stock size in medium-term projections.

The correlations between the survivor estimates are negligible.

North Sea Cod

CORR	2	3	4	5	6	7	8	9	10
2	1.000	0.030	0.018	0.007	0.003	0.002	0.001	0.000	0.000
3		1.000	0.029	0.012	0.006	0.003	0.001	0.001	0.000
4			1.000	0.025	0.012	0.007	0.003	0.002	0.000
5				1.000	0.025	0.016	0.007	0.004	0.001
6					1.000	0.030	0.014	0.008	0.002
7						1.000	0.025	0.015	0.003
8							1.000	0.027	0.006
9								1.000	-0.078
10									1.000

North Sea Plaice

CORR	2	3	4	5	6	7	8	9	10	11	12	13	14
2	1.000	0.092	0.072	0.057	0.038	0.025	0.015	0.012	0.008	0.006	0.004	0.004	0.004
3		1.000	0.102	0.081	0.055	0.036	0.025	0.017	0.011	0.009	0.007	0.006	0.006
4			1.000	0.104	0.071	0.046	0.034	0.025	0.015	0.012	0.009	0.009	0.008
5				1.000	0.093	0.060	0.045	0.034	0.022	0.016	0.013	0.012	0.012
6					1.000	0.086	0.066	0.051	0.034	0.026	0.020	0.019	0.019
7						1.000	0.097	0.077	0.055	0.041	0.036	0.031	0.032
8							1.000	0.111	0.085	0.062	0.057	0.052	0.051
9								1.000	0.121	0.090	0.082	0.077	0.080
10									1.000	0.124	0.113	0.110	0.116
11										1.000	0.152	0.150	0.161
12											1.000	0.187	0.198
13												1.000	0.161
14													1.000

North Sea Sole

CORR	2	3	4	5	6	7	8	9	10	11	12	13	14
2	1.000	0.051	0.032	0.024	0.021	0.019	0.007	0.006	0.004	0.003	0.001	0.002	0.001
3		1.000	0.047	0.034	0.029	0.027	0.010	0.008	0.005	0.004	0.002	0.002	0.001
4			1.000	0.046	0.039	0.034	0.013	0.012	0.007	0.005	0.003	0.004	0.001
5				1.000	0.055	0.046	0.019	0.017	0.012	0.008	0.004	0.007	0.002
6					1.000	0.063	0.029	0.027	0.019	0.012	0.007	0.011	0.004
7						1.000	0.047	0.042	0.028	0.019	0.010	0.016	0.007
8							1.000	0.068	0.045	0.031	0.016	0.024	0.013
9								1.000	0.058	0.033	0.021	0.030	0.015
10									1.000	0.055	0.031	0.038	0.017
11										1.000	0.041	0.040	0.021
12											1.000	0.048	0.028
13												1.000	-0.105
14													1.000

5.3 Inclusion of Variance/Covariance of Population Estimates in Short-term Projections

Two approaches for calculating uncertainties in short-term catch forecasts were compared (Sinclair and Gavaris 1996). In one, an integrated formulation of ADAPT was used to project population state variables (yield, F, etc.) and their variances over the short term (1 - 2 years). This method used the analytically determined variance/covariance of the population state at the beginning of the projection period (Gavaris 1993). The second approach used Monte Carlo simulations where only the variances of the population estimates at the beginning of the projection period were considered. Both methods were used on two stocks, haddock on eastern Georges Bank and cod in the southern Gulf of St. Lawrence.

The choice between either including the covariance of population estimates or not will probably be stock specific, and depend on the magnitude of the covariance. In the cases examined here, there was little difference between the two approaches.

5.4 General Points on the Selection of S-R Relationships.

Classical stock-recruitment functions (Beverton-Holt, Ricker etc.) are used to describe average expected recruitment as a function of SSB. The actual process leading from SSB to recruitment is complex, however, and includes the relationship between SSB and the amount and quality of eggs, the predation on eggs, larvae and juveniles, the condition of the offspring, the egg and larval transport to suitable nursery areas, etc. All this leads to substantial year-to-year variations in recruitment, even for similar levels of SSB. A model of the stock-recruitment process, therefore, has to characterise not only the changes in average recruitment as a function of SSB, but also the nature of the variability for each level of SSB.

Depending on how the modelled system is bounded, some sources of recruitment variation are intrinsic, in the sense that they may be explicitly modelled, and some are extrinsic and usually treated as random variables or known driving forces estimated from other sources. Intrinsic sources include, in particular, the effect of the spawning stock biomass as such, but they may also include the age and/or size composition of the spawning stock, if there are indications that some sizes or ages produce eggs of better quality, and the size of previous year classes, if cannibalism can be a regulating factor. Sources of recruitment variation commonly treated as extrinsic in single-species models include environmental conditions and predation. These may be incorporated as time trends in model parameters either induced by specified driving forces or based on direct modelling of the historical recruitment trends. In multispecies models, the effects of predators on the stock-recruitment dynamics of any given species can be explicitly modelled. In all cases, unpredictable variability needs to be added.

Commonly used models can be broadly classified into parametric and non-parametric. The non-parametric approach essentially draws among the historical recruitments. These recruitments may be given different probabilities, according to the difference in parental SSB, which is the essence of the kernel type of models. In the parametric models, a specified function of the SSB is assumed, and its parameters are estimated from historical data. Variability around this curve is commonly described using a parametric probability distribution function; alternatively, the empirical distribution of residuals around the parametric curve can be used in the simulations. In either case, the term treated as stochastic should be independent of the SSB and other variables used as predictors. This may involve transforming the stochastic variable, e.g. by assuming an SSB-dependent variance if necessary.

Ideally, a stock-recruitment model should take into account all sources of uncertainty. These include the appropriateness of the model used, i.e. uncertainty about model structure (e.g. a dome-shaped curve versus an asymptotic one, assumptions about time dependency of parameters etc.), errors in parameter estimates for a given model structure, and the uncertainty created by the stochastic nature of the process. Quantifying the uncertainty about parameter values, conditional on the structural assumptions being correct, is relatively easy. Parameters can then be treated as random quantities in the simulation by drawing the set of parameter values used for each stock projection from a joint probability distribution. Bayesian methods are appropriate for this problem, but multivariate distributions with a variance-covariance equal to the variance-covariance of the parameter estimates (e.g. as estimated from the Hessian) can provide a good enough approximation to a full Bayesian posterior.

The other sources of uncertainty are more difficult to incorporate. The existence of errors in the data used to estimate the parameters, i.e. the stock and recruitment estimates from the assessment, are themselves a source of uncertainty about model structure and parameter values. Their effects can be important, inducing bias in the parameter estimates. The same is true for the time-series nature of the stock-recruitment process (i.e. the dependency of the SSB on previous recruitments), which is ignored in standard stock-recruitment analyses. Alternative approaches that estimate stock-recruitment parameters jointly with the historical series of recruitments and SSBs may be considered; in these approaches the uncertainty in abundance estimates reflects directly in uncertainty of stock-recruitment parameters.

The specification of the stock-recruitment model, and the uncertainty about the parameter values may have profound effects on the evaluation of management procedures, the probabilities of exceeding management thresholds, the danger of collapse etc. Sensitivity to different assumptions about model structure should be explored and alternative models should be considered if necessary.

A common problem in stock-recruitment analysis is that the range of historical SSBs is too narrow and the data provide essentially no information about important properties of the stock-recruitment relationship, like the slope at the origin or, in the case of a dome-shaped functions, the SSB level that produces maximum recruitment. This problem is well exemplified by the North Sea plaice (see Section 6.4). Due to the rigid functional forms commonly assumed, conventional statistics (e.g. the variance-covariance of model parameters) tend to underestimate the uncertainty about those key features. Any predictions made outside the range of historical experience are extrapolations based on the deterministic functional form assumed, as fitted to the historical data. Unfortunately, a stock-recruitment relationship for all the range of plausible SSB levels needs to be specified, as simulated stock trajectories are likely to fall outside the observed range, even if the implemented harvesting strategy attempts to prevent it.

When the stock-recruitment relationship is viewed in conjunction with a harvesting strategy, the precautionary approach would indicate that, in the absence of information, assumptions about productivity at unobserved SSB levels should not be more optimistic than what the historical trends indicate. Parameter values could thus be constrained so that recruitment or the number of recruits produced per unit of spawning biomass does not exceed the maximum levels observed. In a Bayesian framework, this can be achieved by placing prior distributions on the model parameters. Objective priors, on the other hand, could be constructed based on information provided for other fish stocks (see for example Liermann and Hilborn, 1996 for an analysis of depensation in fish stocks). When evaluating the performance of the management procedures it is important to compute the probability that the stock falls below the minimum historical level, as predictions are very uncertain for those stock levels.

External influences appearing as time-dependent variations in the recruitment will carry over to the residuals. The residuals of a parametric model should therefore be examined for autocorrelations, and modelled as a stochastic process if necessary. This can be done by including autocorrelations in the distribution of the stochastic element, or by applying more elaborate stochastic models.

It is quite common that the distribution of recruitments is asymmetric, with many 'normal' and a few extreme year classes. Typical examples in the ICES area are several haddock stocks, horse mackerel, some herring stocks and the North Sea plaice. These extreme year classes have a profound effect on the population dynamics, since they often dominate the stock. For management, the most important question in these cases may be how rapid it is advisable to deplete such large year classes, which in turn depends on the time interval between them. If extreme years classes are sufficiently distinct, they may be treated separately, and their occurrence in time may be modelled explicitly. By doing so, one will avoid problems with parameterisation of stock-recruitment functions and with awkward distributions of errors. Differential treatment of outliers may be accomplished by using robust estimation methods. If only a few extreme year classes have been observed, one may have to assume that they occur with a constant probability; if there is information, either in the time series of recruitments themselves or on possible factors that can explain these exceptional year classes, more complex models may be developed (see e.g. WD#10).

6 NORTH SEA PLAICE

Considerable work has been undertaken to initiate a CFE for North Sea plaice, as described in various working documents (see list of Working Documents in Section 11.1). The work is based on extensive data analyses, construction of underlying system models and simulation. The details are discussed in the following sections.

Specifically, the use of a system model with feedback control, developed to investigate management options for North Sea plaice fisheries, is described. The work has been carried out using an evaluation framework being developed at Lowestoft (Kell and Stokes, 1995). The work is a continuation of that presented to the 1995 ICES Long-Term Management Measures Working Group (Anon, 1995a) and follows earlier recommendations from that group. Details are provided in WD 19 and in WDs 23-27.

Section 6.6 shows outputs from medium-term projections made using a variety of approaches. Also included are outputs from the feedback control approach, run under similar assumptions. The purpose is to investigate the utility of the simple medium-term projection methods. A medium-term projection method, including a stock recruitment model with stochastic variation, which allows a catch control law to be specified is presented. This is used to investigate how the North Sea plaice fishery will respond to different control law specifications.

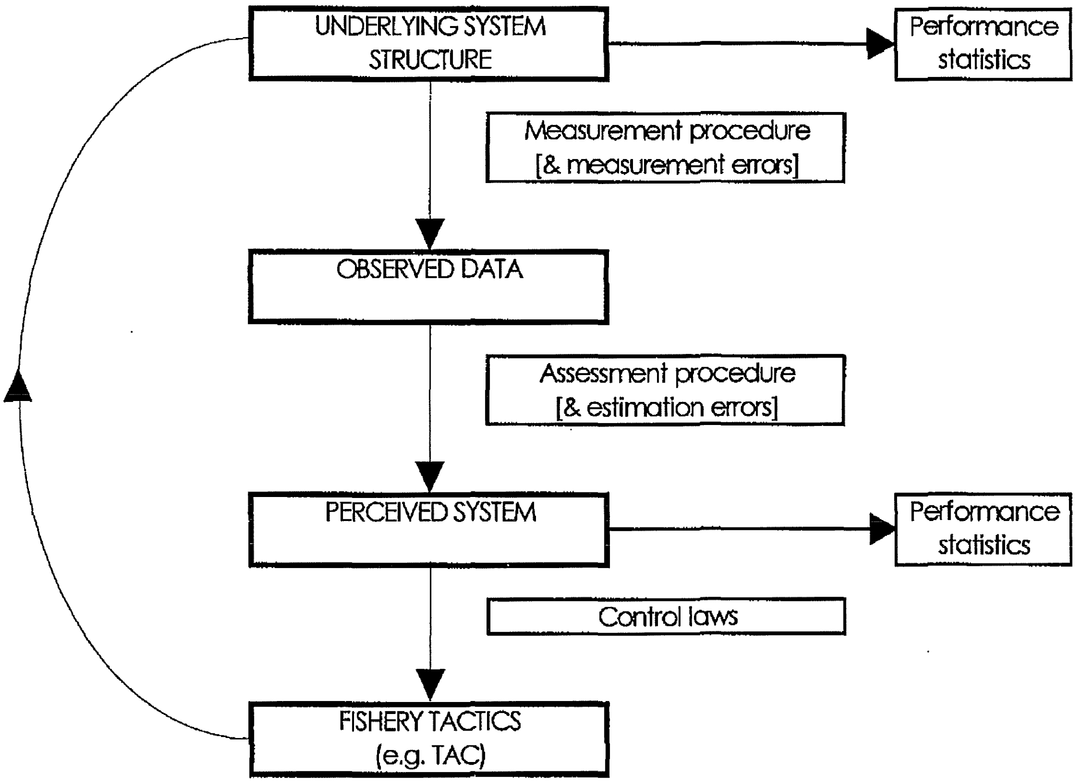
6.1 Scenario Model Structure

The model structure illustrated in Figure 6.1 follows the approach described in the 1994 LTMMWG (Anon 1994a). There is an underlying system, corresponding to the real world, about which inferences have to be made from data. These observations (sampled with error) are then used to estimate the status of a perceived system using assessment methods. The perceived and actual systems are not necessarily the same, reflecting uncertainty about fleet, stock and other dynamics.

The perceived status of the stock influences the management action taken, depending on the catch control laws employed. The performance of a particular management procedure (i.e. an assessment procedure plus spawning stock biomass and catches over time or, in principle, any other quantities of interest which may be modelled (e.g. economic indicators such as net present value or measures of stability such as the average annual variation in catch or implied effort).

Modelling the management of fisheries and stocks under uncertainty requires models which represent the underlying population dynamics, assessment of the status of the stocks, prediction and implementation of consequent management actions and the monitoring of performance relative to management objectives. It is possible to use such models both to test the robustness of management procedures to assumptions about the underlying dynamics, and to compare the performance of procedures, for any given set of assumptions about the underlying system.

Figure. 6.1 Flow chart for simulations used in the evaluation framework (after Anon, 1994a)



6.1.1 The underlying system

Underlying system models should be plausible, well-founded in theory and conditioned on data. Creation of further elaborate models is dependent on biological (and other) knowledge, theoretical considerations and, primarily, data analysis. The underlying and perceived systems used in this example are simple, single-species discrete time models. More complexity can easily be incorporated, if supported by the available data - but the important feature of these models is that they should include plausible alternatives.

6.1.2 Perceived system and stock assessment

The assessment procedure uses the simulated observed data in addition to assumptions about the underlying system. In principle, alternative age-based assessment procedures, length-based or stock-production models, may also be investigated as part of the management procedures.

The perceived system is formalised in the assessment, any assumptions made about it and any subsequent analyses (e.g. a fit to estimated stock and recruitment data). It consists of stock size estimates by age and year, fishing mortality estimates by age and year and a large range of biological reference point estimates.

A simple catch projection program (e.g. Anon, 1995b) using the same age-structured time step and population model as the rest of the simulation is included.

6.1.3 Feedback between perceived and underlying systems

Given estimates of the current stock status (F, SSB, etc.) a target fishing mortality or catch can be estimated corresponding to some biological reference point such as F_{med}, $F_{Status\ Quo}$, F_{MBAL}, $F_{0.1}$, F_{Max}, $F_{30\%Max}$. A variety of catch control laws, constructed from these biological reference points, have been investigated.

The fishery operates by taking the allowed catch from the true population with the possibility of implementation deviations. For instance, unreported landings may mean that the TAC is exceeded, although the reported total international catch is in agreement with the TAC. Overall F by fleet is calculated for a given catch, allowing the true partial Fs by fleet to be determined (with bias or error if required).

6.2 North Sea Plaice Scenario Model: Underlying System Model Components

An underlying system model has been implemented for North Sea plaice. The building of the model, and the associated estimation of parameter and variances, was performed using appropriate statistical methods applied to data from the North Sea Demersal Working Group, English research surveys and official English vessel trip records and market samples. The details of this process were given in WDs 23-27 and are summarised below.

6.2.1 Growth and maturity

A von Bertalanffy growth model was used, and parameters estimated under an assumption of a constant coefficient of variation (cv). The non-linear parameters of the function were estimated using a standard linearisation of the von Bertalanffy model (Campana *et al.*, 1995).

Maturity was modelled as a binary variable (immature/mature) and fitted as a function of age. Estimated probabilities of maturity were related to age through a standard logistic assumption (WD27).

Data collected during English Groundfish Surveys were used for the estimation of parameters and standard errors. The growth models were used in the simulations to estimate mean weights at age. Maturity was used to calculate SSB in the true population. Although there appeared to be temporal and spatial effects present in the growth and maturity data, the current underlying system model does not take these into account.

6.2.2 Catchability

Catchability by fleet was modelled separately for the fleets considered and fitted under an additivity assumption (WD25). CPUE data (Anon., 1995b) and the numbers-at-age from a cohort analysis were combined, and parameters were estimated under an assumption of a constant coefficient of variation (cv).

Estimates of catchability were used to generate CPUE indices for the assessment tuning fleets, and to provide estimates of F. The initial population numbers in the simulations were generated from the expected values of F and their pointwise variances.

6.2.3 Catch at age

Catch numbers-at-age were modelled for a variety of fleets using temporal and spatial variables (month, year, latitude, and longitude) and fitted under an additivity assumption. Parameter estimates were obtained using projection pursuit regression to allow for the possibility of nonlinearity in any independent variables. Vessel characteristics (length of vessel, and horse-power) and trip characteristics (days at sea, and number of hauls) were found not to be significant (WD23).

The estimated catch numbers-at-age were corrected to agree with those used in the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (Anon., 1995b).

Catch at age data were used to estimate the selection pattern of the commercial fleets in the simulations.

6.2.4 Recruitment

An underlying Ricker stock-recruitment relationship was assumed in order to estimate the recruits at age 1 in each simulation year. Parameters were estimated under an assumption of a constant coefficient of variation (cv) in the level of recruitment. Data from the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (Anon., 1995b) were used for the estimation of parameters together with associated standard errors.

6.3 Scenario Runs of the North Sea Plaice Model

The comparative merits of two particular management strategies, using control laws to set TACs, were investigated. Catch ratios between fleets were maintained at the levels recorded in 1993 to preclude "competitive exclusion" of fleets. One control law (CCL1) sets the TAC corresponding to the average of $F_{Status\ Quo}$ and F_{med}. If the SSB in the first projection year (recalculated at each simulation time step) is below MBAL (currently 300,000t for North Sea plaice), the TAC is set to correspond to the average of $(F_{Status\ Quo} + F_{med})/2$ and F_{MBAL}, where F_{MBAL} is the level of F that would take SSB back to the MBAL within one year.

A second control law (CCL2) sets a TAC for a three year period, the TAC in each year being the average of the projected TACs (calculated as $(F_{Status\ Quo} + F_{med})/2$) in the next three years. If in any of these years the projected SSB falls below the MBAL, the value of catch used in the estimation of the average is substituted by the minimum annual catch that would have ensured that SSB was at MBAL in all of the three projection years.

The assessment procedures used were XSA and a "perfect" assessment, where the N and F vectors from the true population are passed to the prediction program. This permits the benefits of improvements in the assessment methods to be investigated.

Misreporting was including by letting fishermen maintain their effort, and hence catches, above the TAC level if the implied effort was reduced in any year. The actual effort was set to the average of that implied by the TAC and that from the previous year. Catches used in the assessments were adjusted to accord with the TACs.

A total of 24 scenarios were run, each for 22 years (1994 - 2015), with a hundred simulations in each. The design is shown in Figures 6.3 a,b & c. Results for a selection of metrics are shown in the same figure. The figure illustrates the experimental design, as a block diagram, and shows summary statistics for all 24 scenarios for two metrics (average SSB and average yield), plus average recruitment, in the final ten years of the runs. Figures 6.3 d & e are summary plots for a range of metrics. The former shows how the robustness of the one annual control law (CCL1) can be tested by varying the underlying system assumptions (in this case by introducing a misreporting rule for fishermen). The latter shows how the performance of control laws (one annual and the other multiannual) might be compared when simulated on the same underlying system model.

The sample results are shown to illustrate the range of ways in which the vast array of outputs from scenario modelling work might be summarised and communicated. In practice, a large amount of diagnostic output is also looked at (WD 20). There is a need to find standard ways of presenting such diagnostic outputs to facilitate interpretation. There is a further need to identify metrics that represent management objectives. These are subjects that need further investigation.

Figure 6.3a Comparison of mean SSB over last ten years by scenario.

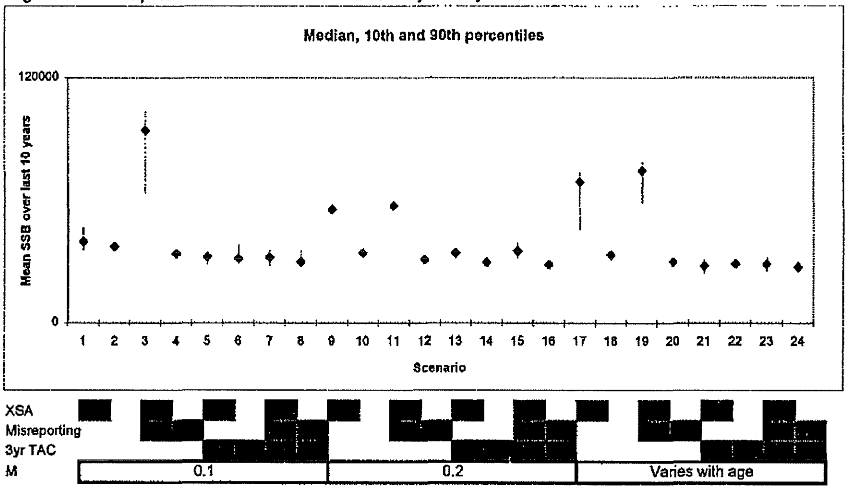


Figure 6.3b Comparison of mean recrutment over last ten years by scenario.

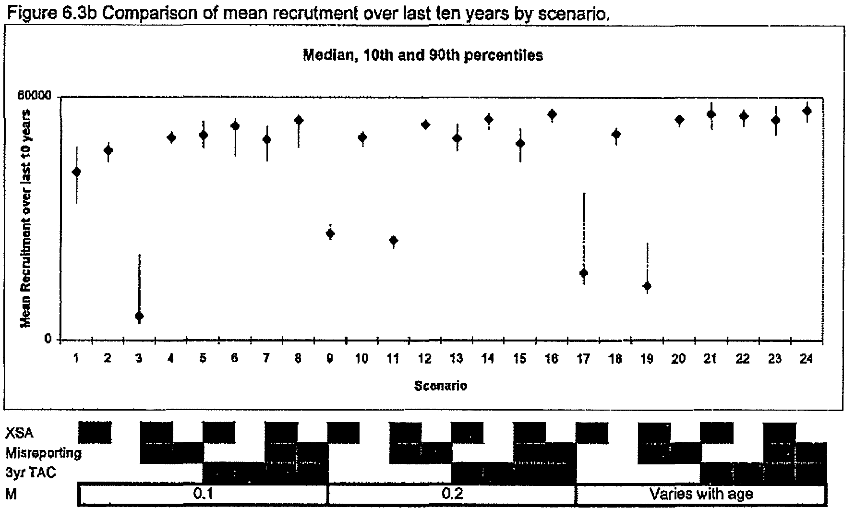


Figure 6.3c Comparison of mean yield over last ten years by scenario.

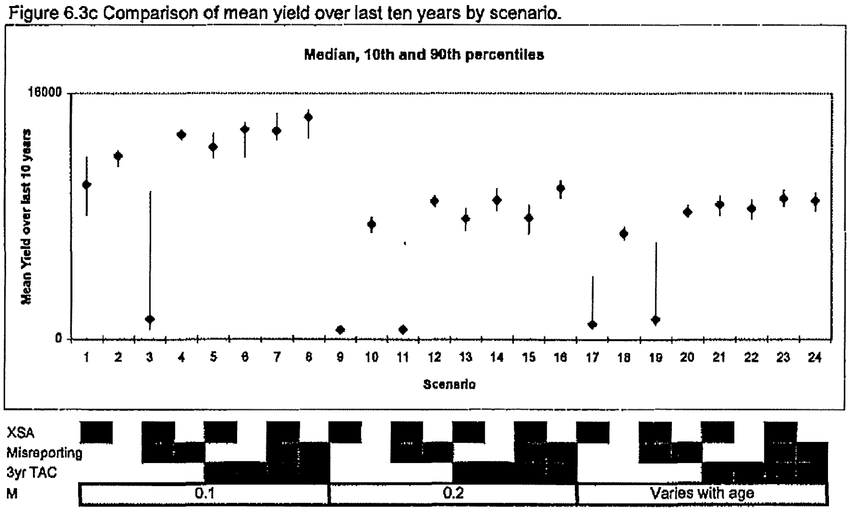


Figure 6.3d. Comparison of summary statistics for the two catch control laws, hilo lines show the 10th, 50th and 90th percentiles

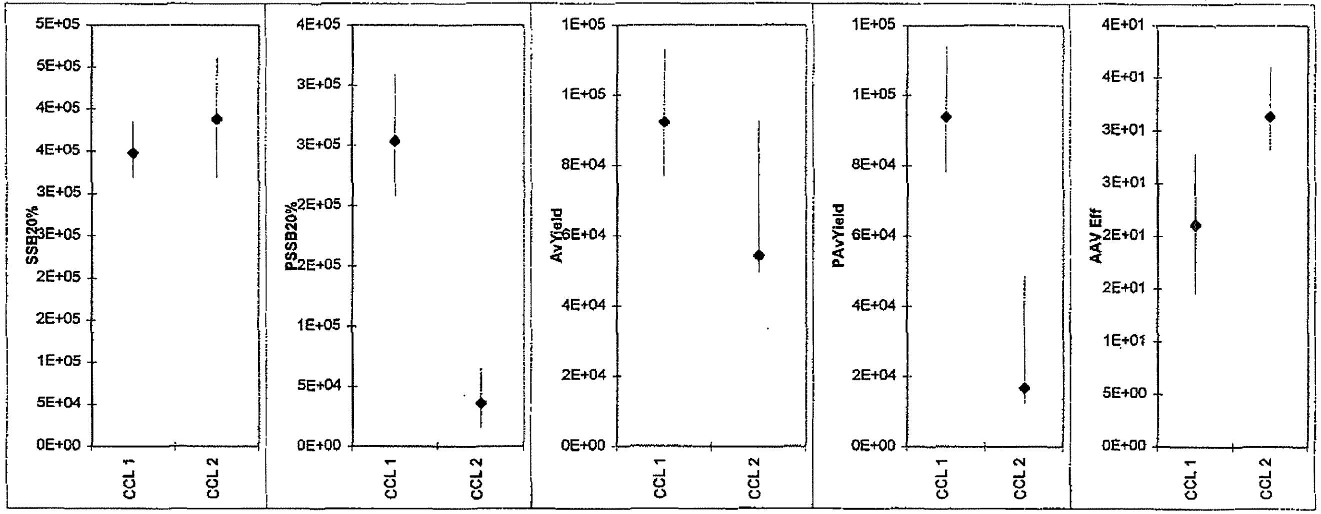
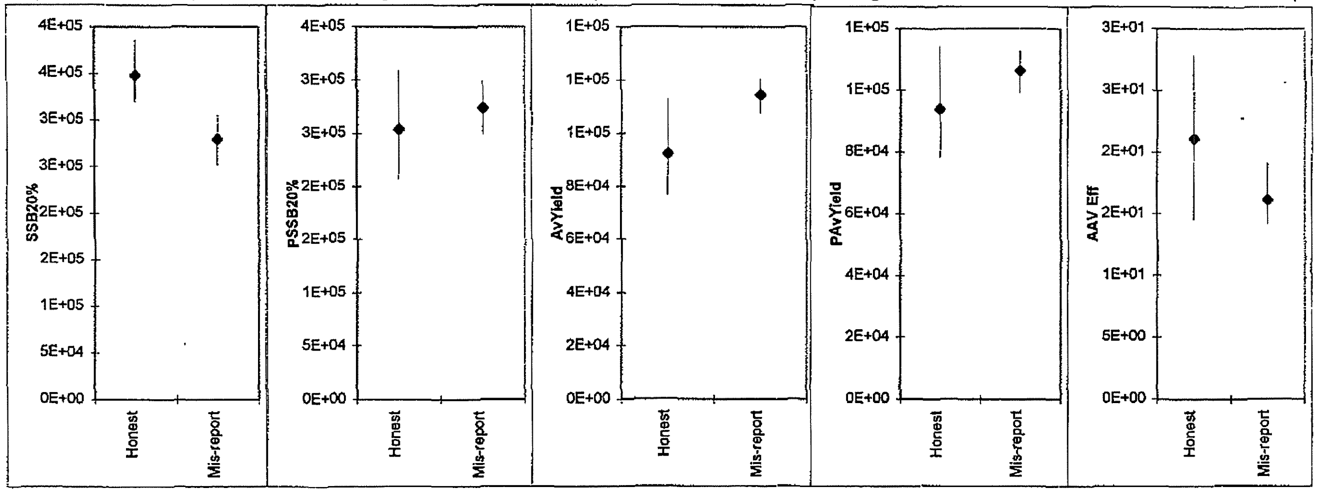


Figure 6.3e. Comparison of summary statistics for mis-reporting and no mis-reporting, hilo lines show the 10th, 50th and 90th p



SSB20%	Twentieth percentile of true SSB across years from each simulation
PSSB20%	Twentieth percentile of percieved SSB across years from each simulation
AvYield	Average true yield
PAvYield	Average perceived yield
AAVEff	Average annual variation in true Effort

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6.4 Additional Scenario Runs of the North Sea Plaice Model

6.4.1 Modelling of North Sea plaice stock and recruitment at the Working Group

Four main features of the stock-recruitment data (Figure 6.4.1) were considered relevant in terms of policy evaluation: (1) for the range of biomass observed, average recruitment tends to decline with increasing SSB; (2) there is no information about the relationship between stock and recruitment at low stock biomass and, in particular, about the level of SSB at which average recruitment would start to decline; (3) three exceptionally strong year classes (1965, 1983 and 1987) appear as extremes; (4) when these strong year classes are removed, the remaining ones show evidence of serial correlation.

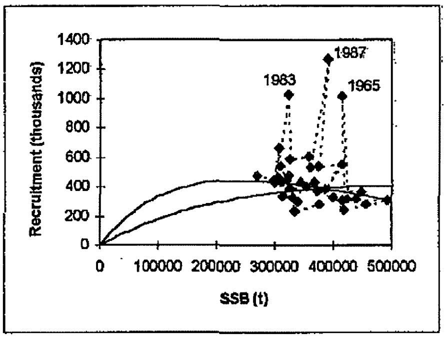


Figure 6.4.1. North Sea plaice stock-recruitment data and two Ricker functions fitted assuming serially autocorrelated log-normal errors. The steepest curve resulted from estimating the three parameters (a, b, and P); for the other, the slope at the origin (=exp(a)) was fixed at 2.15, the maximum R/SSB observed discounting the extreme year classes, and only b and P were estimated.

In WD10 change-point models were introduced and developed in an attempt to account for the three large year classes. During the meeting, it was decided that implementation of that model for prediction purposes was better considered in another forum. A simpler model was discussed and implemented which treats recruitment as a stochastic process with a short-term time dependency.

A Ricker stock-recruitment function was chosen. It was decided to treat the occurrence of extreme year classes separately in stock projections, and so year classes 1965, 1983 and 1987 were excluded from the data used to estimate stock-recruitment parameters. Such year classes may be due to exceptional environmental conditions, which render a simple relationship between stock and recruitment inappropriate. Temperature was suggested as a possible factor, but this was investigated at the meeting and shown to be an unlikely explanation. Moreover, since such year classes have a substantial impact on the stock in subsequent years, it may be more appropriate to model their probability of occurrence separately, rather than letting them appear as extremes in a simple probability distribution.

When the three large year classes were removed, there was evidence of autocorrelation of orders one and three in the time series of recruitments, and in the residuals of a Ricker function fitted to the data (in log-scale) assuming independent log-normal errors. Only first-order autocorrelations were included in the model. Non-stationarity in the time series of recruits was explored, but no firm conclusions were reached.

The model was parameterised as follows:

$$R_t = SSB_{t-1} e^{a - b \cdot SSB_{t-1} + \varepsilon_t} \qquad (1)$$

An autoregressive model of order one was assumed for the errors so that

$$\varepsilon_{t+1} = \rho \varepsilon_t + \upsilon_{t+1} \qquad (2)$$

where ρ is the correlation coefficient and $\{\upsilon_t\}$ are a series of independent normally distributed random variables with mean zero and variance σ^2.

Parameter estimates were obtained by maximum likelihood, ignoring the existence of measurement errors in both the SSBs and the recruitments. The extreme year classes were excluded from the analysis, and so the year classes following them (i.e. 1966, 1984 and 1988) were predicted from the ones preceding the extreme events. Variances for these observations were thus adjusted upwards to reflect the fact that a two-year-ahead prediction was used (i.e. $V[\varepsilon_{t+2}|\varepsilon_t] = \sigma^2(1+\rho^2)$). The variance for the first residual was set to $V[\varepsilon_1] = \sigma^2/(1-\rho)$.

When parameters a, b, ρ and σ^2 were estimated from the data, a very steep Ricker curve resulted. The spawning biomass associated with maximum recruitment was below the minimum observed SSB. Figure 6.4.2 shows the likelihood profile for the parameter corresponding to SSB for maximum recruitment (= $1/b$) and the minimum observed SSB (vertical line). The estimate of the slope at the origin (= exp(a)) was more than twice the maximum R/SSB ratio observed (with extreme year classes excluded). One-sided confidence limits obtained from the likelihood profile indicated a 0.95 probability that the slope at the origin exceeded the max(R/SSB). This case illustrates the limitations of rigid stock-recruitment functions for quantifying the uncertainty about key features of the stock-recruitment relationship, such as the slope at the origin. In the case of the Ricker curve, a negative slope between R and SSB contains information about the slope at the origin even if no data exist for low SSB levels. Thus, estimates of parameter uncertainty based on the model structure being correct may seriously underestimate the true uncertainty about the stock-recruitment relationship for SSB levels outside the historical range.

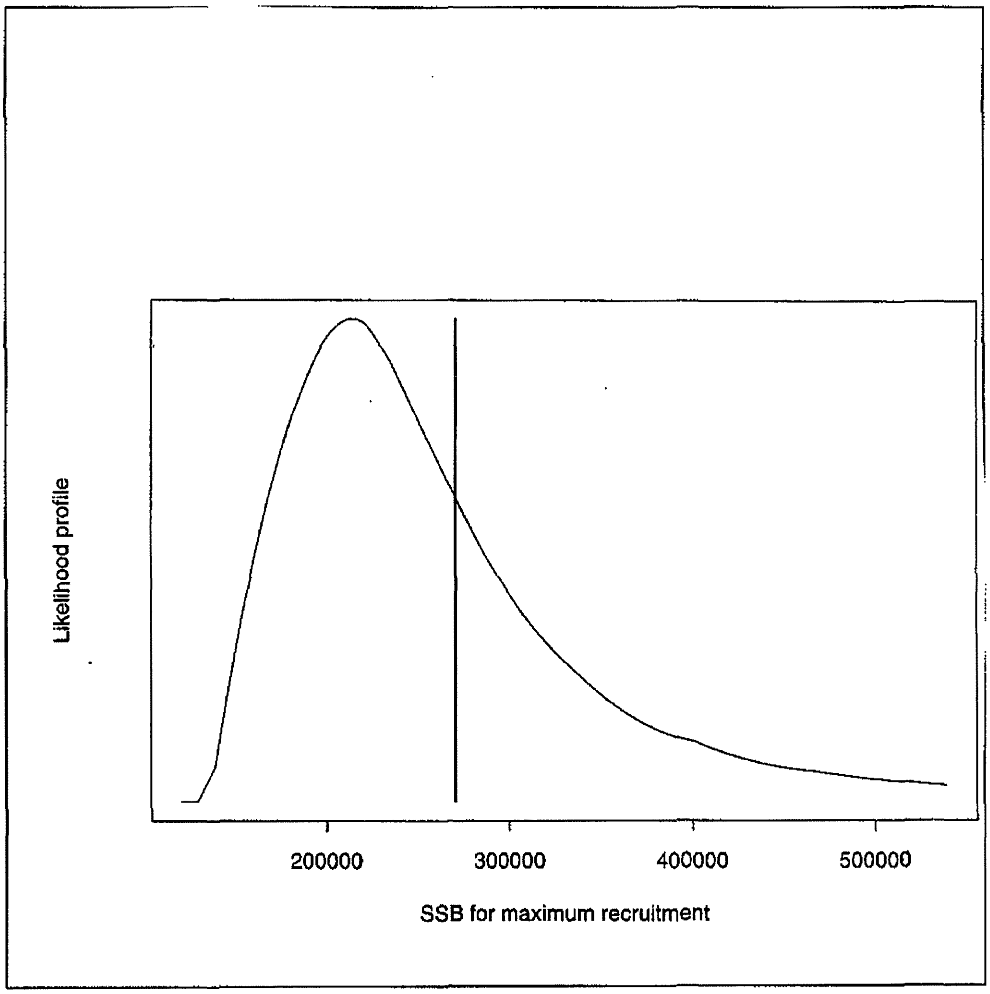


Figure 6.4.2. Likelihood profile for the SSB associated with maximum recruitment (=1/b) and minimum observed SSB (vertical line).

Since assumptions about the form of the stock-recruitment curve at low stock levels have important implications for policy evaluation, it was decided to constrain the curve in this region rather than to estimate it from the existing data. This was achieved by assuming a slope at the origin equal to the highest R/SSB ratio observed, discounting the extreme year classes (i.e. exp(a) was set to 2.15). An alternative, less conservative approach would have been to bound the level of SSB that produces maximum recruitment so that it could not have been lower than the minimum observed SSB. The functions fitted to the data are shown in Figure 6.4.1. Parameter estimates, and their standard errors and correlations were b = 1.9531e-06 (s.d.= 3.0374e-08), ρ = 0.67 (s.d.=0.1232), corr(b, ρ) = 0.19. The covariance matrix of the parameter estimates was approximated from the inverse of the Hessian matrix. It was assumed that extreme year classes of a magnitude comparable to those observed would occur with constant probability equal to the fraction of year classes that were extreme (= 3/37).

The simulation algorithm involves the following steps:

1) Set a=ln(2.15) and draw b and ρ from a bi-variate normal distribution with means and covariances as given above.
2) Compute $\hat{\sigma}^2|a,b,\rho$, i.e. the estimate of the variance of υ conditional on the parameter values drawn. To do this, first compute the residuals (in log-scale) for the a and b values selected and then compute
$$\hat{\sigma}^2 = \sum \frac{(\varepsilon_t - \rho\varepsilon_{t-1})^2}{n-2}$$
3) Compute $\varepsilon_{1993}|a,b,\rho$.
4) Obtain ε_{t+1} from equation (2) by drawing υ_{t+1} from a normal distribution with mean zero and variance equal to $\hat{\sigma}^2|a,b,\rho$.
5) Compute R_{+1}.
6) Repeat steps 4) and 5) into the future.
7) For each year t draw a random value from a Bernoulli distribution with probability of drawing a value of one equal to 3/37; if the value equals one, then replace R_t generated from the stock-recruitment model by a value selected at random from the three extreme year classes.

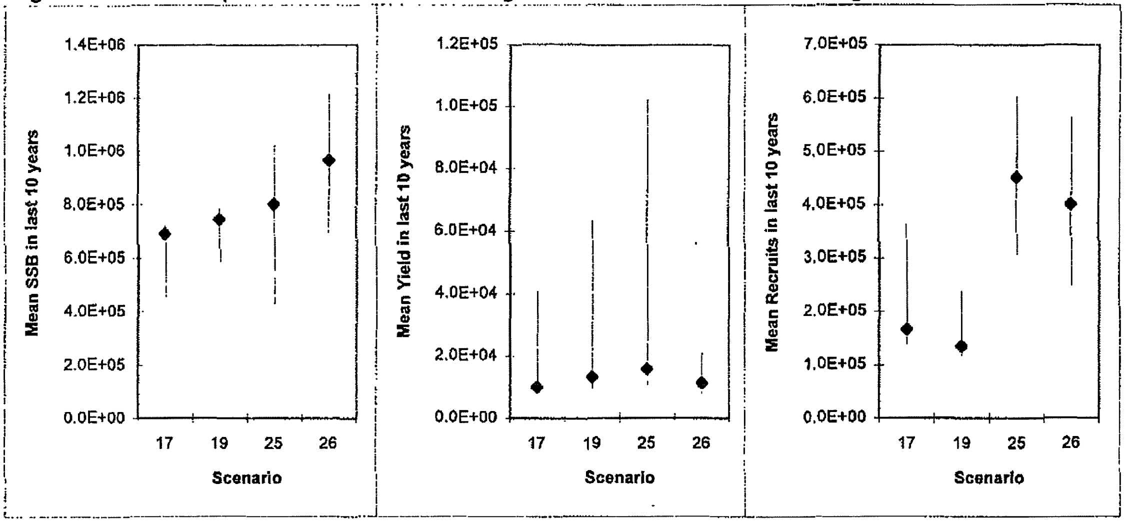
If should be noted that step 7) allows for the possibility that an extreme recruitment value occurs at low or even zero SSB. This will need to be modified if the formulation is used in further scenario work.

6.4.2 Scenario definitions and outputs

Four scenario runs were made which utilised the stock-recruitment formulation described above (Section 6.4.1). The first two were intended to be used in a comparison with standard medium-term projections. They both assumed that effort was held constant at the 1993 level. Otherwise, they were the same as scenarios 17 and 19, as defined in Figure 6.3a-c. Output trajectories of perceived SSB and projected yield are shown in Fig. 6.6.4-6.6.11, where they are compared with the medium-term projections. They differ from the medium-term projections in that the underlying system model assumes an age structured mortality schedule, with higher values on early ages. Consequently, the SSB levels are lower. The difference in the mortality schedule also led to a constant bias in the perceived F_{med}, as the XSA assumption was of a constant mortality (with lower values on the younger ages).

Results from the scenarios using CCL1 are shown in Figure 6.4.3 in the form of comparison plots for the average actual SSBs, yields and recruitments over the final ten years of the runs. The plots clearly show that the reformulated recruitment has a major effect on the median SSB and recruitment levels, but little effect on the actual yield. The distributions on these quantities, however, generally reflect the greater recruitment variability in the reformulated recruitment function. Fig. 6.4.4 shows the actual recruitment at age 1 used in scenarios 17 and 25. These clearly show the effect of the newly formulated stock-recruitment relationship. Comparison plots of this kind could be used to investigate the robustness of one management procedure (in this case an XSA assessment plus CCL1) to variations in the underlying system model assumptions (in this case both misreporting and recruitment formulation). The robustness can only be gauged with respect to particular management objectives.

Figure 6.4.3 A comparison of scenarios designed to test the effect of altering the stock recruitment relationship.



Scenario	Mis-reporting	Stock recruitment
17	Yes	Ricker
19	No	Ricker
25	Yes	Constrained Ricker with bootstrapped excedences
26	No	Constrained Ricker with bootstrapped excedences

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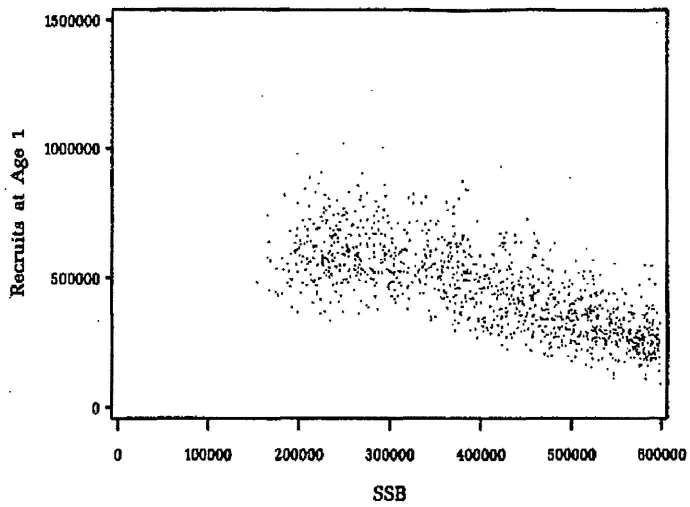


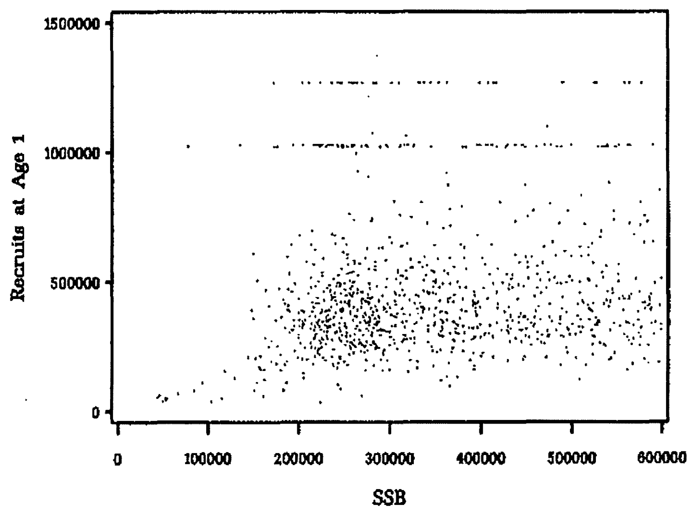


Figure 6.4.4. Simulated recruitment vs SSB from two simulations.

6.5 Future Work

The system models developed so far are clearly incomplete and approximate only some of the many features of the North Sea plaice (or flatfish) fishery. Immediate aspects that need to be investigated are: multispecies interactions (biological and technical), stock structure, migration, more elaborate stock-recruitment formulations, better descriptions of the major fishing fleets and, perhaps, economic factors. Most importantly, the system models developed need to be validated against data. One way of achieving this is to start simulations at some period in the past and to ensure that model outputs are consistent with observations (data). In this way, it will also be possible to start simulations in the current year, with the underlying population structures representative not of the currently perceived structures, but rather of the "true" ones.

Work so far can be identified with partial fulfilment of steps 3 and 5 of a CFE, as outlined in Section 3. To be consistent with that outline, management objectives and viable management actions need to be identified and steps 2 and 3 need to be fully undertaken so that step 5, essentially "uncertainty analysis", can be completed.

The modelling and programming work described in this section and WD 19 has demonstrated that it is feasible to proceed with the system modelling approach with full feedback control for North Sea plaice, and possibly for other stocks and fisheries. Now that the approach is developed and many prototype system models exist, it is necessary to involve a wider range of expertise, primarily biological, and to work through steps 2 and 3 of the CFE as outlined in Section 3. Only then can appropriate system models be built and the full range of uncertainty analyses be conducted to evaluate the likely performance of various management procedures.

A fractional factorial design (see e.g. Box *et al*, 1978) can be used to set up a balanced experiment to optimise the information content of scenario runs, and allow the analysis of the output data to test hypotheses by ANOVA. This was done for the simple, 24 scenario example in Section 6.3 and it is intended to use such an approach for future work.

6.6 Medium-projections for North Sea Plaice

6.6.1 Introduction

Annual assessments of North Sea plaice usually include a medium-term (10 year) projection. These projections use the VPA output as the basis of the calculations with an attempt to incorporate uncertainty. The principal reason for these calculations is to see the expected stock trajectory if the present exploitation level is maintained. Clearly a likely problem of such a minimalist approach is that the perception of the stock state and dynamics may be misleading. The development of more complex simulation models of whole systems offers a means of investigating whether the simple projection models are adequate for the purpose. At the meeting, three medium-term projection methods were considered in this context.

Some of the simulations involved a fishing mortality target such as *status quo* F, which clearly does not satisfy the criteria set out in Sections 3-4.

6.6.2 Medium-term projection methods

6.6.2.1 Variance projection (WGFRAN3)

The standard North Sea plaice projection is based on the age structured output from XSA from the most recent year. These input values or "parameters" are used to project the population forward as a standard book-keeping exercise. Given estimates of the covariance matrix of the parameters it is possible to calculate the variance of the projected yield and biomass using standard methods (e.g. Seber, 1973). It is also possible to evaluate the contribution each parameter makes to the variance in the output values. No stock recruitment relationship is used. This is described more fully in Prager and MacCall (1988) and Cook (1993). In the example run here it has been assumed that the covariances are negligible.

6.6.2.2 Stochastic recruitment (WGMTERM)

Anon (1994b) describes the current method used by the North Sea Demersal Working Group for performing medium-term projections. As in the previous method, the projection is based on an age structured book-keeping calculation. Variability is included only in recruitment and the initial stock size. All other input values are treated as constant.

Stock and recruitment is modelled using a standard stock-recruitment function fitted to the estimated values from the assessment. Variability is introduced by bootstrapping the residuals obtained after fitting the model.

6.6.2.3 Simple spreadsheet model

The Northern Pelagic and North Western Working Groups use simple spreadsheet models for their medium-term projections. These models are forward projection models similar to WGTERM, but they allow for the inclusion of an arbitrary harvest control law.

These models are quite useful in terms of investigating the short-, medium- and long-term properties of projections.

The present implementation of the model for North Sea plaice includes random variation around a Ricker stock and recruitment curve and estimation errors in the initial stock size as in other simulations in this report. Errors in future assessments are simulated by implementing any HCL through a 20% CV on the fishing mortality which is assumed by the HCL.

This procedure was used to consider the possible effects on yield and SSB from using a number of different HCLs.

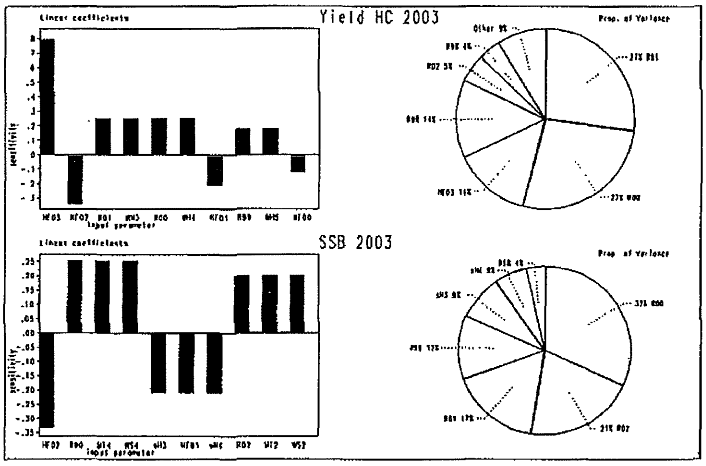
6.6.3 Example projections

Projections for North Sea plaice were run using the three methods with 1994 as the base year. This uses the assessment performed by the North Sea Demersal Working Group in 1995 (Anon. 1996) to provide the input data. Table 6.6.1 shows the input data used. In the case of WGTERM, only the CVs for the starting populations are used.

The stock-recruitment model used in WGMTERM was a fitted Beverton-Holt curve with autocorrelated errors [$R = 5.95 * R/(1 + S/75.92)$]. The same parameters but without the autocorrelations were used in the spreadsheet model.

Projections for the first two models were run assuming *status quo* fishing mortality for a period of ten years. Figure 6.6.1 shows the linear sensitivity coefficients and partial variances associated with forecast catch and SSB at the end of the 10 year period. The linear coefficients indicate the structural dependence of the forecast value on the input data (see Table 6.6.1 for interpretation of labels). Only the values for the ten largest sensitivities are shown. These coefficients can be compared to the contribution each parameter makes to the variance in the forecast value. These pie diagrams in Figure 6.6.1 show that variability in recruitment dominates the total variance and suggest that for this forecast the variability in most of the input values can be ignored.

Figure 6.6.1 Plaice, North Sea. Sensitivity analysis of short term forecast.



Figures 6.6.4-11 show the expected distribution of yield and SSB over the projection period. Both the medium-term and variance projections show an expected decline in these quantities with very similar spread of expected trajectories. It appears that the stock recruitment function in this analysis has little effect since the variance projection method assumes stationary mean recruitment. Other trajectories in these figures are described in Section 6.4.2.

Fig. 6.6.2. Medium term projection using variance projection method. Lines show 5,25,50, 75 and 95 percentiles. Line joining points shows the trajectory estimated in the 1995 assessment.

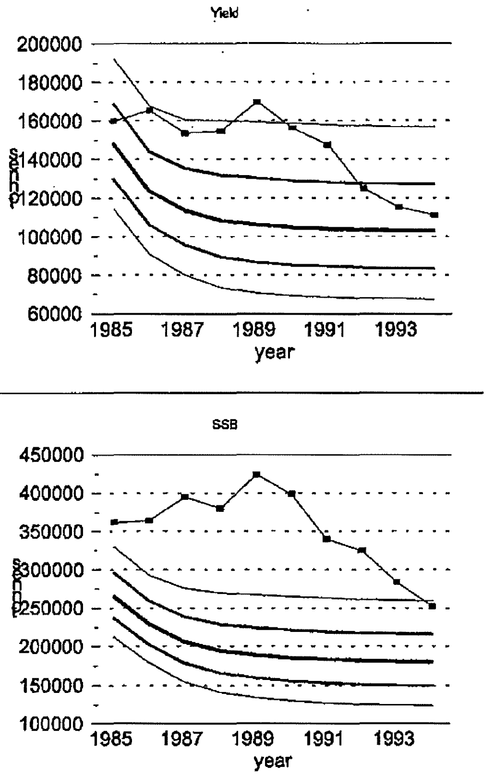
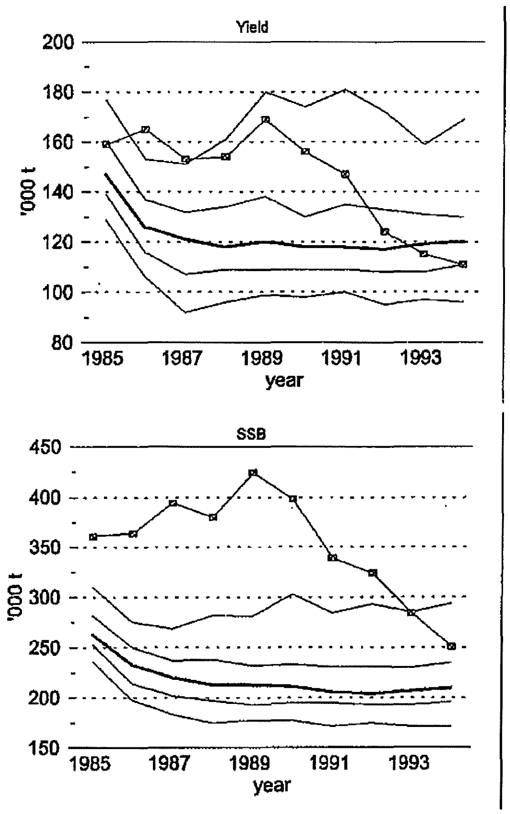


Figure 6.6.3 Medium-term projection using WGMTERM. Lines show 5,25,50,75,95 percentiles. Line joining points shows the trajectory estimated in the 1995 assessment.



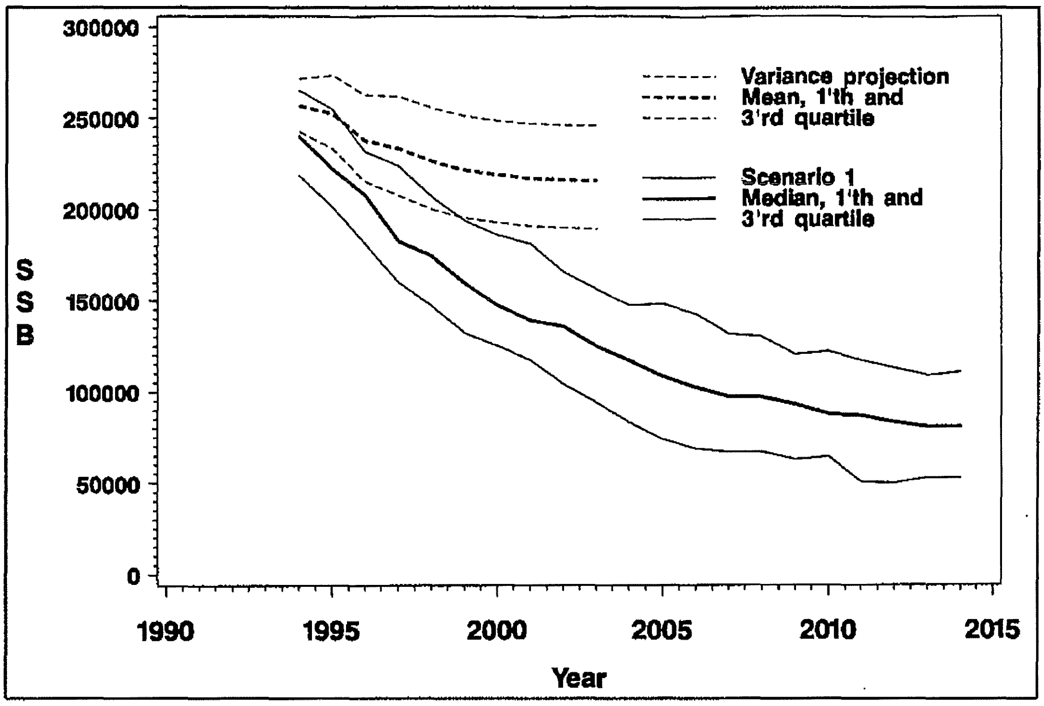


Figure 6.6.4 NORTH SEA PLAICE: Medium-term predictions ("status quo" F) of SSB from Scenario 1 and from the variance projection method.

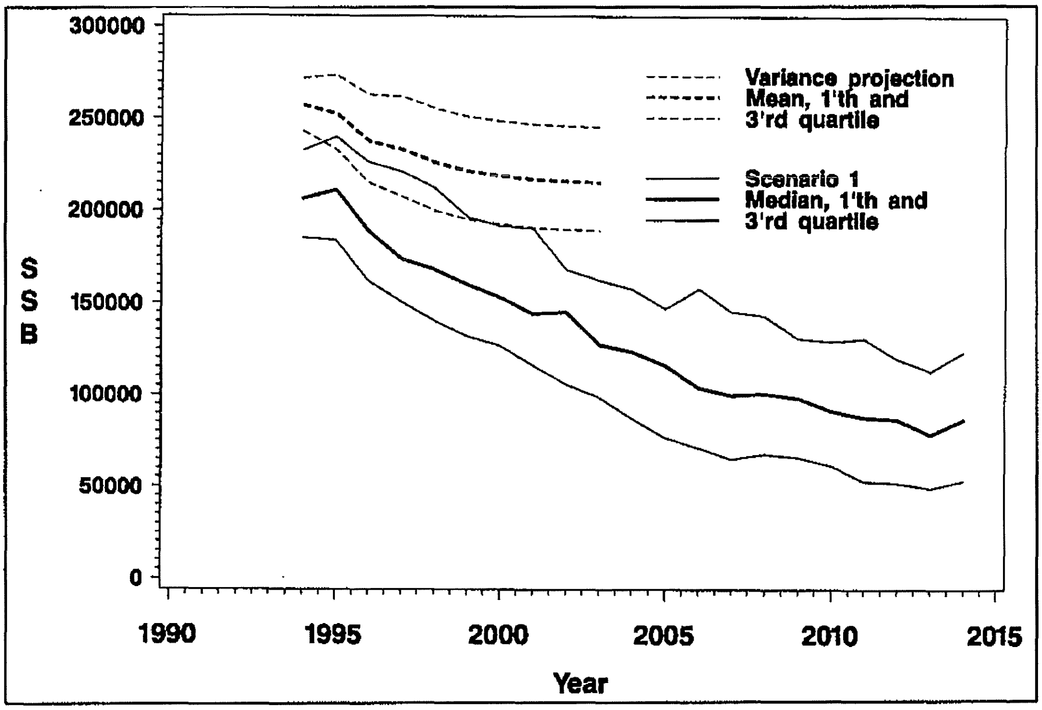


Figure 6.6.5 NORTH SEA PLAICE : Medium-term predictions ("status quo" F) of perceived SSB from Scenario 1 and SSB from the variance projection method.

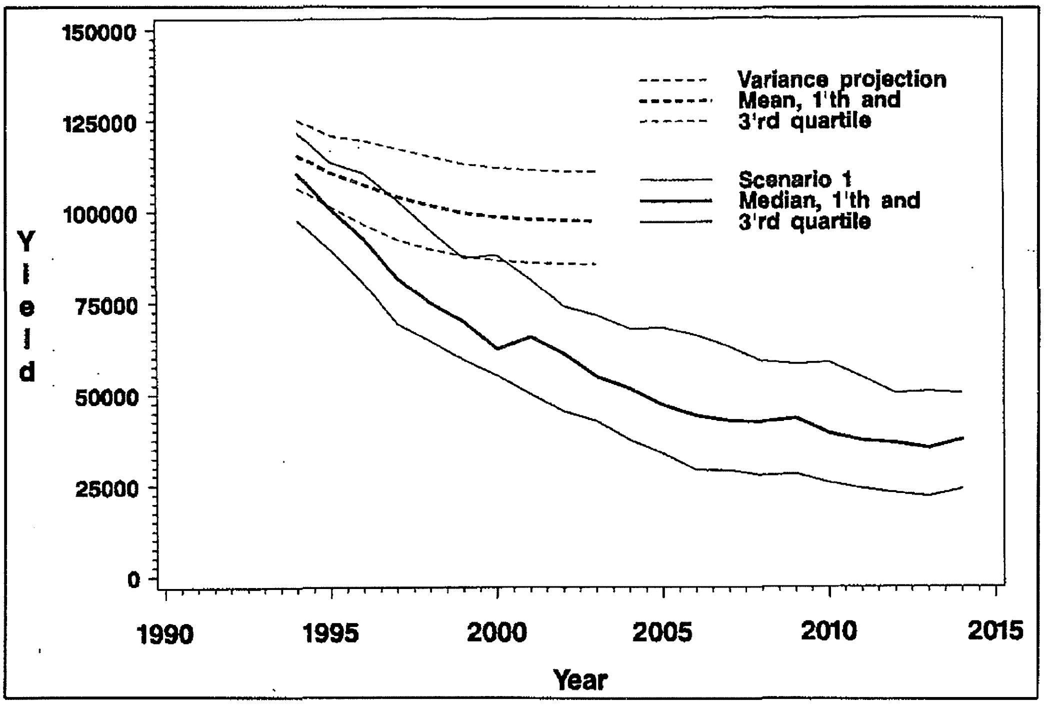


Figure 6.6.6 NORTH SEA PLAICE: Medium-term predictions ("status quo" F) of Yield from Scenario 1 and the variance projection method.

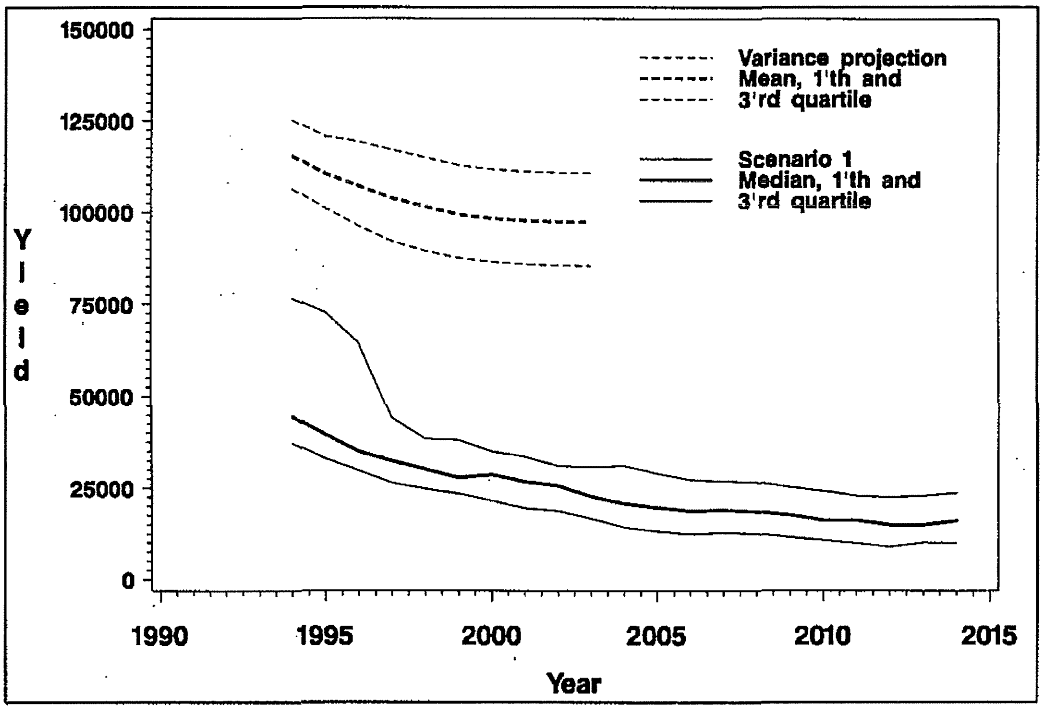


Figure 6.6.7 NORTH SEA PLAICE: Medium-term predictions ("status quo" F) of perceived Yield from Scenario 1 and Yield from the variance projection method.

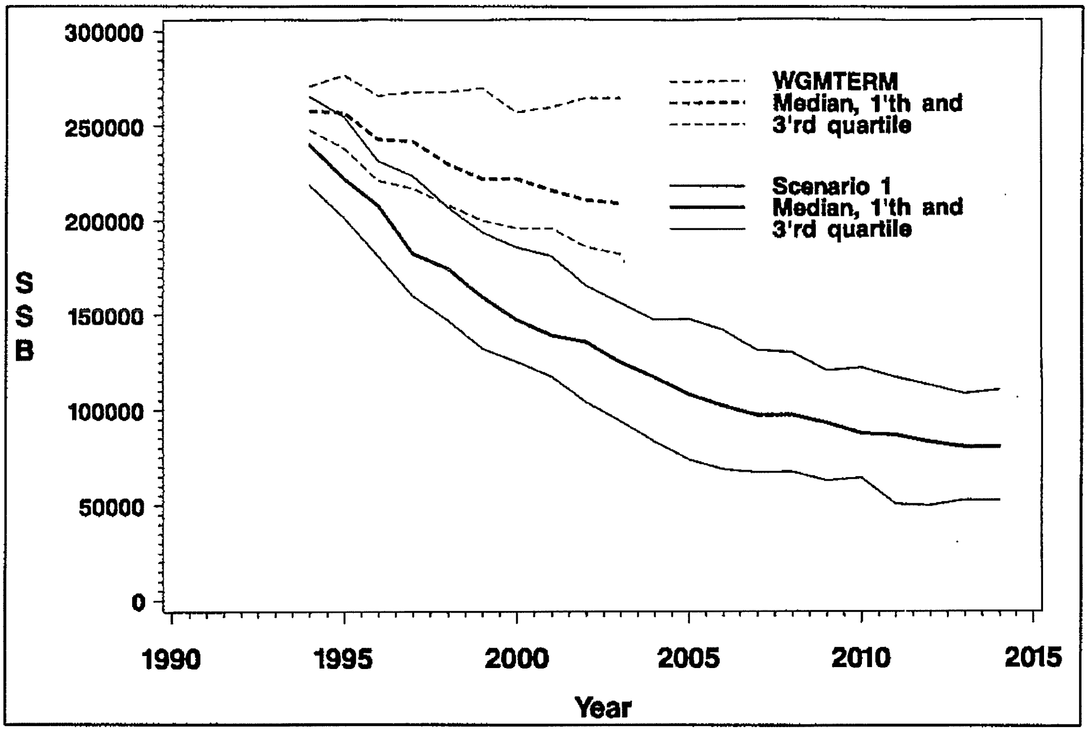


Figure 6.6.8 NORTH SEA PLAICE: Medium-term predictions ("status quo" F) of SSB from Scenario 1 and from the WGMTERM simulation.

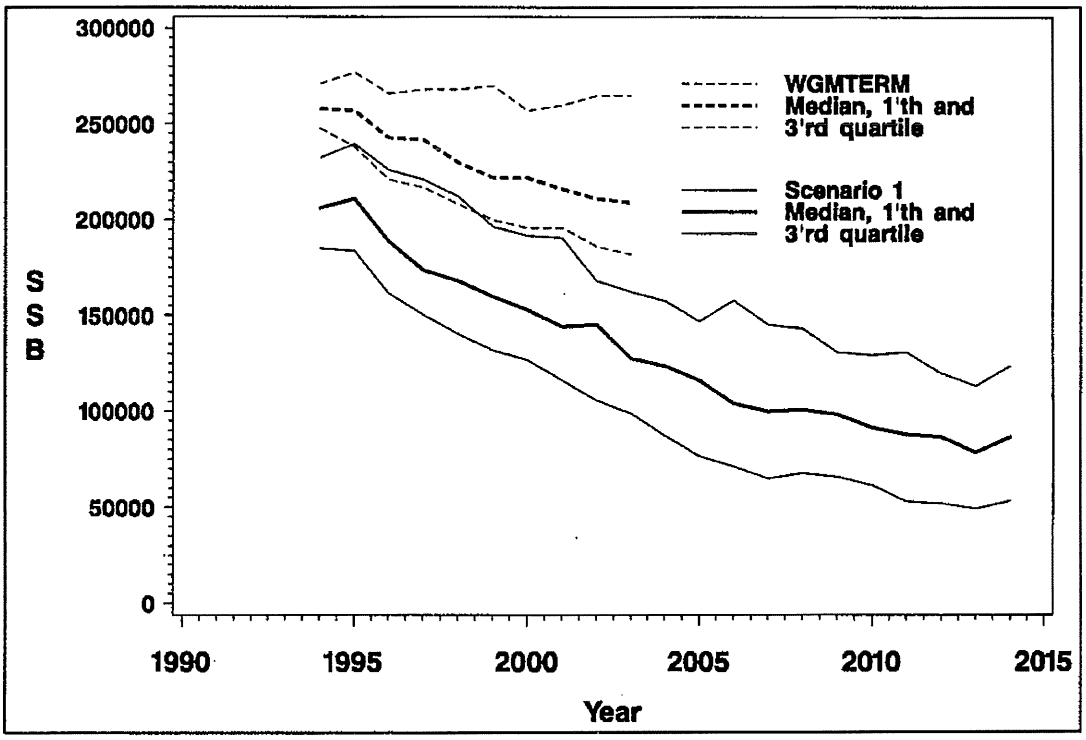


Figure 6.6.9 NORTH SEA PLAICE : Medium-term predictions ("status quo" F) of perceived SSB from Scenario 1 and SSB from the WGMTERM simulation.

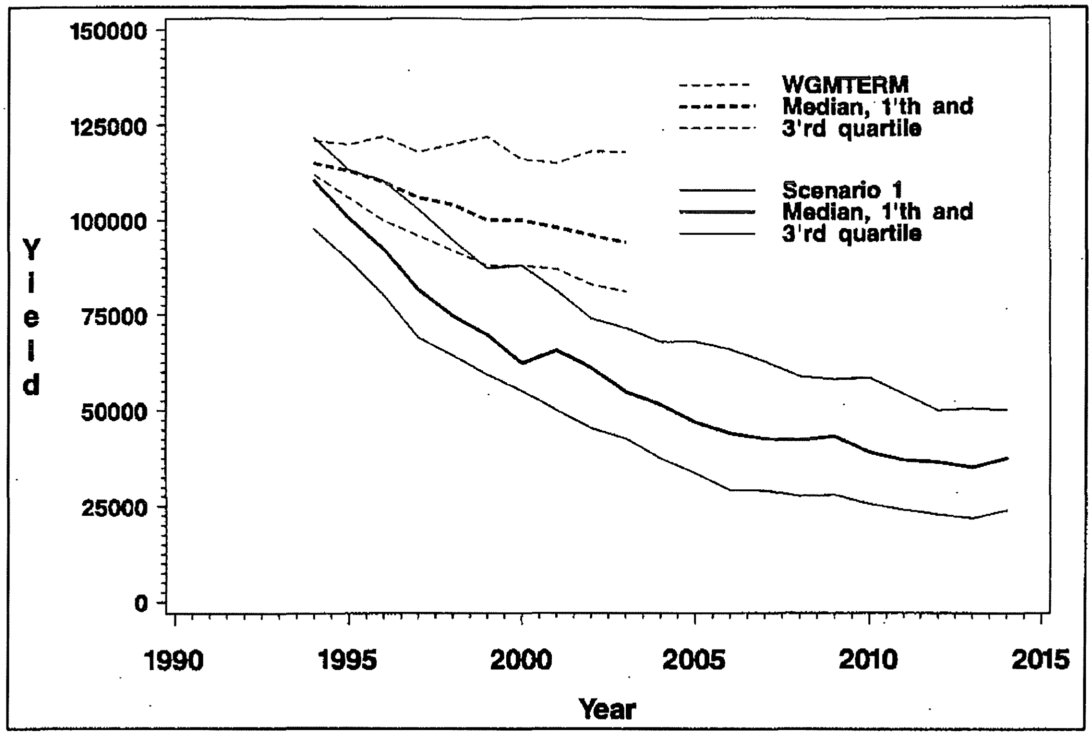


Figure 6.6.10 NORTH SEA PLAICE: Medium-term predictions ("status quo" F) of Yield from Scenario 1 and the WGMTERM simulation.

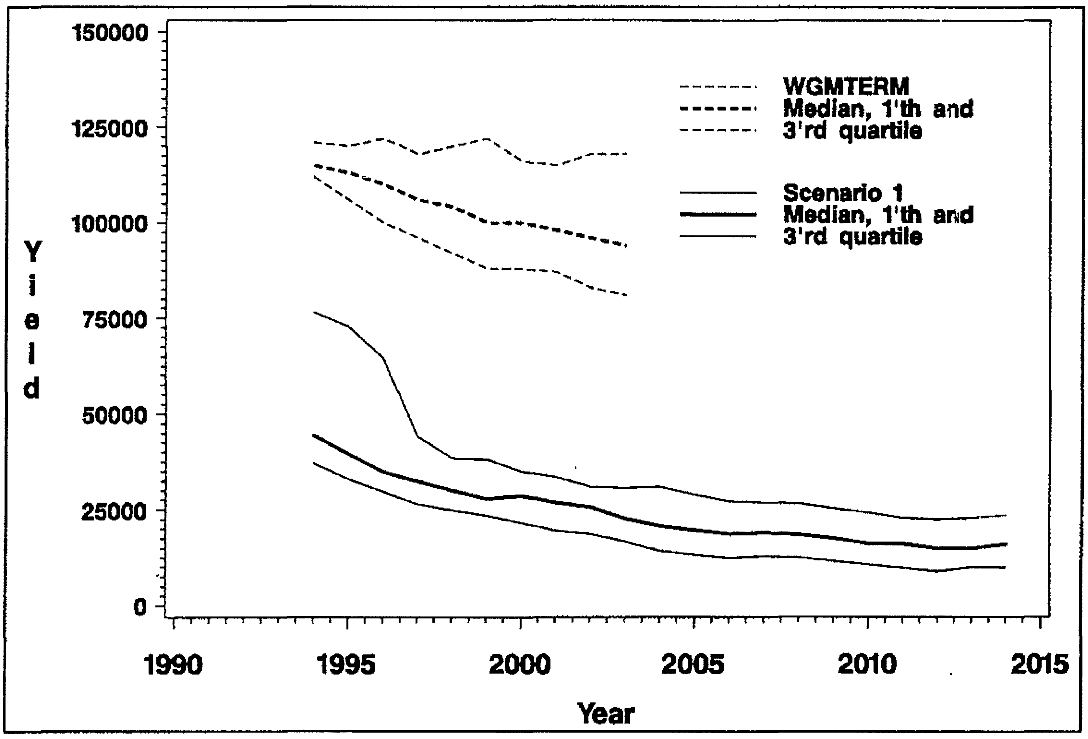


Figure 6.6.11 NORTH SEA PLAICE: Medium-term predictions ("status quo" F) of perceived Yield from Scenario 1 and Yield from the WGMTERM simulation.

6.6.4 Comparisons of HCLs

The spreadsheet model was used to consider various harvest control laws. These included combinations of fishing mortality and using an MBAL to close the fishery. In particular, the *status quo* fishing mortality was used along with MBAL=300 thousand tonnes. Alternative HCLs include the use of lower target fishing mortalities and the use of an intermediate strategy to go from the closed fishery to the target level.

The data on which these analyses are based are given along with approximate equilibrium curves in Figures 6.6.12-13. It is seen from these figures that considerable care must be taken in the estimation of the stock-recruitment function, since there are indications that the resulting equilibrium yield curve is somewhat too low in relation to the observed catches.

The equilibrium curves and CCL curves in the figure are simply based on using the final year from a 30-year forward projection to compute an approximate equilibrium population and associated catches if a HCL is applied to that population.

Examples of these strategies in relation to the equilibrium yield curve are given in Figure 6.6.14.

Although the nature of the annual advice given for this stock is somewhat similar to these harvesting scenarios, the results of this exercise can merely be used as indications of the expected frequency of the stock dropping below MBAL. This is seen in Figures 6.6.15-20.

It is seen that when the target F is as high as the *status quo* fishing mortality, one would expect the stock to drop below MBAL repeatedly. If the intermediate slope linking the target fishing mortality to closure is too low, then the target fishing mortality is not reached and the stock remains underutilized.

These results are summarized in the form of probability levels in Table 6.6.2.

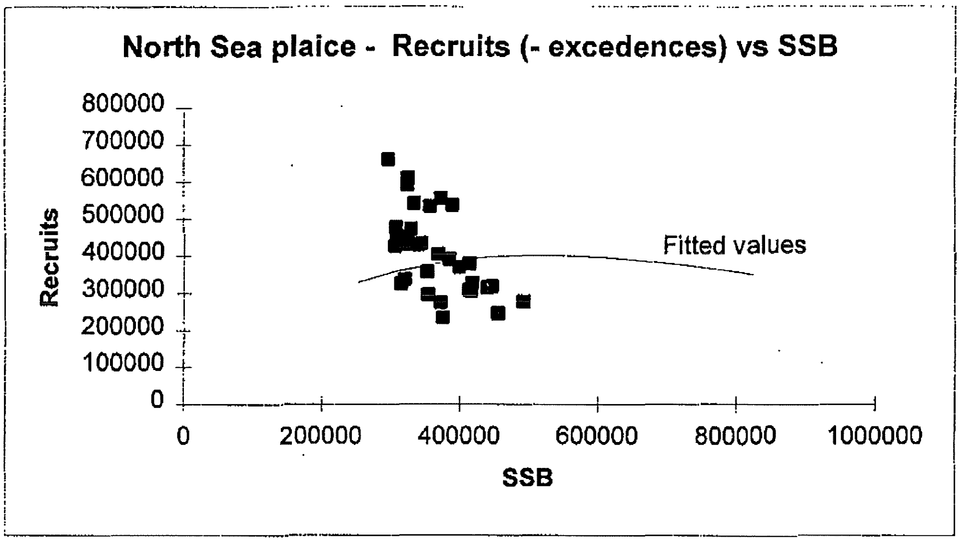


Figure 6.6.12 The spawning stock and recruitment relationship for North Sea Plaice used within the spreadsheet model and the actual data points.

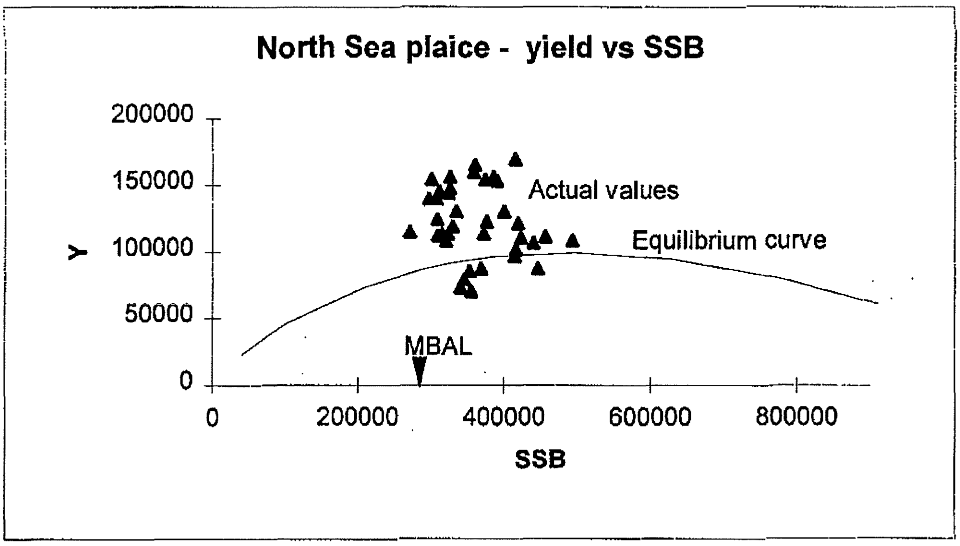


Figure 6.6.13 The equilibrium yield - SSB curve generated by the spreadsheet model, using the fitted Ricker curve and the actual data points.

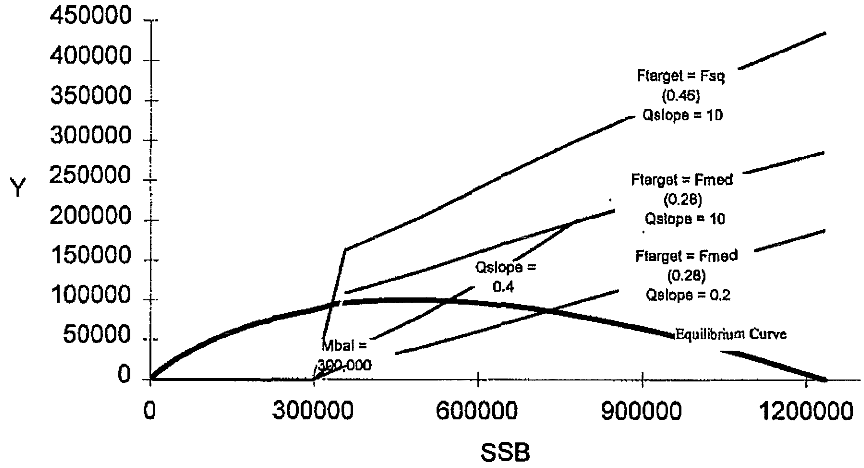


Figure 6.6.14 Example harvest control law strategies used within the spreadsheet projection model.

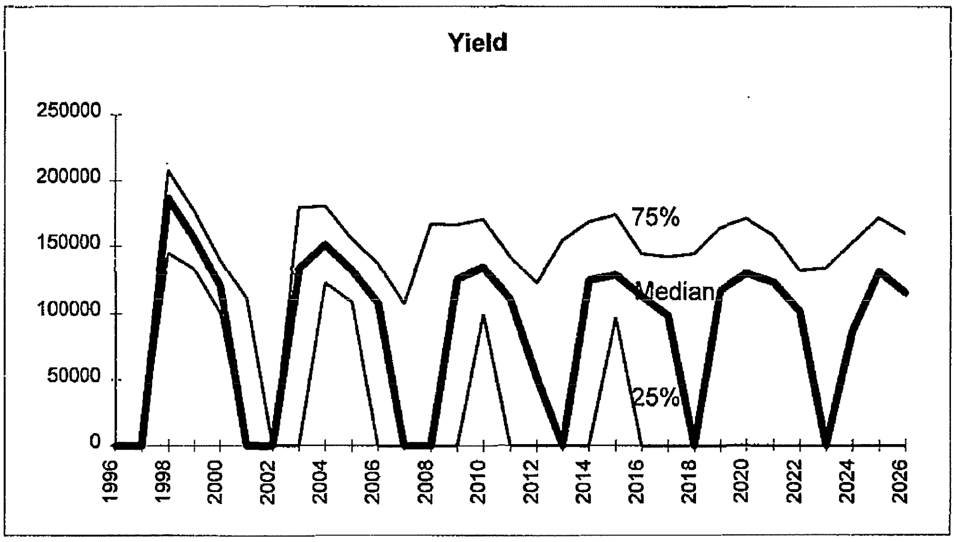


Figure 6.6.15 The yield from a spreadsheet model projection for North Sea plaice with the harvest control law $F_{target} = F_{status\ quo}$, MBAL = 300,000 t, Slope = 100, 100 simulations.

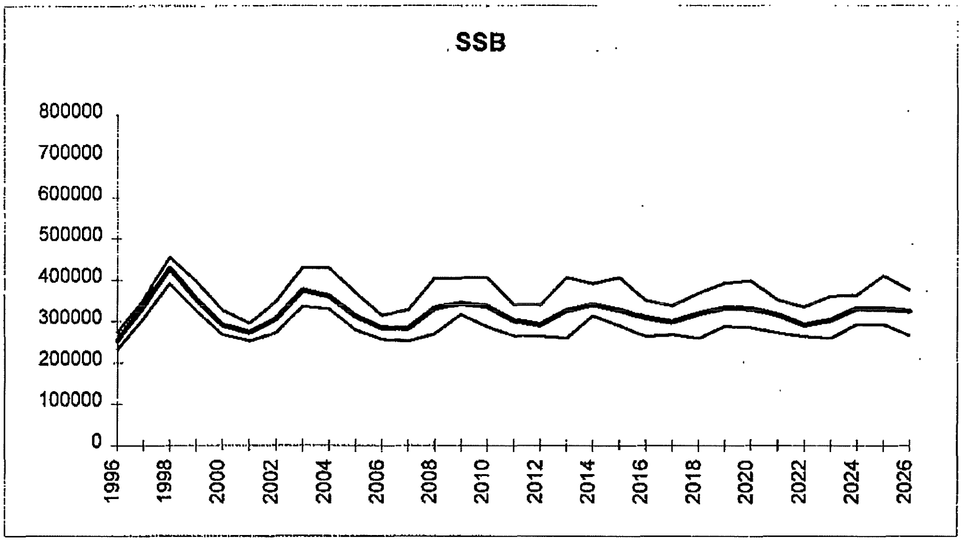


Figure 6.6.16 The SSB from a spreadsheet model projection for North Sea plaice with the harvest control law $F_{target} = F_{status\ quo}$, MBAL = 300,000 t, Slope = 100, 100 simulations.

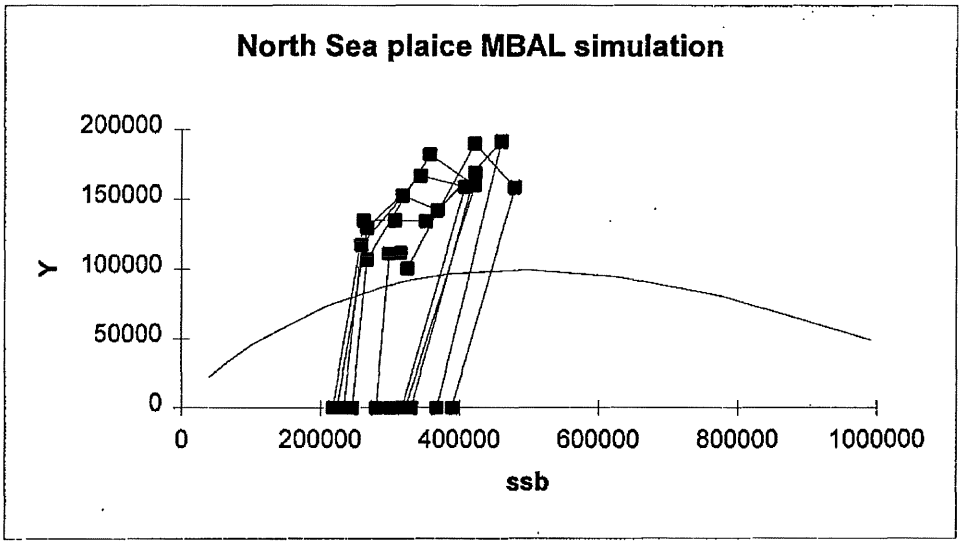


Figure 6.6.17 The yield - SSB trajectory of a projection from the spreadsheet model using the harvest control law. MBAL = 300,000 t, F = $F_{status\ quo}$, Slope = 100.

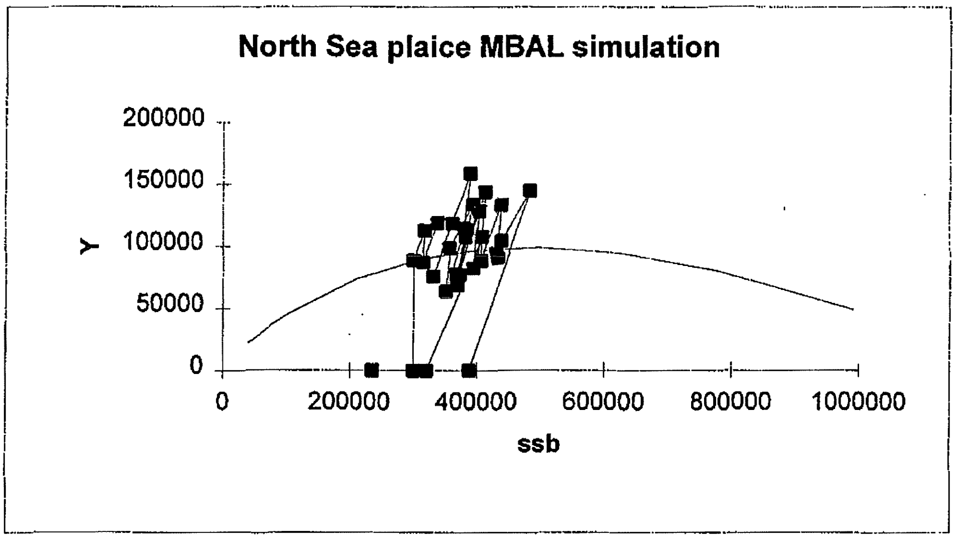


Figure 6.6.18 The yield - SSB trajectory of a projection from the spreadsheet model using the harvest control law MBAL = 300,000 t, F = F_{med}, Slope = 100.

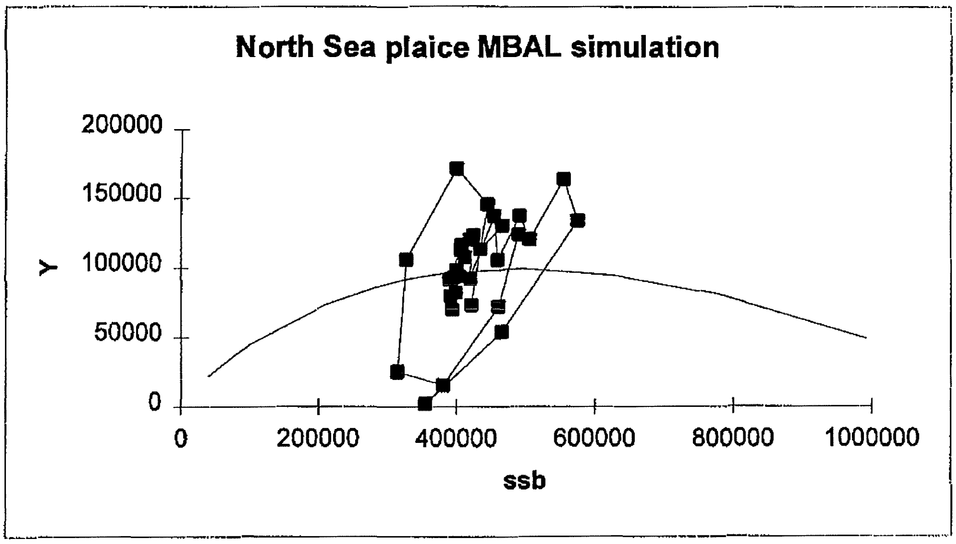


Figure 6.6.19 The yield - SSB trajectory of a projection from the spreadsheet model using the harvest control law MBAL = 300,000 t, F = F_{med}, Slope = 1.0.

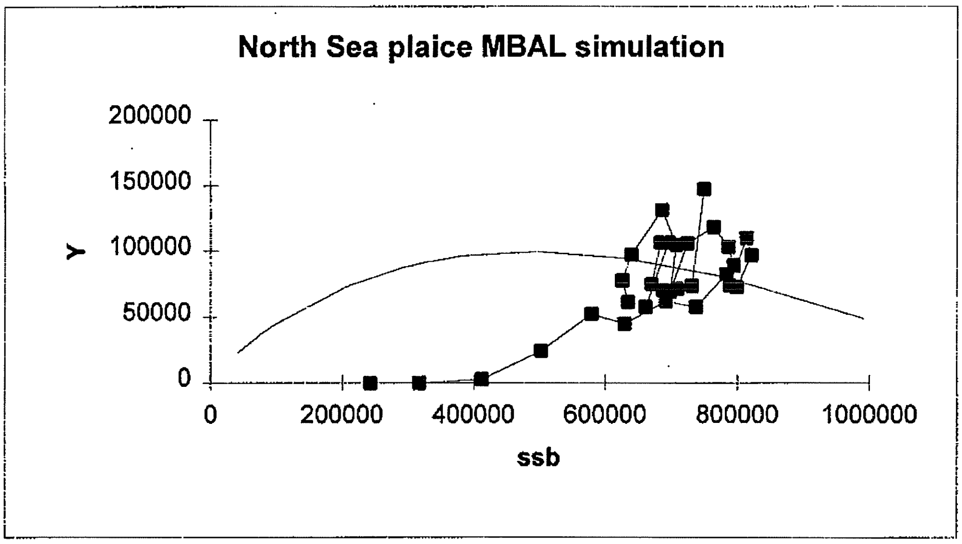


Figure 6.6.20. The yield - SSB trajectory of a projection from the spreadsheet model using the harvest control law MBAL = 300,000 t, F = F_{med}, Slope = 0.2.

6.6.5 Retrospective example

The examples reported above suggest that different assumptions about variablity in the projection lead to similar conclusions about the stock trajectory for the same structural model. However, this gives no indication as to whether the projection is close to a description of the real world. A retrospective analysis was run to see if a projection performed on the basis of an assessment performed in 1984 would be consistent with the stock trajectory estimated from the most recent stock assessment.

A standard ICES assessment was performed using XSA on the plaice catch at age data up to and including 1984. The estimated values were used in the same way as in Sections 6.6.2.1 and 6.6.2.2 to perform a forward projection up to 1994 using the two methods.

The results are plotted in Figures 6.6.2 and 6.6.3 with the converged VPA values for SSB and estimated catch from the 1984 assessment shown. Although the observed catch conforms to the predicted catch under the assumption of *status quo* fishing mortality, the observed SSB trajectory is quite different from that expected. Further, as seen in Figure 6.6.2, the initial stock size is assigned a CV which does not allow the bounds to include the back-calculated values. The discrepancy is due to:

a) a low estimate of the stock size and a high estimated fishing mortality rate in 1984 compared to the converged assessment,

b) the occurrence of two very large year classes which would not be predicted on the basis of the frequency of observed large year classes up to 1984 and

c) the assigned CV for the starting year not being large enough.

This lack of consistency between the expected trajectory and estimated stock trajectory illustrates the problems of making accurate forward projections and the impossibility of predicting events such as the strong 1983 and 1987 year classes if such events have not been observed in the past.

Finally, it should be noted that little can be said about the relationship between the current estimate of SSB in 1993-4 and the projections, since the current estimates of these quantities have a high variance.

6.6.6 Concluding remarks

These comparisons do not lead to a clear conclusion as to whether the simpler models are adequate to estimate expected future stock trajectories under present exploitation rates. Further work is required to resolve some of the issues involved.

7 OTHER CASE STUDIES CONSIDERED

7.1 Introduction

In addition to North Sea plaice, a number of other case studies were considered. These case studies have been undertaken by various groups and individuals at different times in the past. The examples presented range from simple analyses of fundamental population biology to extensive simulations of economic benefits from different harvesting strategies.

7.2 North Sea Plaice and Haddock

Although 'comprehensive assessment' is a fairly recent term, the single most comprehensive assessment of fish stocks is probably the one given for North Sea plaice and haddock in Beverton and Holt (1957). This work documents the effects of a very wide variety of assumptions on production estimates. In particular, it includes the development of appropriate stock-recruitment curves for the two stocks, the assumptions of different density-dependent responses in growth etc.

Since this work was carried out before the advent of computers, it does not include dynamic modelling which describes the time trajectories towards equilibrium or the uncertainty surrounding such trajectories (i.e. the medium-term predictions).

7.3 West Greenland Shrimp Fishery

The properties of various management strategies have been explored in relation to the long-term objective of maximising the total cumulated resource rent of the Greenland shrimp fishery in the Davis Strait. These strategies have been implemented through a set of control laws, including different potential sources of uncertainty. The control laws have comprised both direct effort and TAC-based policies. The targeted factors (fishing effort or catches) implementing the control laws have been kept either constant within the management period or possibly linearly related to the level of spawning biomass, should this drop below a precautionary MBAL. Gaps between the underlying and perceived models have been introduced in the simulations through three potential sources of uncertainty, including biological, economic, and political considerations. Biological sources of uncertainty, which have included the natural fluctuations in recruitment, and also the estimation error in the stock numbers at age, have been modelled by stochastic processes. An economic source of error has been implemented by incorporating high-grading of catches, in addition to a constant discard ratio. Eventually, a political source of error has been implemented by introducing the decision of partially ignoring the biological advice provided by the control laws in favour of high levels of fishing effort. Both economic and political sources of uncertainty have been modelled by deterministic processes. Results from the simulations suggest that high-grading of catches, and the decision of implementing a political TAC, generate a significant increase in fishing effort beyond the expectations of the assessment biologists, which reduces the average long-term resource rent and levels of biomass. Thus, in the high-grading scenario, SSB barely exceeds the MBAL threshold.

7.4 Icelandic Summer-Spawning Herring

Jakobsson *et al.* (1993) give a fairly extensive overview of the biology of Icelandic summer-spawning herring. Among the issues evaluated are the assessments, density responses, natural mortality and the stock-recruitment relationship. This form of analysis would form a natural basis for a comprehensive fishery evaluation in which the next steps would be the computation of equilibrium yield curves, estimation of uncertainty and Monte Carlo evaluation of current ($F_{0.1}$) and alternative strategies.

7.5 Iceland Cod

Cod in the Iceland area has been through an analysis process which included a review of most existing data leading to multispecies bio-economic modelling. The resulting models were used for the evaluation of harvesting control laws which were subsequently implemented.

7.6 Strategic Analysis of the Baltic Cod Fishery

7.6.1 Baltic cod production system

Baltic cod could be a good example of a management problem where a strategic analysis might be justified. Large changes in environmental conditions and in the fish species interactions lead to an uncertain system that is inherently difficult to manage while the eutrophication of the Baltic Sea increases the risk that spawning conditions will become less and less favourable. The risk of successive poor year classes possibly leading to a collapse of the fishery is therefore also increasing.

Available data suggest that the recruitment to the Baltic cod stocks depends mostly on three factors: 1) the volume of water suitable for cod egg fertilisation and development, called here the reproduction volume (spvol), 2) the size of the cod spawning stock and, 3) the size of the sprat stock as a predator on early life stages of cod (Sparholt 1995). The interactions between these factors are complex, and the empirical data show only some of the possible combinations. Such environmentally driven uncertainty is difficult to model as background noise in the stock-recruitment relationship, while the effect of cod biomass on the sprat stock as well as cod cannibalism, evident in MSVPA results, further complicates the interactions in the system. These complex and uncertain interactions and their effect on cod production are the main sources of uncertainty for the long-term management of Baltic cod stocks.

7.6.2 Time scale of planning

The principal management tools available are changing the overall exploitation level (tactically driven by a yearly TAC) and the mesh size in the trawl fishery. This means that the time scale to be considered in the analysis is bound to be long. Past fishery data can be used to estimate the overall uncertainties and general level of variance in the stocks, but the effect of the management measures will only be felt some 10 years or so after the analysis is made. Hypotheses on the different causalities can be used as uncertain information and the effects of the hypotheses on management decisions could be used as criteria for assessing the importance of different hypothesis in planning research. Such information is valuable because it can lead to changes in the management strategy. Strategic decision analysis is used to evaluate structural changes of the system (Sutherland, 1983) such as mesh sizes and size limits.

7.6.3 Management objectives

Socio-economic considerations are needed to evaluate the biological components of possible fishery management objectives. Even though the internationally accepted management objectives for Baltic cod are not quantified, it should be possible to formulate quantifiable objectives, such as mean future catch and annual variability of catch, which the different interested parties in the Baltic cod fishery could use to evaluate the usefulness of management decisions. Other criteria could be:

1. fishermen's income: the annual variance in CPUE can be used as an index for fishermen's income;

2. biodiversity: the invasion of the cod in northern parts of the Baltic Sea at the end of the 1970s had a major impact on the sport fishery of Sweden and Finland. Therefore, the size of the cod stock can be seen as a biodiversity factor in the Baltic Sea which is also important for interest groups other than fishermen. In addition, cod is the main fish predator in the Baltic Sea and the biomass of cod affects the biodiversity of the Baltic Sea;

3. new investments in the fishery: these are usually carried out during good years, but they cause economic and biological problems during poor catch years. This investment behaviour supports the use of catch variance as one part of the objective function (management criteria).

These biological variables can be considered as elements of the general objectives, which can to some extent be assessed by fish stock assessment tools.

7.6.4 Controlling mechanisms in management

Controlling mesh sizes in the trawl fishery and the overall exploitation rate on the stock are the most important biologically based control mechanisms available for Baltic Sea cod. Both have an effect on the mean catch and also on the interannual variability of the catches and CPUEs. There are recent suggestions for changing the mesh size in the Baltic cod fishery to reduce the number of young cod in the catches, thus increasing the number of age-groups in the stock to act as a buffer against annual recruitment variability. Moreover, a higher stock biomass would act as a buffer in the case of successive poor recruitments, thereby reducing the need for sudden changes in the TAC. The current biomass is very low and it might become necessary to close the fishery if recruitment failure occurs. Increasing the mesh size could be a mechanism to ensure that most of the fish have a chance to spawn at least once. This is especially important when other management methods do not work as expected. These controlling mechanisms can be used as strategic tools to improve the economic results of the fishery.

Recent doubts concerning the reliability of Baltic cod catch statistics due to misreporting have a large effect both on the reliability of stock predictions and on implementation error. It seems that attempts to manage the Baltic cod fishery only by a TAC have not been sufficient to ensure sustainability.

7.6.5 Meaning of environmental knowledge for management strategy

Long-term predictions of recruitment are uncertain, but environmental data can be used as a source of information concerning the general variability of recruitment, and the probability of poor successive years. The process of inflows to the Baltic is difficult to simulate: the model has to include time trends as well as a probability of large positive values. These high values break down the autocorrelation of the reproduction volume data, but the recruitment is dependent on the frequency of these phenomena and their realistic modelling is a central task in uncertainty estimation.

7.6.6 Methodological approach

Bayesian influence diagrams (e.g. Oliver and Smith, 1990) are suggested for the analysis of uncertainties. They belong to Bayesian network models which are becoming increasingly popular in management science. Many environmental (e.g. Varis *et al.* 1990;. 1993) and some fisheries applications (Kuikka & Varis, 1992, Hilden 1995) have been carried out. One essential part of the software is that the information base of the model can be easily checked and the objective function easily changed. Therefore, this kind of methodology might be useful as a decision aid in fisheries negotiations. In resource management, the application of Bayesian analysis has been largely dominated by classical Bayesian inference, i.e. parameter estimation, in which the Bayesian analysis is restricted to the parameter space. In decision theory, the idea of considering the entire model as a construct subject to uncertainty stems from the game theory of the 1930s and 1940s (Shafer 1990). Bayesian decision theory with conditional probabilities was developed into a more applicable level towards the late 1960s (Howard 1968, Raiffa 1968).

Bayesian networks can be used as meta-models, including the most crucial elements of diagnoses, forecasts, actions, and objectives. The model is a network of nodes connected with one-directional links. The nodes represent probabilistic variables, deterministic variables, and decisions. Like a decision tree, the diagram describes causality of the flow of information and probabilistic dependencies in a system. Influence diagrams can be evaluated in a couple of ways. The most used approaches are the node reduction techniques by Schachter (1986) and the decision tree-based approach by ADA (1992).

7.6.7 Examples

Two examples are given in Figure 7.6.1. The upper one is a simple example of a usual management decision. The size of the stock (called 'state of nature' in Bayesian decision analysis) is assessed by an assessment procedure which leads to a decision. The accuracy of this information can be described by conditional probabilities, which can be estimated by stock assessment procedures, or by the historical data on the success of the working groups. The objective is the size of the stock when a TAC is removed from the stock, and it depends on the TAC decision and the real state of the stock. The possibility of making a wrong decision (i.e. stock collapse) depends on the reliability of the stock assessments, and on prior knowledge about the state of the stock. The prior can also be non-informative, i.e. all states have the same probability. A non-informative prior leads to a higher probability of making an error in the decision. Real TAC decisions also include uncertain elements between the decision and the objective, especially if the objective is described as future recruitment.

The second example in Figure 7.6.1 is a first description of a model of Baltic cod fishery management. The problem was described above. Mesh size and exploitation levels (by tactical TAC decisions) are used as control (decision) variables. Mean catch and/or variability of the catch can be evaluated by this model structure. The mesh type (shape of retention rate) and the exploitation level have an effect both on the mean catch per recruit and on the variance of catch per recruit. Biomass of the stock can be managed by these, and it has an effect on the sprat stock and on the recruitment, which determine the amount of removals. Moreover, future cannibalism rate is also an important source of management uncertainty. Unknown rates of natural mortality could also be included in the model as another source of uncertainty. The probability of successive poor years depends on the autocorrelation in the spvol.

In this case, the model is used as a meta-model, and a long-term simulation model is used to estimate the conditional probabilities. For example, the model can be analysed by different natural mortalities or cannibalism rates. Then the resulting distributions are discretized and this information is included in the model. In the analysis, the effect of natural mortality can be changed simply by changing the probability distribution of that node, and the possible changes in the decision combinations can be evaluated. Also, the value of information analysis for the cannibalism rate, recruitment of sprat and autocorrelation of spvol might be interesting. The building of the model must be done in pieces to keep the whole model understandable.

7.6.8 Comments on approach

Bayesian network approaches seem to include properties which are useful for the strategic analysis of the fishery and also for planning fisheries research. One of these is the value of information analysis, which shows the importance of different information sources for management decisions. These estimates can be used as one criterion when research is planned. For example, in the case of Baltic cod it might be possible to show which parts of the complex recruitment model include the most important uncertainties. The value of information analysis is that the importance of information is evaluated by the objectives and by the possibilities for controlling the uncertainties by decision variables. Influence diagrams might also be valuable in developing and testing simulation models, because the different combinations of inputs and outputs can be stored in a model and easily be evaluated.

However, more practical experience is needed before it is possible to judge the real usefulness of this kind of tool for the fisheries evaluation work of ICES. The Baltic cod management problem will be one of these exercises. Results will be available at the next COMFIE meeting.

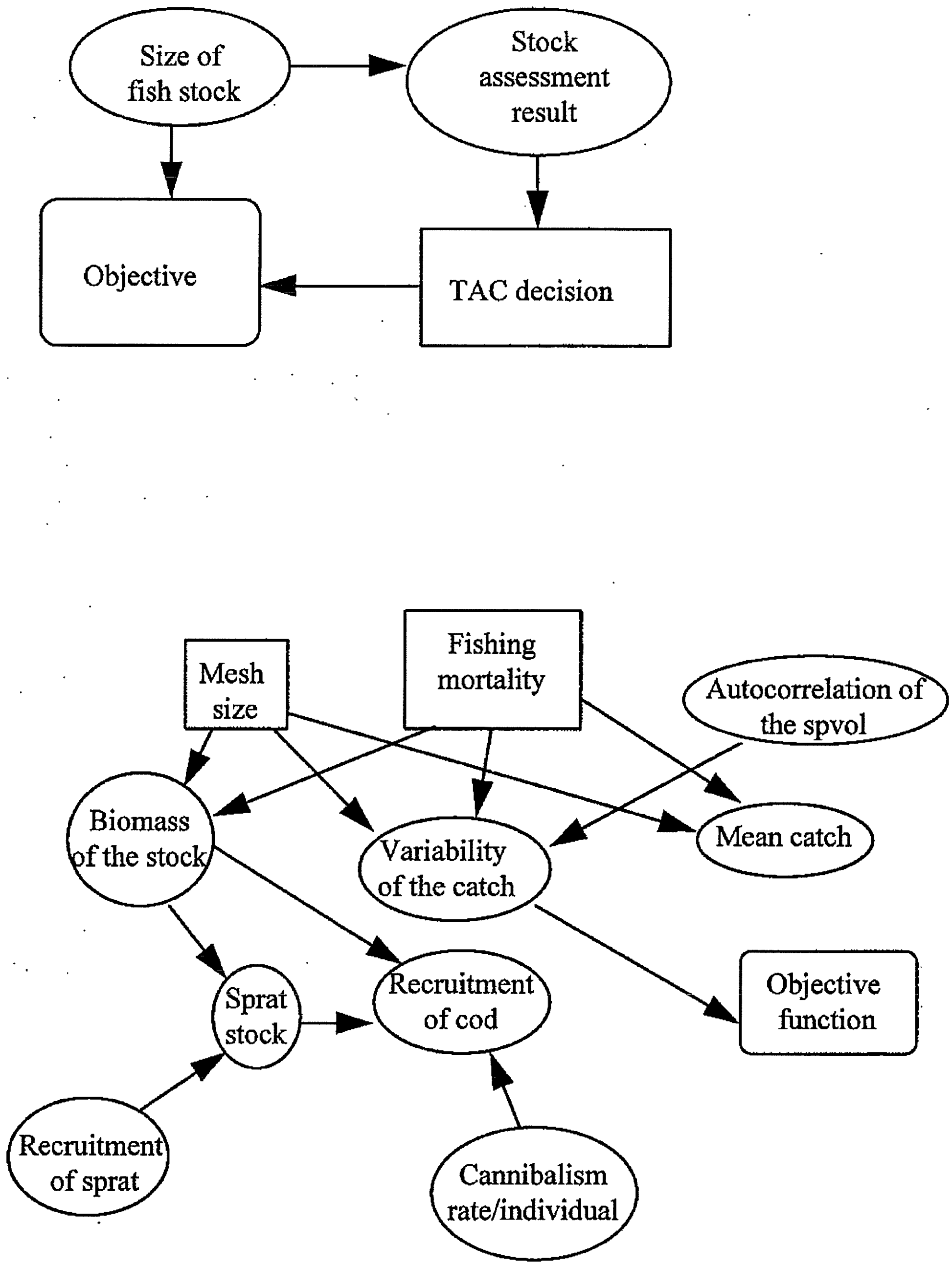


Figure 7.6.1. Two examples of fisheries management models formulated by influence diagrams. See text for explanations.

7.7 Bristol Channel Sole

An evaluation of the population biology of Bristol Channel sole is given in Horwood (1993). This evaluation is mostly based on the methodology in Beverton and Holt (1957) and does not include the various medium-term simulations or other Monte Carlo-based evaluations of harvesting strategies for the sole.

7.8 Managing Celtic Sea Fisheries with Multi-Annual Strategies

Most of the north-eastern Atlantic stocks are currently fished above the biological reference points (F_{max}, MBAL, ...) advocated by scientific bodies. The problems for advisers are then not only to identify appropriate long-term targets, but also to advise on how to achieve them from the current position. In attempting to achieve such targets, advisers and managers have faced two major problems. A first difficulty arises from the impracticability of (a) simultaneously maximising yields, stabilising fisheries outcomes, ensuring the stocks safety, and also (b) optimising both short- and long-term outcomes for the fishing industry. A second difficulty resides in the lack of predictability, several years ahead, inherent in factors influencing decisions. These include the inter-annual variability of recruitment and the environment, market prices, scientific advice, and such unpredictability adversely affects any long-term planning for the fishing industry. These twin issues have been addressed, by exploring the transition phase between a high level of fishing effort towards a long-term target, by combining the concepts of multi-annual and compromise strategies. Such strategies have been applied to the management of the demersal mixed-species and multi-fleet fisheries of the Celtic Sea, with the long-term objective of reaching the optimal level of fishing effort by fleet which maximises total gross revenues.

The management has been split into periods of several years, referred to as "resolution periods". One "mobile target" is calculated for each resolution period as a weighted compromise between the long-term target and the current level of fishing effort at the beginning of the resolution period. Multi-annual fishing effort by fleet is set in advance for a resolution period, at the end of which they are updated. These values of fishing effort are calculated in order to achieve a second weighted compromise of three criteria: (i) achieving the mobile target, (ii) minimising variability in fishing effort, (iii) minimising variability in yield. The relative performance of each strategy has been compared through a set of specific short- and long-term indices related to the average gross revenues, the variability in both fishing effort and yield, and the risk of the harvested stocks dropping below a critical biological level. Three rules have then been fixed in order to select a set of sensible strategies with respect to the relative values of the performance indices. Thus, any sensible strategy should (i) ensure the safety of the stocks, (ii) improve the long-term performance of management (i.e. lower fishing effort and yield variability, higher gross revenue) in comparison with the short term, (iii) improve the short-term performance of management in comparison with the historical values.

Results from the simulations suggest that the best strategies, regarding the three adopted management rules, are found when (i) the mobile target is about half way between the long-term target and the value of the fishing effort at the beginning of the resolution period, (ii) the length of the resolution period is 5 years, and (iii) the criteria for achieving the mobile target and minimising the fluctuations in both fishing effort and yield are equally weighted. These results illustrate the potential benefits expected by the application of multi-annual and compromise strategies. However, the conclusions achieved should not be incautiously broadened to other fishery study cases, since some of the results are dependent upon the agreed long-term targets, which are specific to the Celtic Sea fisheries and stock management.

8 ORGANISATION OF COMFIE

8.1 Introduction

The role of COMFIE is discussed in Section 3 and terms of reference are presented in Section 1.1. This section specifies the work that COMFIE proposes to conduct over the next few meetings in order to address the terms of reference.

8.2 Structure of Future Meetings

The scope of the terms of reference requires that COMFIE meet on an annual basis. It is anticipated that most of the work will be conducted intersessionally. At the annual meetings, working group members will review the progress on specific CFEs and provide guidance on the steps required to ensure completion of the CFEs within a reasonable time period. COMFIE will also address the methods required to conduct CFEs. Because of the obvious need for medium-term projections, COMFIE identified work on medium-term projection methods as a priority for its next meeting.

8.3 Intersessional Work

As discussed in Section 3, a CFE involves a number of steps, many of which can be technically complex. Furthermore, the CFE requires input from a range of disciplines and it may be necessary for the chairman to solicit participation from the appropriate experts. Thus, completion of a CFE is well beyond the scope of what can be achieved at regular meetings of COMFIE. In order for COMFIE to complete its terms of reference, most of the work must be conducted intersessionally, in co-operation with national laboratories, the relevant assessment working groups and other experts.

8.4 Future CFEs

8.4.1 Background

As described in various sections of this report, it is envisaged that COMFIE will consider several different stock/fishery complexes at future meetings. It is of considerable importance that intersessional work be undertaken on the various stocks since it is not possible to undertake full comprehensive evaluations during the meetings of the group.

8.4.2 Iceland haddock

Icelandic haddock has not been assessed through ICES in recent years, but the fishery for haddock in Icelandic waters is fairly important, particularly in certain areas. A comprehensive assessment is currently being undertaken and would benefit considerably from a peer review and feedback from COMFIE. Interesting aspects of this stock include the usual high variability in recruitment, apparent density-dependent growth, complex growth-maturation dynamics and local pockets of slow-growing haddock.

8.4.3 Future case studies: Norwegian Spring-spawning Herring

The biomass of Norwegian spring-spawning herring was more than 10 million t in the 1950s and the annual yield exceeded one million t. The stock collapsed in the late 1960s and started to recover slowly from the mid-1970s. The spawning stock increased abruptly in 1986 and 1987 when the good 1983 year class matured.

In the 1996 assessment of the stock the Northern Pelagic and Blue Whiting Fisheries Working Group did not present any advice due to considerable uncertainty about the recruitment model for the stock and a sub-group was appointed to select a recruitment model to use in medium-term projections. The recruitment time series exhibits a pattern of few but very good year classes with a recruitment CV of about 2.0. The main rationale behind the management in recent years has been to keep a spawning stock high enough in the future to take full advantage of good recruitment conditions. The management of the stock will totally hinge around the stock-recruitment relationship used.

The sub-group will also improve the assessment by combining tagging and acoustic data in the tuning of the VPA, including the covariance of number at age in the initial stock in the medium-term projection and redefining the stock-recruitment relationship when M is changed in the risk analysis. The tuning of the VPA is difficult since the various time series of acoustic surveys are not consistent. The age distribution of the surveys is subject to large errors, since the sampling, especially in the wintering areas, is extremely difficult. The assessment method applied at present does not take into account the error structure of the surveys.

Work is also undertaken to evaluate management objectives and to construct a simple scenario model for the stock.

Rich year classes will enter the Barents Sea and have a negative influence on the capelin, thereby causing reduced individual growth of the North-east Arctic cod stock. There exist multispecies models designed for studying the cod-capelin-herring system in the Barents Sea, as well as a database of stomach content data that could be used for studying multispecies effects. Also, there is a large amount of yet unavailable qualitative stomach content data from the Barents Sea obtained by Russian scientists that goes back at least as far as the period at present used for the VPA (1950).

Prior to the stock collapse the Norwegian spring-spawning herring migrated between Norway and Iceland. At present the stock migrates from the Norwegian coast after spawning to the international part of the Norwegian Sea. There is considerable international disagreement on how to allocate quotas between countries.

In summary, the stock is large, the methodological problems are similar to those being worked on in COMFIE and improvements to the analytical tools are badly needed. Several scientists are working on improving the basis for the assessment independently of COMFIE activity and, finally, there is a large international management dispute over the stock which can lead to the quotas being driven up. The stock should be an interesting case study for testing new tools as well as an important stock to assess comprehensively.

8.4.4 A Comprehensive Evaluation of Southern Gulf of St. Lawrence Groundfish Fisheries

Groundfish fisheries in the southern Gulf of St. Lawrence have been directed toward Atlantic cod, American plaice, white hake, witch flounder and winter flounder, listed in order of catch importance. Cod-directed fishing was closed in 1993 due to low stock size, and this was followed by a closure of the white hake fishery in 1995. These closures have led to many important questions regarding stock assessment, stock predictions and management.

Technical interactions among these species vary seasonally and geographically. While there is no directed fishing for cod and white hake, they are still taken as by-catch in other fisheries. Analysis of the commercial logbook data from the past 10 years would be useful for examining the predictability of fishery distribution and catch composition. Density-dependent effects on distribution could also be investigated. This would be useful for examining the feasibility of area and seasonal single species quotas when one or more species are threatened. Furthermore, the aggregate fishing effort in the area was well above sustainable levels and substantial reductions are needed. What is the appropriate aggregate total fishing effort?

Groundfish resources in the southern Gulf of St. Lawrence have been surveyed annually since 1971. The 1996 survey will be the fourth since the fishery for cod was closed, during which time the fishing mortality has been close to zero. This provides a unique opportunity to estimate the natural mortality of this stock, albeit at a relatively low level of abundance.

There is considerable uncertainty about the stock structure and appropriate management unit definition for white hake and witch flounder. Morphometric and meristic data indicate at least two stocks of hake in the area, and that both may migrate out of the current management unit (NAFO Division 4T) in winter. Similarly, witch flounder is managed as one stock in the entire Gulf of St. Lawrence (NAFO Division. 4RST). It is possible that separate northern and southern components exist.

Recruitment to the southern Gulf of St. Lawrence cod stock and juvenile survival (R/S) have been well below average during the late 1980s and early 1990s. There has been no sign of improvement since the fishery was closed in 1993. Additional study is required to determine if this is due to increased mortality in the juvenile stage, due possibly to adverse environmental conditions, increased predation, or discarding. Alternatively, has this resulted from reduced fecundity or elimination of spawning components? While not all of these questions are tractable with current data (fecundity, predation), some work is possible on questions of environmental effects and spawning stock structure.

Current weights at age of cod are well below average. The stock went from very high weights at age in the late 1970s to the lowest observed values since the 1950s. Feeding data have been collected periodically over this time period, and these may be useful for examining possible causes. There may also be information in otolith collections that may be useful in tracking individual fish growth and for testing hypotheses of density-dependent, environmentally dependent, or size selective mortality effects on growth.

8.4.5 Further possible CFEs

COMFIE noted that among the more southern species, the stock of anchovy in the Bay of Biscay would provide an important addition to the present list of comprehensive evaluations due to the difference from the other stocks in terms of age structure, data availability and nature of the fishery.

The present list does not include a typical stock/fishery with limited data. All evaluations presently under consideration can be based on an extensive database and knowledge of age structure etc. It would therefore be of considerable theoretical and practical interest to add fisheries for species such as oceanic *Sebastes mentella* and deep-sea *S. mentella* in the Irminger Sea, or Greenland halibut across the North Atlantic. In both cases there is considerable stock-identification uncertainty, age reading problems abound etc.

8.5 Publication Routes

Various forms of publication were discussed by COMFIE. It is anticipated that the main report of each meeting will be published as part of the ICES Cooperative Research Report series. Considerable effort will be involved in the generation of CFEs. Background documentation for each CFE should be published by the main participants in the primary literature, possibly as a series of related papers in a single volume.

9 OTHER BUSINESS

COMFIE considered the draft report of the Study Group on the Management Performance of Individual Transferable Quota (ITQ) Systems. The report provides an extensive list of references which will be useful to working group members. If the Study Group can identify and quantify the impacts of ITQ management (both beneficial and negative), their work will assist COMFIE in evaluating alternative harvest scenarios.

10 RECOMMENDATIONS

The Comprehensive Fishery Evaluation Working Group recommends that:

- the next meeting be scheduled for June 1997 at a venue to be decided which must accommodate up to 40 people.
- MSY, F_{MSY} and B_{MSY} be calculated for all major stocks for which the appropriate input is available.

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11.1 Working Documents

1. C.M. O'Brien. Indices of dispersion with an application to English groundfish surveys.

2. C.M. O'Brien. Modelling over-dispersion in groundfish surveys.

3. C.M. O'Brien and B.D. Rackham. Spatial aggregation in North Sea cod based on preliminary statistical analyses of 3rd quarter EGFS data for the years 1988-1993.

4. C.M. O'Brien and B.D. Rackham. Spatial aggregation in North Sea haddock based on preliminary statistical analyses of 3rd quarter EGFS data for the years 1988-1993.

5. C.M. O'Brien and B.D. Rackham. Spatial aggregation in North Sea whiting based on preliminary statistical analyses of 3rd quarter EGFS data for the years 1988-1993.

6. C.M. O'Brien and B.D. Rackham. Comparison of aggregation in North Sea cod, haddock and whiting based on analyses of 3rd quarter EGFS data for the years 1988-1993.

7. C.M. O'Brien and B.D. Rackham. Spatial aggregation in North Sea plaice based on preliminary statistical analyses of 3rd quarter EGFS data for the years 1988-1993.

8. C.M. O'Brien. Models of spatial aggregation that are both consistent and inconsistent with the common assumptions about catch distributions.

9. C.M. O'Brien. Thoughts on the development of a statistical model for the analysis of English tagging experiments on cod and plaice.

10. C.M. O'Brien. Time domain changes in the stock-recruitment relationship for North Sea plaice.

11. C.M. O'Brien. A new form of structural variation appropriate to the modelling of recruitment data.

12. C.M. O'Brien. Time domain changes in stock-recruitment relationships in the Irish Sea.

13. M. McAllister. A Bayesian Approach to Model Selection Using the Sampling/Importance Resampling Algorithm: Application to North Sea Plaice (*Pleuronectes platessa*).

14. M. McAllister and E.K. Pikitch. A Bayesian Approach to Choosing a Design for Surveying Fishery Resources: Application to the Eastern Bering Sea Trawl Survey.

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20. K. Stokes, L. Kell and M.T. Smith. Objectives, metrics, statistics and communication.

21. L.T. Kell and T.K. Stokes. Modelling Multi-species Interactions in System Models for the Evaluation of Management Under Uncertainty.

22. M. Smith. Using Visual Basic to control simulation models in Excel.

23. L. Kell and B.D. Rackham. Estimation of catch at age for fleets with sparse length and age data: North Sea plaice.

24. L. Kell and B.D. Rackham. Estimation of catch at age for fleets with sparse length and age data: Method.

25. L. Kell and B.D. Rackham. Modelling Catchability of Research and Fishing Vessels: North Sea Plaice.

26. L. Kell and B.D. Rackham. Modelling Catchability of Research and Fishing Vessels: Methods.

27. L. Kell and B.D. Rackham. Modelling Growth and maturity: Methods.

28. P. Marchal. Managing growth overfishing with multi-annual compromise strategies.

29. L. Kell and N.J.C. Strachan. Spatial Differences in North Sea Whiting.

30. L.J. Richards, J.T. Schnute and Norm Olsen. Graphical and analytical methods for age-structured assessment.

31. S. Kuikka. Use of Bayesian networks in fisheries management: analysis of uncertainties in parameters and in model structure.

32. L. Kell., M. Smith and K. Stokes. Evaluating and comparing management procedures.

Table 2.3.1: Comparison of yield per recruit reference points and the associated equilibrium SSB/R and Y/R estimated for southern Gulf of St. Lawrence cod over the four time periods 1975-79, 1980-84, 1985-89, and 1990-95.

	$F_{0.1}$			F_{max}		
Years	F	SSB/R	Y/R	F	SSB/R	Y/R
75-79	0.21	5.70	0.87	0.36	3.87	0.93
80-84	0.18	4.96	0.65	0.29	3.73	0.69
85-89	0.17	3.58	0.43	0.30	2.59	0.45
90-95	0.21	2.74	0.37	0.92	1.16	0.42

Table 2.3.2: Comparison of spawning stock biomass per recruit reference points and the associated equilibrium SSB/R and Y/R estimated for southern Gulf of St. Lawrence cod over the four time periods 1975-79, 1980-84, 1985-89, and 1990-95.

	F_{med}		
Years	F	SSB/R	Y/R
75-79	0.55	2.75	0.90
80-84	0.47	2.67	0.66
85-89	0.25	2.88	0.45
90-95	0.16	3.1	0.34

Table 2.3.3: Comparison of age-structured production reference points (F_{MSY} and F_{crash}) and the associated equilibrium SSB/R, Y/R, and MSY estimated for southern Gulf of St. Lawrence cod over the four time periods 1975-79, 1980-84, 1985-89, and 1990-95.

	F_{MSY}				
	F	SSB/R	Y/R	MSY	F_{crash}
75-79	0.40	3.60	0.93	78053	1.33
80-84	0.30	3.59	0.69	58041	1.47
85-89	0.23	3.01	0.45	37460	0.92
90-95	0.23	2.58	0.38	30653	0.79

Table 2.3.4: Percent maximum spawning biomass per recruit associated with various biological reference points for southern Gulf of St. Lawrence cod over four time periods.

		% Max SSB/R			
	Max SSB/R	$F_{0.1}$	F_{max}	F_{med}	F_{MSY}
75-79	12.06	47%	32%	23%	30%
80-84	9.67	51%	39%	28%	37%
85-89	7.10	50%	36%	41%	42%
90-95	5.53	50%	21%	56%	47%

Table 2.4.1: Comparison of F-based biological reference points for several fish stocks in the ICES area. Three sets of age-structured production analysis reference points were calculated for North Sea cod, where three different stock-recruitment relationships were used (column S-R; S = Shepherd curve, B = Beverton and Holt curve, R = Ricker curve.). Four sets of yield per recruit and spawning stock biomass per recruit reference points were calculated for southern Gulf of St. Lawrence cod, using mean weights at age and average fishing mortalities from four time periods.

	$F_{0.1}$	F_{max}	F_{med}	F_{high}	F_{MSY}	F_{crash}	S-R	F_{comfie}
North Sea Cod	0.18	0.28	0.83	1.10	0.72	0.91	S	0.28
	0.18	0.28	0.83	1.10	0.24	1.10	B	0.24
	0.18	0.28	0.83	1.10	0.58	1.05	R	0.28
North Sea Plaice	0.18	0.25	0.28	0.48	0.25	2.48	B	0.25
Iceland Cod	0.20	0.40	0.44	1.11	0.42	0.80	R	0.40
Iceland Herring	0.22	0.46	0.40	1.13	0.28	0.80	R	0.28
Southern Gulf of St. Lawrence Cod								
1975-79	0.21	0.36	0.55	2.24	0.40	1.33	R	0.36
1980-84	0.18	0.29	0.47	2.83	0.30	1.47	R	0.29
1985-89	0.17	0.30	0.25	1.41	0.23	0.92	R	0.23
1990-95	0.21	0.92	0.16	.96	0.23	0.79	R	0.16

Table 4.4.1: Assorted biological reference points and performance statistics for North Sea cod.

	F	S/R	Y/R	% Max S/R	eq S	eq R	eq Y
$F_{0.1}$	0.18	3.61	0.74	40%	508	141	105
F_{max}	0.28	2.40	0.78	27%	440	183	143
F_{med}	0.83	0.40	0.60	4%	155	385	230
F_{high}	1.10	0.22	0.54	2%	0	0	0
F_{msy}	0.72	0.53	0.63	6%	214	401	252
F_{crash}	0.91	0.33	0.58	4%	0	0	0

Table 6.6.1. Plaice North Sea. Input data for stock projections. CV is the coefficient of variation

Numbers at age			Weights in stock			Natural mortality		
name	value	CV	name	value	CV	name	value	CV
N1	456000	0.38	WS1	0.14	0.06	M1	0.1	0.1
N2	330040	0.33	WS2	0.24	0.12	M2	0.1	0.1
N3	344149	0.15	WS3	0.27	0.06	M3	0.1	0.1
N4	216504	0.12	WS4	0.29	0.07	M4	0.1	0.1
N5	96824	0.11	WS5	0.34	0.13	M5	0.1	0.1
N6	39911	0.11	WS6	0.43	0.13	M6	0.1	0.1
N7	32043	0.11	WS7	0.52	0.13	M7	0.1	0.1
N8	17060	0.11	WS8	0.62	0.09	M8	0.1	0.1
N9	22149	0.11	WS9	0.69	0.1	M9	0.1	0.1
N10	7820	0.1	WS10	0.76	0.1	M10	0.1	0.1
N11	3064	0.11	WS11	0.84	0.1	M11	0.1	0.1
N12	2143	0.11	WS12	0.98	0.08	M12	0.1	0.1
N13	1927	0.13	WS13	0.99	0.13	M13	0.1	0.1
N14	911	0.14	WS14	0.89	0.14	M14	0.1	0.1
N15	2317	0.16	WS15	0.97	0.16	M15	0.1	0.1

Selectivity at age			Weights in the catch			Proportion mature		
name	value	CV	name	value	CV	name	value	CV
sH1	0.01	1.02	WH1	0.25	0.07	MT1	0	0.1
sH2	0.12	0.34	WH2	0.28	0.05	MT2	0.5	0.1
sH3	0.35	0.24	WH3	0.3	0.03	MT3	0.5	0.1
sH4	0.56	0.2	WH4	0.32	0.06	MT4	1	0.1
sH5	0.72	0.11	WH5	0.37	0.12	MT5	1	0
sH6	0.65	0.09	WH6	0.46	0.13	MT6	1	0
sH7	0.54	0.1	WH7	0.56	0.1	MT7	1	0
sH8	0.43	0.12	WH8	0.65	0.07	MT8	1	0
sH9	0.39	0.13	WH9	0.74	0.07	MT9	1	0
sH10	0.42	0.17	WH10	0.79	0.08	MT10	1	0
sH11	0.37	0.22	WH11	0.89	0.09	MT11	1	0
sH12	0.36	0.21	WH12	0.95	0.07	MT12	1	0
sH13	0.4	0.39	WH13	1	0.09	MTT1	1	0
sH14	0.38	0.24	WH14	0.95	0.12	MT14	1	0
sH15	0.38	0.24	WH15	1.03	0.07	MT15	1	0

Recruitment			Effort multiplier			Year effect on natural mortality		
name	value	CV	name	value	CV	name	value	CV
			HF94	1	0.09	K94	1	0.1
R95	400000	0.4	HF95	1	0.09	K95	1	0.1
R96	400000	0.4	HF96	1	0.09	K96	1	0.1
R97	400000	0.4	HF97	1	0.09	K97	1	0.1
R98	400000	0.4	HF98	1	0.09	K98	1	0.1
R99	400000	0.4	HF99	1	0.09	K99	1	0.1
R00	400000	0.4	HF00	1	0.09	K00	1	0.1
R01	400000	0.4	HF01	1	0.09	K01	1	0.1
R02	400000	0.4	HF02	1	0.09	K02	1	0.1
R03	400000	0.4	HF03	1	0.09	K03	1	0.1

Table 6.6.2 The probability that SSB will be below MBAL in 100 simulations of a stock projection using a range of harvest control law senarios. Fstatus quo = 0.46 F med = 0.28

MBAL	Target	Slope	P[SSB<MBAL]							
			1996	1997	1998	1999	2000	2001	2002	2003
0	Fmed	Fmed	0.94	0.85	0.63	0.51	0.45	0.4	0.38	0.33
0	FSq	FSq	0.94	0.96	0.97	0.98	1	1	1	1
300,000	FSq	Fsq	0.94	0.16	0	0	0	0	0	0
300,000	FSq	100	0.94	0.2	0.01	0.11	0.58	0.81	0.45	0.1
300,000	Fmed	0.1	0.94	0.16	0	0	0	0	0	0
300,000	Fmed	0.28	0.94	0.16	0	0	0	0	0	0
300,000	Fmed	0.5	1	0.16	0	0	0	0	0	0
300,000	Fmed	1	0.94	0.16	0	0	0	0	0	0
300,000	Fmed	1.5	0.94	0.16	0	0	0	0	0	0
300,000	Fmed	2	0.94	0.16	0	0	0	0	0	0
300,000	Fmed	100	0.94	0.18	0	0	0	0	0.01	0.02

Fmed 0.28 Fsq 0.46