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Report of the Study Group on Management Strategies

ICES Headquarters

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1 Introduction

The Study Group met in Copenhagen from 31 January to 4 February at ICES Headquarters under the co-chairmanship of Dankert Skagen (Norway) and John Simmonds (UK) with the following terms of reference:

a. define a framework based on long-term considerations for management strategy evaluations in a Precautionary Approach context. The framework will replace the existing PA framework. The framework shall include both context analysis and evaluation of management plans (including harvest control rules and effort regulations as possible elements of management plans) and provide for both recovery plans and management of a stock under sustainable exploitation;
b. describe the framework in a separate document (eventually to become an element in the quality handbook) providing a description of the approach and operational guidelines for implementation of management strategy evaluations by ICES;
c. provide operational guidance for working groups in 2005 to explore and present options for management strategies including harvest control rules and targets;
d. as a component in practical guidance review available software that can be used to evaluate various variants of harvest control rules within the framework defined under a). It has priority to identify software that directly or with realistic modifications can be implemented by the fisheries assessment working groups in the 2005 assessment round.

Terms of reference a) and b) deal with a description of the general framework of the development of a strategy to manage fisheries including the process of how to derive at such a multi-annual management strategy including requirements to enable an evaluation of such a strategy. Terms of reference c) and d) aim to give guidance to the process of evaluation of these strategies.

The report is organized in sections. Section 2 describes the conceptual issues around management strategies including the role of the different parties in the fisheries system. Examples are given in Section 5 for a number of fisheries and stocks for which such strategies have been implemented and evaluated. Section 3 provides a general overview of the scope of the issues, the fisheries that require different management strategies, the differences in biological characteristics of exploited species that may call for different management strategies. Section 4 describes how long term management strategies could be developed including the role of the different parties in the process. In section 4.4 a framework is presented for evaluation of management strategies, which is developed further in section 7 where simulation is described in detail. Section 5 gives seven examples of management strategies that are already in use. There are some specific types of management measures that present their own specific challenges for evaluators and will need to be considered. Several of such types of management action are identified in section 6 and it is anticipated that additional types, as they present themselves in future, should be similarly analysed to identify special issues related to their evaluation. Section 7 draws heavily on the experience of the Methods WG (ICES 2004a) and provides standards for simulation. Section 8 provides a brief review of the software currently available and indicates which are currently suitable for use in management strategy evaluations, in particular for HCR simulationand how they are documented. Methods that are still under development are also noted.

A list of participants to the meeting is given in Annex 1 (The terminology used in this report is explained in Annex 2.

1.1 Operational guidance for working groups in 2005

The SG is requested to provide guidance for the exploration and presentation of options for management strategies including harvest control rules (HCRs) and targets. For 2005 there are several specific requests for advice for the North Sea stocks of cod, plaice, sandeel, and Norway pout, for area IV and VI angler fish and western horse mackerel, as well as for an extended HCR for North-East arctic cod. For several other stocks, work is underway to develop HCRs, within and outside the assessment WGs, for example Anchovy in the Bay of Biscay and Herring in Division VIa North. In addition there is a general requirement for operational guidance requested under the MoUs from the Client Commissions[1]. Specifically there is a request for HCR advice in setting TACs or levels of effort or both. The MoUs indicate these should be consistent with the recovery plans, precautionary criteria, long term sustainable exploitation, high long-term yields and a low risk of depleting the productive potential of the stock.

The SGMAS recognizes that to respond to these requests a balance of expertise between knowledge of the stocks / fisheries, expertise on the development of management strategies and technical skills related to evaluation of management strategies and HCRs is required. Specifically for 2005 SGMAS considers that this is a task that could be carried out under the umbrella of the ICES species/area based WGs. However, SGMAS has concerns with asking assessment WGs to carry out such a tasks given that WGs are already heavily committed. Also there may in some cases be a lack of the appropriate expertise to address these requests. Therefore, responding to the requests in the first paragraph will result in WGs having to make a trade-off between existing assessment tasks and new management strategies' evaluation responsibilities. In any case, intersessional work undertaken by specialists or Study Groups gathering the required expertise will be necessary if significant progress is to be made.

It is recognized that presenting ideas as part of a dialog with managers is an important part of the development of HCRs and that it is unlikely that this will be available for many stock within 2005. In the absence of specific targets for management objectives, ICES will at least regard the Precautionary approach as an objective. In this respect, ICES will evaluate a management strategy to its own standards, which imply that the risk of SSB falling below B_{lim} should be low, i.e. less than 5-10% However, it is recognized that in earlier phases of the development of management strategies, information on the level of risk associated with alternative strategies will be of interest to managers, who may want to balance risk against potential gains.

Many recent proposals for HCRs aim at reducing year-to-year variation in the catches. Hence, tradeoffs between maximum long term yield and yield stability needs to be highlighted.

Below, suggestions for the evaluation work are given for some of the stocks where such work has been requested.

For North Sea Cod and Plaice the request indicates in detail the simulations that are requested as part of the evaluation. STPR3 / S3S has been used in the recent past for these type of analysis. Also the tools applied for the MATES and MATACS evaluations could be considered for the analysis since they allow the explicit modelling of feedback in assessment bias. Guidance on the need for complex models is given in Section 7.5

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1 Paragraph 3 in the MoU states: The European Commission requires that ICES will develop its form of advice according to the needs of the Common Fisheries Policy (CFP), and in particular will move towards the provision of long-term and multiannual advice as according to Articles 5 and 6 of the new Common Fisheries Policy framework regulation (EC 2371/2002).

For cod the request is for the situation after the stock has been rebuilt to above B_{pa}. There is currently an accepted assessment, but no accepted prediction. In the long-term perspective, this may improve, and the type of HCR that is outlined may then turn out to be adequate. Further dialogue is encouraged because other types of management strategies may have to be considered in a further dialogue with managers. Section 3 gives some indications of types of management strategies that may be worth considering.

For both cod and plaice, discarding is a major source of mortality, and there may be interactions between state of the stock, management measures and discarding. To what extent this interaction can be modelled explicitly is not clear, but as a minimum, the HCR should tolerate the extent of discarding that seems plausible. Likewise, in order to evaluate the effect of measures that aim at reducing discards, quantification of discards, including age (or size) distribution is essential.

Both for Horse mackerel and Anglerfish the development of management strategies is in the early phase. None of these can be assessed analytically at present, and alternative management strategies that do not rely on analytic assessment may have to be considered. Some suggestions can be found in Section 3, but the SG has not so far considered this field in depth.

For Norway pout and Sandeel, which are both short-lived species, harvest control rules based on annual assessments and predictions are not adequate, because of the rapid turnover in the stock. Management using in-year monitoring to set or adjust quotas seems to be adequate. Such monitoring must be able to recognize poor year classes, but should also be able to reliably recognize good year classes in order not to be unduly restrictive. Again, the SG has not so far considered such regimes in depth.

2 Conceptual issues

ICES is increasingly being asked to evaluate harvest control rules as a step to move from away from short term crisis management towards long term management. ICES should however from the outset take a wider perspective in order to maintain the long-term basis for the advice. A harvest control rule is one component in a management strategy[2], which describes a procedure for the longer-term management of fisheries. A management strategy – in the terminology of ICES - includes

- A decision (explicit or implicit) on longer term management objectives and performance criteria
- A decision on the relevant knowledge base for tactical management decisions
- Tactical management decisions regarding the fisheries in the current or coming fishing season (including harvest control rules)
- A decision on implementation measures (mainly input or output control etc.)

A management strategy thus includes what is called the knowledge system, the decision-making system and the implementation system (figure 2.1, WGFS: ICES 2001, ICES 2004d). The fleet adaptation system and the underlying resource system represents the objects of management and are thus external to the management strategy itself. This external system should be incorporated in any management strategy evaluation in terms of achievements of objectives, robustness and risk relative to external factors.

2 Other terms used for a 'management strategy' (Sainsbury 1998) is 'management procedures' (the Butterworth school: Butterworth and Punt, 1999) or 'closed loop' models (Hilborn and Walters 1992). They are not entirely equivalent. The emphasis here is to evaluate frameworks which strategically defines tactical decisions, thus the term management strategies.

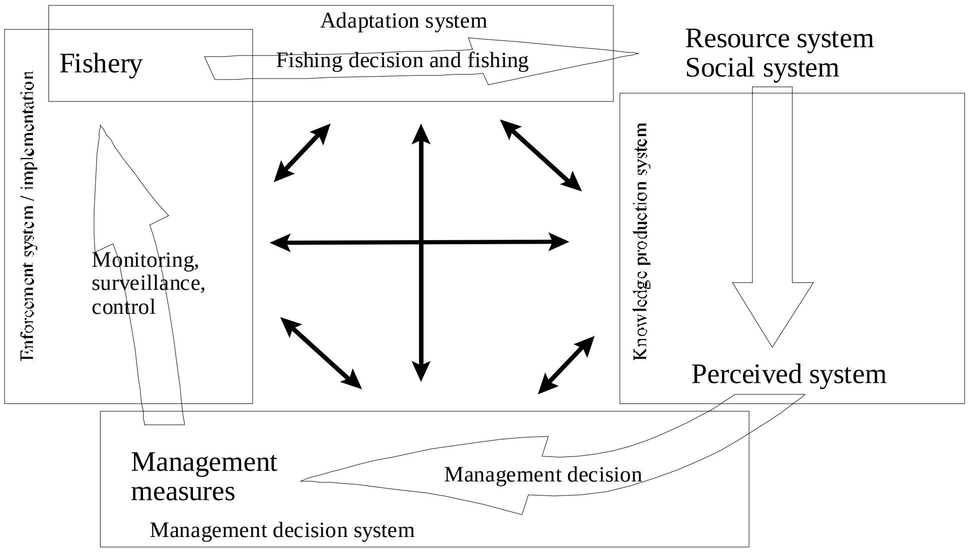


Figure 2.1. The fisheries system. The management strategy identifies the knowledge production system, the management decision system and the implementation system. The adaptation of the fleets and the natural changes in the resource system are external constraints. (ICES, 2001)

The fishery system can also be conceptualized in the form of an management strategy onion (Figure 2.2) where each layer is encompassed by the higher layer. A harvest control rule (HCR) is the lowest level in a hierarchy within the fishery system. There is always an implicit harvest control rule, but it is in most cases in the NE Atlantic area it is not stated explicitly. The present implicit harvest control rule in Europe is to decide an annual TAC on basis of a two year catch forecast based on the population one year prior to the fishing season. This rule is associated with a B_{lim} reference point and two trigger points (B_{pa} and F_{pa}).

Tactical management decisions can include a critical evaluation of the outcome of a harvest control rule and can be subject to requests for flexibility when politically sensitive issues are at stake. However, the long-term benefits of harvest control rules can be undermined by such tactical management decisions.

A management plan includes the decision-making processes (harvest control rules, tactical decision-making) and the sanctions on implementation and the requirements for monitoring and reporting. Management plans may also exist in the form of *rebuilding plans* or *recovery plans*. While management plans can include decision rules that aim at recovery in the case decision parameters fall outside trigger points, recovery plans are only temporary until recovery has been achieved.

Management strategies include decisions on objectives with associated performance criteria, on the implementation measures (e.g. input or output control) and on what is considered a relevant knowledge base for decisions. The knowledge production system should reflect the management strategy. Analytic stock assessments with annual catch forecasts is just one particular approach to produce the knowledge base for tactical management decisions within a management strategy based on annual TACs. Other approaches are direct use of survey indices prior to or in the fishing season or catch rates from the early part of the fishing season. In an effort based management strategy other types of knowledge and other frequencies of updates are required and annual catch forecasts may be irrelevant.

The external constraints include the future state of nature and the future behaviour of the fishing fleet, which includes adaptations to the management. These external constraints cannot be predicted but management strategies can be evaluated in terms of their robustness to changes in these constraints.

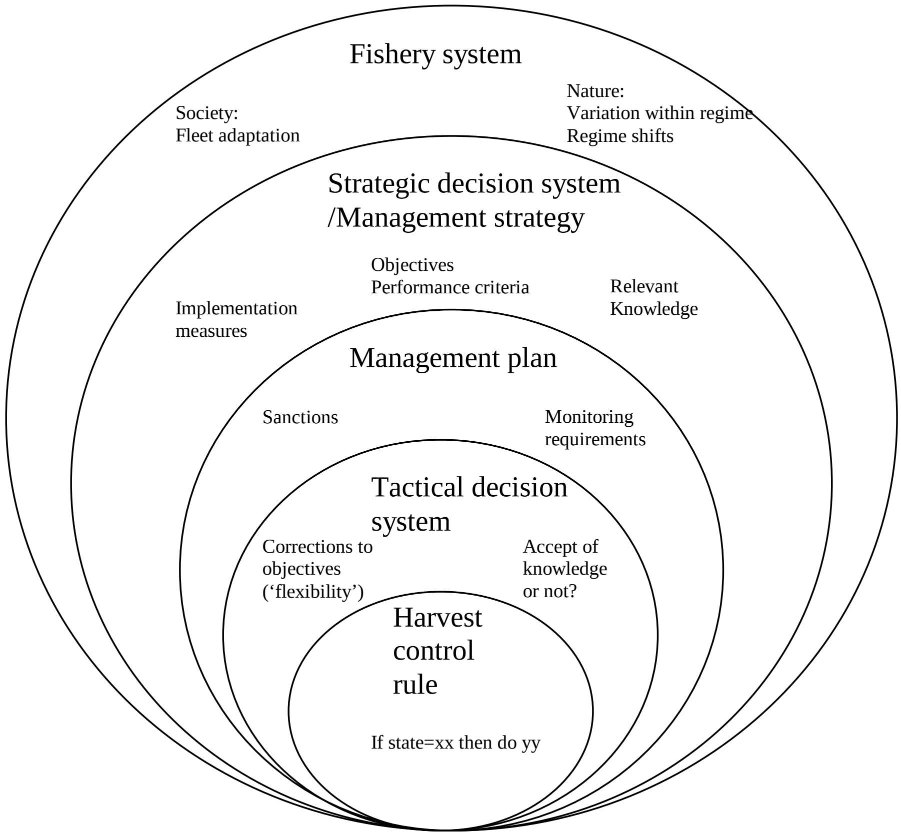


Figure 2.2. The management strategy onion. See text for descriptions of different elements.

An evaluation of a harvest control rule would in principle require the incorporation of all the important elements of the outer layers of the management onion. The HCR evaluations should be carried out against the background of alternative states of external conditions (fleet adaptations and natural dynamics) and to the alternative process dynamics on how the results of HCRs are treated in the fishery system. As an example, the effects of flexibility in the tactical decision-making system should be explored: at which level of flexibility does the efficacy of the HCR break down. Another example: when the knowledge about stock development goes lacking, can the HCR still work?

Many of the processes in the outer layers of the "management onion" are not amenable to a simulation approach and they relate to social processes that cannot be analysed through the lens of the natural sciences. The sensitivity of management strategies to these processes may in some instances be illustrated by robustness testing, but in the longer term a more comprehensive approach will be necessary. In general, the evaluation of management strategies are likely to involve analyses that go beyond the natural sciences which traditionally have defined ICES. ICES should either attract this wider disciplinary perspective or should seek cooperation with other organizations.

The primary focus of SGMAS is to develop a framework that will allow the evaluation of management strategies. In the short term, this will be addressed by defining the elements of the framework and by developing the software tools that will allow simulation of the potential effects of harvest control rules. But the Study Group is aware of the wider context in which these harvest control rules operate. This can partly be incorporated through robustness testing by exploring how sensitive the outcome of HCR simulations are to e.g. implementation bias, data uncertainty and natural dynamics. The wider context can also be incorporated by adding qualifiers to the outcome of simulation based on the analysis of the past performance of the fisheries or of fisheries elsewhere.

Within ICES, the Working Group on Fisheries Systems (WGFS) is tasked with the study of those aspects of the fishery system which are not amenable to natural science approaches. Much of the focus of WGFS is on studies that relate to the implementation processes, the relationships between science and management and the general institutional arrangements within fishery systems. In that sense there is a clear link between SGMAS and WGFS. This is expected to feed into the knowledge that is relevant for evaluating management strategies.

3 Types of management strategies – separate file

3.1 Introduction

There are several types of fisheries that require different management strategies. This section outlines some general types of fisheries and what kinds of management strategies they call for. A management strategy directed to fisheries targetting a single stock may call for a different strategy than those directed to a mixture of different species. Also differences in biological characteristics of exploited species such as short-lived, high production stocks versus long-lived, low production stocks; limitations to obtain timely crucial information on which to base decisions and area- or stock-specific objectives or problems may all call for different management strategies.

3.2 Types of management objectives

In the context of fisheries management Cochrane (2002) makes the distinction between goals and objectives, where goals can be rather broad and may imply trade-offs between different goals, while objectives are much more specific and formulated in such a way that they should all be simultaneously achievable. Cochrane (2002) also identifies four categories of goals; biological, ecological, economic and social (including both political and cultural goals). Goals might include such broad statements as “Ensure long-term sustainable use of the resource” or “Maintain employment in coastal communities”. These might then be translated into specific objectives such as “Maximise long-term yield”, or “Achieve stable and predictable catches over time”.

For the purposes of the present work, the term objectives is used in a somewhat broader sense, covering both broad and specific aspects. Objectives in this sense can thus involve trade-offs, and the way in which management evaluations can often be most helpful is in demonstrating these trade-offs. An example commonly encountered is the trade-off between the objectives of maximising catch and of ensuring year-to-year stability in catch. A greater overall catch may result from allowing more year to year variation in catch, but the extent of this trade-off could be evaluated through simulations. If objectives are specified in terms of employment this has a potential trade-off with sustainability objectives as employment translates into fishing activity and thus fishing mortality.

When advice given by ICES in response to requests by managers does not involve specified management objectives, ICES take the compatibility with the Precautionary Approach as an implicit objective. In HCRs which have been implemented within the ICES area, e.g in EU/Norway management agreements, this PA objective has typically been stated explicitly, i.e. it is a management objective to keep SSB above Blim. This is often coupled with less clearly stated objectives of catch stabilisation.

Commonly, biological objectives for fishery managers will be healthy/productive fish stock, high and stable yield, and low probability of moving a fish stock down to low-productive areas. Economic objectives could for example relate to maintaining profitable fisheries and social objectives to ensuring employment in coastal communities. Alternative HCRs may accomplish these objectives to a varying extent. For highly variable fish stocks, or fish stocks that are at an unproductive level, any HCR will imply trade-offs between the objectives mentioned. In particular, there will be a trade-off between the short- and long-term achievements implications of the HCR.

Ideally, fishery managers should clearly state the objectives they aim to achieve by introducing HCRs. Experience has shown however that such explicit statements are seldom given at the start of the process of developing HCRs. The process has often been to evaluate how various HCRs perform according to the various management objectives. Having done the evaluations, managers are in a better position to refine or define their objectives. The process of developing HCRs and defining the objectives can therefore proceed in an iterative process that involves a close dialogue between managers and scientists.

3.3 Types of fisheries

Fisheries are often conceptualized as the basic elements in a fishery system on which management actions are applied. In this section we outline different aspects that relate to fisheries and that need to be taken into account when implementing a management strategy. The aspects form different dimensions of fisheries.

Targeting single species – targeting multiple species

Targeting multiple species simultaneously (mixed species) or spatially/temporally distinct

Local vs. highly mobile

Small scale – large scale (artisanal to industrial)

National – multi national

Single gear/fleet vs. multi gear/fleet

Company owned – fisher owned

Economic status : comfortable vs. desperate

3.4 Stocks & range of biology

In this section we outline biological aspects that need to be taken into account when implementing a management strategy for a given fishery. This relates to the ‘framework’ aspect of the ToR, and also to the evaluation aspect – is the proposed strategy appropriate for this kind of stock? As with the types of fisheries, these attributes form dimensions that describe different elements of stock dynamics.

Natural lifespan, short – long

Stock movement, Sedentary & local – highly migratory

Distribution, wide - localised

Productivity, Low – high

Aggregation behaviour, schooling – non schooling

Commercial interest, low – high

Recruitment variability, low – high/spasmodic

Ecosystem (trophic level)

3.5 Information base

The information base (or knowledge production system) is an important element of fishery systems. Given a management strategy a particular knowledge production system would be required. An analytic stock assessment with annual catch forecasts is just one special approach to produce the knowledge base for tactical management decisions within a management strategy using annual TACs. In this section we outline different aspects that relate to knowledge production systems and that need to be taken into account when implementing a management strategy. These aspects form dimensions that describe different elements of knowledge production systems. However, there may be interdependence between several of the elements below.

Availability/reliability of analytical assessments: low - high

Availability/reliability of catch forecasts: low - high

Availability/reliability of fishery independent data (e.g. survey data)

Availability/reliability of fishery dependent data (e.g. CPUE data)

Availability/reliability of other data that constitute input to management decision process (e.g. interviews, private logbooks, information from the fishery about spatial distribution of fleet and/or fish)

Socio-economic features that have an impact on fisheries should be taken into account in management strategies. Therefore information on such features should also be considered part of the information base.

3.6 Management measures

Management measures are the mechanisms the fishery manager has to ensure sustainable utilisation of resources. In most fisheries, this can be achieved by regulating the quantity of fish caught, when and where they are caught and the size at which they are caught (Cochrane 2002). This can be done specifically by regulating one or more of the following:

Quota regulations

Vessel licensing

Effort regulation (days at sea)

Technical conservation measures, i.e.

- Gear regulations
- Area closures
- Seasonal closures
- Minimum landing size (MLS)
- Discard regulations
- Bycatch rules

(Subsidies etc. have interactions with these but outside current scope)

Specific issues in relating to the evaluation of the effects of these measures are discussed in Section 6.

3.7 Available HCRs for single species

The recent standard advisory practice by ACFM can be considered as an implicit harvest control rule with two-year catch prognosis based on stock one year prior to fishing seas. The catches derived are based on FPA unless the stock is below BPA. This variant should serve as a comparative reference for new proposals.

Most HCRs that have been presented to ICES for evaluation so far are of the “classic” three-stage archetype, with two trigger-points on the biomass scale, with specified, usually fixed, values for F when B is below the lower trigger point or above the upper one, with a smooth transition at biomass values between the two trigger points (see diagram in Section 5.5.1). In many cases this has been supplemented with constraints on year to year variation of TAC in order to stabilize the catch (Anon 2004,, MATACS: Kell & al, 2001, MATES: Kell & al, 2002, see also Sections 5.3 (NSS herring, 5.5 (NEA cod), 5.7 (NS Herring)) Additional flexibility around this archetype can be incorporated through an increase in F at high stock sizes. Some variants could also allow a buffer around the trigger points to avoid problems with knife-edge changes in advice at values close to the reference points. Similarly there is scope for asymmetry in the HCR such that at a given point on the biomass scale the advised F may differ whether the stock is increasing or decreasing.

An alternative is a decision rule on the basis of generalized parameters and/or in-year information. Generalized parameters: fishing mortality that the stock can sustain. In-year information: surveys or early catch rates. Such rules are presently used for short-lived stocks like anchovy and capelin but could also be applied to longer-lived stocks.

Direct effort-based HCRs have not yet been put into practice in the ICES area, but there are proposals in existence which incorporate elements of effort control and which could be translated into an HCR.

HCRs can be used to derive advice (e.g. TACs) on an annual or multi-annual basis. The approach being considered for the Canadian southern and northern Gulf of St. Lawrence cod stocks uses a multi-annual TAC which is modified according to a set of indices of stock abundance and catch rates

3.8 Specific additional problems for multiple species issues

Single vs. multiple stocks

Some management strategies need to be developed in a multi-species framework. The fisheries may be targeting a single species but management may need to consider their impact on other stocks or components in the eco-system. Examples are capelin and cod off Iceland and in the Barents Sea. More generally fish may be food for predators such as marine mammals and birds. Therefore it will not be possible to optimize yield from two such related species independently and rather a compromise will be required.

Mixed fisheries

Where several species are caught together in a mixed fishery and all these need to be managed, there is a need to couple these species together when considering management. Such mixed-fishery effects add considerable complexity to the management system. Such problems have been addressed for the case of relatively simple systems in other parts of the world. Juvenile sardine is caught as by-catch in the South African anchovy fishery. A HCR is in place to keep the by-catch low and protect the more valuable sardine stock. It is formulated in such way that given an estimate of percentage mix of both species in the catch which, is measured in-season, the anchovy TAC and the sardine by-catch allowance are determined (De Oliveira and Butterworth 2004).

4 Evaluation of strategies

4.1 Introduction

This chapter describes how long term management strategies can be developed, including the role of the different parties in the process. Examples are given for a number of fisheries and stocks for which such strategies have been implemented and evaluated. Further attention is given to the elements that may have to be considered in the development or evaluation of management strategies.

4.2 Interaction with management and interested parties on proposed HCRs

The objectives for fishery management vary, but often refer to attaining a healthy/productive fish stock, high and stable yield, and low probability of moving a fish stock down to low-productive states. Objectives like these, or others, are standards upon which any HCR should be evaluated. The choice of HCR will often reflect a trade-off between stated objectives and to which extent these objectives can be met in the short and long term. Bearing this in mind, the development and evaluation of harvest control rules needs to take place through an ongoing dialogue between ICES and the client fisheries managers. We have identified four guidelines to facilitate these dialogues.

Guideline One: Candidate HCRs should be identified by fishery managers and ICES in a dialogue process

ICES interacts with management through its advisory process. ICES started giving advice on harvest levels in the late 1970s and early 1980s. The form of ICES advice has developed considerably through time. At the outset advice was based on reference points like F_{msy} and $F_{0.1}$. Later, as a consequence of dialogue with managers, ICES gave harvest options if a stock was considered to be within safe biological limits and specific advice if it was considered to be outside such limits.

In 1997 the ICES incorporated the precautionary approach in its fisheries advice by establishing reference points, in terms of biomass and fishing mortality levels. Again, after extensive dialogue with managers, ICES stated that an alternative to advice based on the PA-reference points would be harvest control rules (HCR) which would also allow to take account (or compromise) for specific management considerations/needs, and management authorities were encouraged to formulate such HCRs.

To some extent, this dialogue between ICES and the managers has highlighted the need for managers to be proactive when formulating HCR, and management authorities have, to a certain extent responded to that need. There seems to be several ways this has been done;

A. Prior to a formulation of an HCR, management authorities may have forwarded requests to ICES, in the form of requests for simulation exercises. Based on analysis of consequences, the management authorities have been in a position to choose a HCR, upon which future advice could be based.

B. Formulation of HCR has also been done directly by the management authorities. This was the case for NEA Cod and Haddock where the managers identified HCR’s and forwarded them to ICES for evaluation.

C. Scientists from the relevant parties, have used the same biological forecast model and data as the ICES WGs to evaluate a number of scenario's/options, whereupon management authorities have selected a HCR. This process was chosen for the Norwegian spring spawning herring.

New candidates for HCRs should then be identified by fisheries managers, ICES or through cooperation between the two parties. In this regard, it is important to have a clear understanding of who has the responsibility to move the process forward.

This dialogue should not be restricted to ICES and fishery managers, but extended to include interested parties (e.g. the new regional advisory committees (RACs), fishermen, fish processors, NGOs).

Guideline Two: Sufficient time and resources should be allocated to the dialogue

No matter how well defined a set of HCRs may be, the interaction between managers ICES and various interested parties about their evaluation is a learning process for all parties. ICES' understanding of why managers have chosen to formulate the HCRs in particular ways will grow just as will the managers understanding of the various effects of the HCRs. For this reason attempts should be made to limit the time pressure on the discussions and provide the interactions with resources that reflect the importance of the fisheries being managed.

Guideline Three: Standards for acceptable risk

ICES should evaluate whether it finds the rule to be in accordance with its standards for responsible harvesting. Those standards are not, in themselves, scientific standards and should not be presented as such (see Guideline Four below). Rather, the standards should reflect ICES own commitment to the precautionary approach, the background of which can be found, inter alia, in the FAO Code of Conduct for responsible fishing or the UN Fish stock agreement. Thus, ICES should be in a position to reject a HCR if it is found not to meet required standards. More preferably, ICES may suggest amendments to the rule so that it meets the existing requirements. Within the HCR that meets ICES standards, it is the responsibility of fishery managers to choose HCR that implies an acceptable risk.

When the knowledgebase on fishery systems increases, evaluations of management strategies will be dealing with an increasingly number of factors. There is a need for close communication between ICES and management authorities concerning acceptable risk related to these factors.

Guideline Four: Care in protecting the "Science Boundary"

It is important in dialogues between managers and scientists for participants to be conscious about where the boundary is between what is a scientific decision and what is not (Gieryn 1983, Jasanoff 2002). When science is used to support any area of policy there is always some desire from the decision-maker's side to try to define issues as technical rather than political because they are under pressure to justify their decisions to their superiors and the public. Any decision that can be presented as the technical outcome of an objective process is easier to justify. The inappropriate "technisizing" of what are fundamentally political questions will in the long run undermine both the legitimacy of science as the source of authoritative descriptions of nature and of transparent political processes as the appropriate way to make decisions about policies, risks and the allocation of resources (Wilson and Delaney 2005).

The movement of the science boundary can be subtle, and will be part of a process. It is an interesting question, for example, how much a shift from giving stock-based advice to giving fisheries-based advice moves ICES away from traditional biological approaches. It is also important that broad discussions about HCR's do not blur the mandate of science specifically.

ICES should preserve for itself responsibility for conducting scientific assessments in the best available manner. Assessment products needed to drive HCRs might be added to the assessment, but agreement on an HCR structure should not necessarily mean dropping assessment elements not used by the rule.

Example: Norwegian spring spawning herring

After the collapse of Norwegian spring spawning herring (NSSH) in the late 1960s, it took two decades before the stock was at a healthy state. Being aware of the highly variable recruitment of the stock there was, both within management and the scientific community, awareness of the need to establish an HCR for the stock. The process to establish the HCR for the stock was based on several steps. First, scientists of the relevant parties met to simulate consequences of various HCR, being in the form of fixed F, or fixed F combined with annual harvest ceiling. The consequences of the various HCR's were presented to the managers who at first did not choose a HCR. New simulations were requested, and the relevant WG of ICES also provided simulations. This process was going back and forth between scientists and management authorities until the managers finally decided upon a HCR.

Example: North East Arctic Cod

During the 1990s, the TAC for NEA cod varied dramatically. Russia and Norway, responsible for the management of the stock, identified the need to establish an HCR for the stock in 2001. A sub-group of scientists and managers were given the task to explore relevant aspects for a HCR. Based on their report and on general consultations, Russia and Norway identified a HCR for both cod and haddock in 2002. The HCR were forwarded to ICES for evaluation. ICES evaluated the HCR for NEA cod in 2004, and pointed on the need to develop the rule further for situations when the spawning stock is below Bpa. Again, scientists from Russia and Norway worked together to simulate the consequences of various extensions of the rule. Based upon this work, the management authorities agreed upon an extended HCR (also covering SSB levels below Bpa) and forwarded the rule to ICES for evaluation.

4.3 Quantitative and qualitative evaluation

Some aspects of a management strategy can be evaluated in quantitative terms, like risks, yields, stability of catches, etc. This will typically be carried out though simulation. There are other aspects that cannot be quantified directly but still may have impact on management strategy performance and may provide insights that can be informative both as a guidance in general or in indicating where useful numerical approaches may be obtained. Such information is an integral part of the basis for evaluation, and the evaluation should not be restricted to what can be expressed numerically through simulation. Obviously, such information is essential when the management strategy is primarily based on that kind of information. For example, combined qualitative and quantitative indicators are being considered as an overall index of stock abundance for management purposes for the Northern Gulf of St. Lawrence cod, Canada.

4.4 Guidelines for Evaluation

Here we provide guidance for the evaluation of management strategies and HCRs. We list a number of items that should be addressed in the process of evaluation of a management strategy and note features that should be considered for each item. Some of the points covered in the list deal with the evaluation of management strategies in general while others pertain to more specifically to simulation.

This section should be considered as a description of those aspects that should be or could be considered in an evaluation. The list is not considered fully comprehensive as yet, and is under development.

4.4.1 General Considerations

Not all of the items listed will require detailed evaluation. The extensive list is provided as an aid memoir to the evaluation to ensure that the concepts laid out below are not accidentally ignored. In case where there are items that are not evaluated, but may possibly be relevant, this should be stated and communicated together with the evaluation of the management strategy or HCRs. To carry out an evaluation therefore requires consideration of each item, selecting or rejecting the requirement to include the item. The following criteria should be applied to each item under consideration:

- Does this item apply to the management strategy that is being evaluated?
- Even though it applies is its effect likely to be important? For simplicity should this item be excluded from evaluation?
- Is there sufficient information to effectively evaluate the use of this item in the management strategy?
- Where the item requires implementation: has the effectiveness of implementation been considered?
- In simulation studies
    - Can the item be parameterized for use in a simulation and has that been done with adequate verification?
    - Is the appropriate level of uncertainty included in the simulation directly for each parameter or dealt with as a general additional uncertainty?

4.4.2 Specific items

A. Management Objectives

The following aspects of management objectives should be considered. In cases where an objective is not clear, either the managers can be asked to be more explicit or the scientists can carry out evaluations in accordance with different interpretations of the objective.

A.a Broad objectives

Do the managers have objectives in relation to:

- Sustainability?
- Precautionary approach?
    - Are there reference points or other ways to tell whether the stock is managed in accordance with the precautionary approach?
    - Is a specific risk level defined?
- Ecosystem objectives
    - Consideration of, non-target species, eco-system function, habitat destruction etc;
- Socio-economic objectives.
    - If specific objectives are defined, do they have a direct or indirect influence on stock dynamics?
    - Can this influence be quantified?

A.b Operational Objectives

- Are there longer-term stock size objectives (a target, above a threshold)?

- Yield requirements
    - year to year stability
    - maximal long term yield
    - "acceptable" short term consequences in return for long term benefits
    - relative stability in shared stocks
- Stability of fishing mortality (fishing effort)
- Revenue related objectives.
- By-catch objectives (limiting impact on other species)?
- In a rebuilding situation are there rebuilding targets
    - Is there a time frame?
    - Is there a biomass requirement?

B. Conformity of a HCR to the management strategy

When considering HCRs as elements of a management strategy it is necessary to consider, whether the knowledge base supports the specific HCR and whether the management tools suit the stock biology. Specifically, it should be considered whether

- Is the specific HCR suited to the general characteristics of the stock(s) in question? (See Section 3, e.g. short-lived species would not be good candidates for multi-annual TAC or other measures, stocks exhibiting spasmodic recruitment may need different measures to protect large year classes as they recruit to the fishery.)
- Is the HCR is capable of achieving the objectives of the management plan? (For example: Are the reference points or trigger values set in a mutually compatible manner?)
- Is there is a suitable knowledge base to implement the HCR? (For example is the HCR based on stock-recruitment relationships that are sufficiently well known; and is the sampling of commercial catches sufficient to provide a sound basis for analytical approaches if the HCR requires this?)
- Are there known issues related to the implementation of regulations:
    - are 'black' landings known or suspected to be sufficient to distort cause and effect of the rule;
    - is there non-compliance with technical measures sufficient to hinder the achievement of their intended objective;
    - Can the implementation errors be quantified?

C. HCR simulation parameterization

In the simulation of a HCR, the parameterization needs to be fully documented and verified as far a possible. This is discussed in detail in Section 7. Here we provide only a brief list of the major items that require consideration. For evaluation purposes it is necessary to consider in detail the elements described in Section 7.2 and the validation described in Section 7.4.

C.a Does the biological part of the operating model represent the stock with a full range of plausible dynamics with respect to:

C.a.a recruitment;
C.a.b natural mortality;
C.a.c growth;
C.a.d maturity;

- *At a more complex level*

- *several species;*
- *multi-species interactions;*
- *cannibalism*
- *spatial aspects;*
- *seasonal/temporal aspects;*
- *density dependence;*
- *length based dependence;*
- *covariance between variables; and*
- *auto-correlation in, for example, recruitment.*

C.b Does the fishery part of the operating model represent the fishery with a full range of plausible dynamics with regard to

C.b.a selectivity-at-age (by fleet/mesh-size and discards);

C.b.b relation between effort/TAC and removal (either fishing mortality or numbers); and

C.b.c spatial structure?

C.c Is the simulation fully able to represent the knowledge and decision process.

C.c.a data collection (observation);

C.c.b assessment either fully or as a source of observation error;

C.c.c advice; and

C.c.d decision-making.

- *At a more complex level*

- *survey design;*
- *sample size;*
- *stratification;*
- *measurement error;*
- *length/weight measurement error;*
- *ageing errors;*
- *sexing errors;*
- *maturity errors*

D Management measures

Management measures consist of a variety of tools, TAC, effort control, fishery access, technical measures including gear regulations and area or seasonal closures. There will be some situations where technical measures require implementation in a simulation thorough simplification of the effect of the measures as a simple fishing mortality term, and in other situations through more detailed simulations. A detailed discussion of the issues is provided in section 7.6 although currently the required instructions for simulation are not available to the SG and need to be developed further.

- Does the management strategy include specific gear related technical measures: For example to change catchability (selectivity by size), to improve species selectivity or for environmental/ecosystem objectives (disturbance; contact)? Taking the following elements into account could be relevant:
    - change in mesh size and/or mesh shape, gear design and material;
    - introduction of devices to improve selectivity such as escape panels; escape measurements

- restriction on the number of different gears on board (one net rule)
- restrictions on specific fleets
- Can the effect of such measures be quantified?

- Does the management involve closed areas and seasons to protect certain parts of stock (E.g. juveniles, adults), key biological features such as spawning or for habitat protection
  - Temporary closure in time and space
  - Permanent closure (MPAs)
  - Can the effect be quantified?
- Does the management strategy include specific effort related measures, TAC related measures or a combination: for example operational limits, or capacity limits, designed to restrict fishing effort?
  - Limit to days at sea;
  - Limits vessel size of vessel horsepower;
  - Limits on number and length of gill nets or lines;
  - Can the effect be quantitatively related to fishing mortality?
  - Are there combined TAC and effort regulations
  - Are the units of effort measurement appropriate?

E The Robustness of the management strategy

A management strategy should be robust to uncertainties related to the data or to the assessment model, uncertainties regarding future states of nature, implementation error, etc. The current assessment method used to evaluate the stock may not be accurate and the effect of this needs to be taken into account. The simulation of HCRs is dealt with in Section 7. However, there are other sources of precision and bias that may need to be considered within the evaluation of the management strategy. Sources of bias include implementation errors.

- Precision and bias in the assessment
- How sensitive is the HCR to assumptions (e.g. recruitment model)?
- Is bias stable or dependent on stock and regulations applied (i.e. slowly changing bias causing overestimation during decline and underestimated in rises)
- Does management implement the HCR, or respond more slowly to restriction and faster to relaxation?
- Are possible implementation failures taken into account?
- Are technical measures implemented successfully?

These aspects can be dealt with consistently within the simulation framework as explicit errors or as a sensitivity analysis tested against a range of implementation failure.

Additional information that should be provided in the conclusions of the management strategy study

- The conditions under which the management strategy is applicable.
  - State the range of sensitivity covered in the evaluation.
  - Are there exceptional circumstances that need to be kept in mind, such as shifts in regime or change in state of stock outside the current data range that will require revaluation of the management strategy?
  - State a time period or duration after which certain elements should be verified or evaluated.
  - Are there parameters of the management strategy that may need to be revised under given circumstances?
- Is there asymmetry in the errors or costs; i.e. Are there some risks that need to be avoided more than others?
- Is forgone yield a suitable measure of cost of failure?
- Are there mechanisms to ensure that adequate action can be taken if the normal management strategy fails?

To improve on the dialog can we bring out information on management issues that may be helpful?

- Are there conflicting objectives and information on trade off required between them? Does the evaluation inform on these tradeoffs?
- Can we highlight where tradeoffs between conflicting objectives seem counter-productive?
- Where short-term gains are giving major long-term losses.
- In a dialog process we can advise on questions that may be more informative than those posed at the start of the study.
- Are they critical aspects not previously identified that must be achieved for management to work in this way?
- Have the performances of alternative sensible management plans or HCRs been evaluated and presented for comparison?
- Following on the above, is there a more robust alternative management plans or HCR that is able to deliver more effectively the management objectives?

5 Examples of harvest control rules

5.1 Southern Hake and Iberian *Nephrops* Stocks (ICES Div. VIIIc and IXa)

5.1.1 Background

In 2002, ACFM recommended very drastic measures for the Southern Hake stock and the Iberian stocks of *Nephrops*: as close to zero as practicable in the case of Southern hake, and a zero TAC for *Nephrops*. Moreover, stocks managed in conjunction with hake should be managed accordingly to limit the catch of hake to the greatest possible extent. A rebuilding plan with such measures probably was suggested to be in place for several years. Regarding *Nephrops*, due to the mixed nature of the fisheries, ICES recommended that suitable technical measures (closed areas, closed seasons, etc.) were investigated for implementation at the earliest possible opportunity in order to help rebuild the stock.

In June 2003, a Subgroup on Management Objectives (SGMOS) of the Scientific, Technical and Economic Committee for Fisheries (STECF) was formed to address the topic of Recovery plans of Southern hake and Iberian Norway lobster stocks. This report was evaluated and adopted by correspondence by STECF in July 2003.

At present the proposal of the recovery plan is under discussion, due to some difficulties on the agreement between the Industry and Administration in relation to the size and period of the proposed closed areas.

The source of the following descriptions is the report of SGMOS (2003).

5.1.2 Management Objectives

The proposed measures intend to rebuild both stocks in terms of SSB. In the case of the Southern Hake the SSB target was the level reached in late 80s and early 90s (around 23000 t) but for *Nephrops* no target was possible to indicate due to the complex dynamics of this species.

5.1.3 HCR conformity to management plan and strategy

It is no possible to evaluate this issue because the recovery plan is still under discussion. In fact, the TAC_{2005} (5968 t) for hake was not set under the recovery plan criteria, being slightly higher than the TAC_{2004} (5950 t).

5.1.4 Stock simulation parameterization

During the SGMOS meeting different simulations with a set of chosen scenarios for Hake were carried out, which results were afterwards evaluated in *Nephrops*, using the CP software in R (Azevedo and Jardim, 2003).

The existing reference points for the Southern Hake were not considered appropriate by SGMOS, and a recovery target based on 2003 estimate of $F_{0.1}$ (0.15) was chosen. Uncertainties were included in for F-at-ages, higher CV for ages 0 to 2, due to underestimation of catches of fish below the MLS of 27 cm. The coefficient of variation (CV) of F was set at 30% in these age groups and 20% for older ages. Different options for the rest of parameters were used for simulations:

- The recruitment was set at two different values, an optimistic and a pessimistic recruitment.
- The F strategy was defined by two different strategies, a decrease of 10% each year, and an inverted parabola F strategy (high decreases in the beginning of the period and small decreases in the end). The objective was to simulate a linear implementation situation and a situation of delay in applying the proposed strategy. It was assumed that fishing mortality was directly related to effort, so that a 10% reduction in effort should lead to a reduction of up to 10% in F.

The simulations indicated clearly that the differences in recruitment have a high impact on the rebuilding of SSB but the different F strategies are not significant in the recovery time. With a median recruitment the stock will rebuild to SSB levels similar to the early nineties (a 50% increase from current levels and 120% increase from lowest observed SSB) in 6 to 7 years, but if a low recruitment occurs it will take 9 years for the stock to rebuild to that reference level.

For Nephrops the effort of an F strategy of 10% decrease per year was analyzed for *Nephrops* (males) in Functional Units 28-29 (Portuguese waters). This F strategy does not guarantee the rebuilding of the stock. A second simulation was carried out with an inverted parabola F strategy (high decreases in the beginning of the period and small decreases in the end). This strategy showed that the SSB could rebuild to high values (100% above current levels). Based on the two scenarios it was considered that a 10% decrease in F was not sufficient on its own to rebuild the *Nephrops* stocks, so this effort reduction should be implemented together with a set of additional technical measures to assure a significant and fast decrease in F, equivalent to 50 % in 2 years, as the closure of the selected *Nephrops* fishing grounds to all fishing.

The proposed recovery plan had the following components:

- A 10% annual reduction in effort to all vessels which land hake and *Nephrops* in these areas,
- The closure of selected *Nephrops* fishing grounds to all fishing.

5.1.4.1 The Robustness of the HCR to uncertainty and bias in infor mation

It is no possible to evaluate this issue because the recovery plan is still under discussion.

5.1.5 Simulation of Technical Measures

No simulations have been conducted on technical measures. However, the convenience of implementing closed areas was widely discussed at SGMOS: Closure of all or part of a fishing ground for a period can be used to protect a particular stage of the life history of the target species – e.g. a spawning area or nursery ground. Such a measure can also be used for other purposes, e.g. to reduce fishing effort, although this always has the problem that closing part of an area can lead to reallocation of fishing effort to other areas. A closed area can be particularly effective in cases where the target species is confined to a relatively well-defined area so closing the area would result in complete protection of that component of the population. This applies to *Nephrops* so closures of this form could be an effective conservation measure for *Nephrops*.

5.1.6 Implementation failures considered in the simulation

No.

Items that should provided in the conclusions of the HCR study

No relevant at present, because the recovery plan has not been yet approved.

Can we point out management issues that may be helpful

ACFM in 2004 advised for both species of anglerfish in Atlantic Iberian waters a zero fishing mortality in 2005, to bring Spawning stock biomass back to $\mathbf{B}_{MSY}$ in the short term. If this is not possible then a recovery plan should be established that will ensure rapid and safe recovery of the SSB above $\mathbf{B}_{MSY}$ (ICES, 2004b).

The proposal for Southern Hake and *Nephrops* recovery plan does not take into account these species which are caught in the same fisheries. Due to hake, *Nephrops* and anglerfish are caught together by some fisheries, an integrated recovery plan instead of two may be recommended.

5.2 Northern Hake

5.2.1 Context

Following concerns over the level of the SSB which steadily declined during the 80s and stabilized at a low level afterwards and poor recruitments at the end of the 90s, an emergency plan was implemented in 2001 by the Commission for the recovery of the northern hake stock (Council Regulations N°1162/2001, 2602/2001 and 494/2002). First, a 100 mm minimum mesh size has been implemented for otter-trawlers when hake comprises more than 20% of the total amount of marine organisms retained onboard. This measure did not apply to vessels less than 12 m in length and which return to port within 24 hours of their most recent departure. Second, two areas have been defined, one in Sub area VII and the other in Sub area VIII, where a 100 mm minimum mesh size is required for all otter-trawlers, whatever the amount of hake caught. Following this emergency plan, the Commission proposed a regulation [COM(2001) 724] which included harvest control rules for the selection of TACs for a number of fish stocks including northern hake. For hake, the proposals were that the TACs shall not exceed a level for which scientific evaluation has indicated that they will result in an increase in the quantities of mature fish in the sea of 15% and that yearly variation in TACs should not exceed 50%.

A STECF Subgroup on Review of Stocks (SGRST) met on 20-22 March 2002 to evaluate the risks and benefits of the proposed harvest control rules. The software CS (version 4) was used to evaluate the HCR. Biomass based and fishing mortality based harvest control ruled were tested. From the scenarios tested, it was found that most had a high probability to achieve a recovery (SSB above Bpa) during a 10 years period.

Measures for the recovery of the northern hake stock that were finally established in 2004 (EC Reg. No 811/2004) are different from the one tested above and have not yet been evaluated. The recovery plan is aimed at achieving a SSB of 140 000 tonnes (B_{pa}) by limiting fishing mortality to F=0.25 and by allowing a maximum change in TAC between years of 15%. It is important to note that since HCR evaluation conducted in 2002, the perception of stock status has also changed due to recent improvements in recruitment level. Current fishing mortality is just above F_{pa} and recovery of the stock is expected to occur at medium term under statu-quo F.

5.2.2 Management Objectives

The measures implemented are for the recovery of the stock. The recovery plan shall thus aim to increase the quantities of mature fish to values equal to or greater than 140 000 tonnes (Bpa). There are no longer-term objectives.

5.2.3 HCR conformity to management plan and strategy

We can consider the HCR suitable for the data and the management and stock biology of this stock. However, knowledge base is poor on certain aspects like S/R relationship, growth, discards (see below).

5.2.4 Stock simulation parameterisation

The population dynamics of the fish stocks are represented by a standard age-structured model with fixed, precisely-known natural mortality rate, maturation, growth and exploitation pattern. The population numbers, standard errors, exploitation patterns and stock and recruitment models and fits were taken from the most recent ICES assessments using XSA (including any revisions undertaken by the ICES Advisory Committee on Fishery Management) (ICES, 2002).. The uncertainties represented in the simulation are recruitment variability and variance in the observation of population abundance at age, at the start of the year in which management measures are to be applied.

Management decisions evaluated were made on the basis of observed populations, and were of three types:

a) Setting a TAC on the basis of a maximum allowed fishing mortality rate (typically, Fpa);
b) Setting a TAC on the basis of a maximum allowed percentage change in the TAC since the previous year;
c) Setting a TAC such that the spawning biomass is expected to increase by a specified percentage during the corresponding year

5.2.5 The Robustness of the HCR to uncertainty and bias in informa tion

There are several sources of uncertainty for this stockand their impact has not been evaluated. This concerns mainly growth, discards estimation, and CPUE indices in the earlier years. The CPUE series and surveys do not cover the whole area. There is a lack of reliable recruitment indices for this stock, which has implications for the quality of short-term forecasts. Northern hake is a wide-ranging stock where the stock definition is considered to be problematic. There are concerns about the accuracy of aging data and the calculation of historic catch-at-age data.

5.2.6 Simulation of Technical Measures

A STECF "Hake Technical Measures meeting" held in Lisbon from October 27 to 31, 2003 was requested to evaluate the impact of the technical measures adopted by Regulation 1162/2001. No simulations were conducted during that meeting. The group concluded that, with the information available, it was not able to measure any impact.

5.2.7 Implementation failures considered in the simulation

Implementation failures were not taken into account.

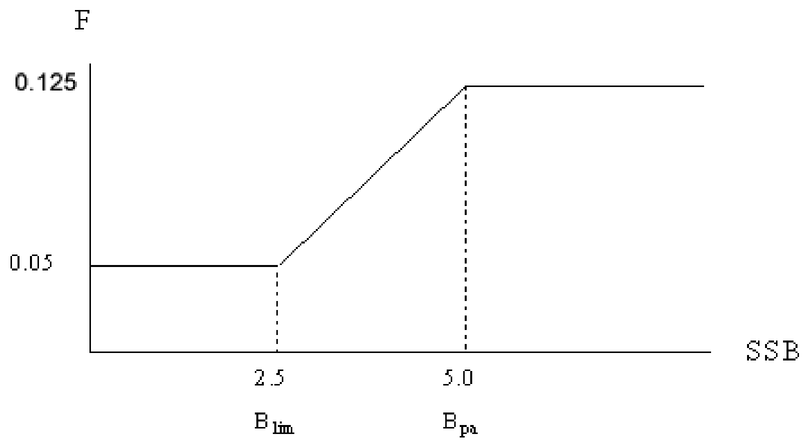
5.2.8 Items that should provided in the conclusions of the HCR study

A series of values of F and Biomass constraints were tested. Almost all scenarios tested lead to a high probability of recovery in the 10 years period. For none of them the maximum 50% variation in yield was found to be a constraint.

5.3 Considerations during the evaluation for Norwegian spring spawning herring

5.3.1 Background

The harvest control rule for Norwegian spring spawning herring was decided upon by the Management Agency i.e. 5 –party coastal states (EU, Faroe Isl, Iceland, Norway and Russia) in 1999 and amended in 2001 with measures to ensure rebuilding of the stock in case if SSB should fall below Bpa. As a basis for deciding the Management Agency appointed a group of scientists and economists to make consider possible HCRs for this stock. (Anon, 1999): The agreed HCR has the following structure:



5.3.2 Management Objectives

The following management objectives were considered:

1. High long term yield , 2) Stability in catches and 3) Low probability of stock collapse i.e. precautionary approach to management. The agreed HCR was a result of a discussion on basis of a decision (trade-off) table given in the Coastal State WG report, and the final agreed HCR did not reflect measures to obtain objective
2. to any significant degree. F_{pa} for this stock is 0.15, the agreed maximum fishing mortality of 0.125 is more relevant with regard to objective 1) than using the F_{pa} as a maximum fishing mortality in the HCR

However, only the performance of the HCR relative to objective 3) was formally evaluated. This was done by ACFM and the HCR was considered to be in accordance with the Precautionary approach in fisheries because of a low probability (>10%) to fall below B_{lim} in the medium term. By introducing the rebuilding element (measures when stock below Bpa) the risk of falling below Blim in the medium term was halved.

5.3.3 HCR conformity to management plan and strategy

This aspect was considered by the Coastal State wg. The broad stock characteristics were a large pelagic stock with spasmodic recruitment. Thus a low fishing mortality was desired in order to be able to utilize the strong year classes over a longer period.

5.3.4 Stock simulation parameterisation

The management agency requested from ICES medium term simulations on yield (range of F's from 0.1 to 0.175) and risk of falling below Blim. These simulations were carried out by the ICES Northern Pelagic working group, using the SeaStar assessment program, and there was a prerequisite from the managers that these simulations should be the basis for the HCR considerations. The considerations of the Northern Pelagic working group on S/R, growth parameters etc were evaluated in a routine sense as ACFM reviewed the assessment report from the Northern Pelagic working group

5.3.5 The Robustness of the HCR to uncertainty and bias in informa tion

Assessment (starting point) error and stochastic S/R included in the medium term simulations.

5.3.6 Simulation of Technical Measures

No such issues have been considered

5.3.7 Implementation failures considered in the simulation

No implementation failures were considered in the simulations. Some irregularities the catch statistics (misreporting, water content) were discussed, but these have not yet been taken into account in assessment or prognosis estimation by the Northern Pelagic working group

5.3.8 Items that should provided in the conclusions of the HCR study

The management agency implemented and made the HCR operational immediately. It can be said to be successful in the sense that the stock has stayed above Bpa since the introduction of the HCR and the estimated present SSB and the recruitment for the coming years seem to be satisfactory. In general, there has not, from the industry of management agency, been any serious considerations on any major revisions of the HCR.

5.3.9 Can we point out management issues that may be helpful

The HCR can be further developed if the management agency will give renewed priority to the management objective of year-to-year stability in catches. Measures included could be catch ceiling and/or maximum change in year to year TAC.

Multi-annual TAC could also be considered as a part of the HCR for this stock

5.4 Evaluation of the Blackwater Herring Management Plan

Multi-annual TAC procedures for the Blackwater herring, a local spring-spawning stock in the Thames Estuary. The stock sustains a small local commercial fishery (peak catch of 606 t during the 1972-1973 fishing season) in the Thames Estuary. Loss of local consumers' interest in the herring product has resulted in a gradual decline in catches and fishing effort for the stock. The stock is assessed using XSA, which relies on the information provided by a scientific trawl survey, and management advice is provided before the fishing season starts in October. Given its current low economic value, managers have requested evaluation of options for multi-annual Total Allowable Catches (TACs) in an attempt to reduce the frequency (and costs) of assessment and associated management advice.

A simulation framework was developed to evaluate the response of the fishery system to a number of multi-annual strategies. The form of the biological model was of single species age-structured population. Removals were undertaken by a single fleet and implementation error was taken into account by simulating the levels of TAC overshoot as measured historically. The assessment was simulated by introducing uncertainty and bias in the numbers at age generated by the operating model. A tentative relationship between sea surface temperature and recruitment was used to predict the impact on future recruitment of increasing sea temperatures in the context of global warming. Hypotheses of auto-correlation and of an environmental effect on recruitment, together with trends in weight-at-age and initial spawning stock biomass level, form the basis for sensitivity tests of the management options considered.

5.4.1 Management Objectives

Broad objectives

Broad objectives such as sustainable utilisation and recautionary approach to management were considered

Management within an ecosystem context. Not mentioned

Socio-economic requirements were:

Reduce management costs by multi-annual strategy

Provide stability in catches

Allow flexibility regarding area where the trawlers operate

Capacity objectives were not relevant.

Operational Objectives

Recovery objectives and longer term objectives were not relevant. Yield requirements were taken into account but by-catch objectives although relevant were not addressed.

5.4.2 HCR conformity to management plan and strategy

A number of management strategies considered applicable to the management and biology of the stock were compared: 1) *annual revision* which corresponded to the strategy in place: TAC was set annually, based on keeping $F = F_{pa}$; 2) *multi-annual, no constraints (3-year/5-year)*; 3) *multi-annual (10%/20%/40%), additional constraint* and 4) *fixed (low/high).*

The HCR adopted (3-year fixed TAC with 40% constraint in TAC variability) seemed appropriate for the fishery which is exploited as a single stock. Relevant biological characteristics are:

NUMBER OF YEAR CLASSES: 8 (last is a +group)

RECRUITMENT HIGHLY VARIABILE (CV = 70%)

SHOALING PELAGIC SPECIES

and the HCR seemed appropriate given those characteristics.

The knowledge base was considered sufficient.

Likely implementation issues known were overshooting of the TAC and under-reporting.

5.4.3 Stock simulation parameterisation

The HCR is robust to alternative S/R relationships. Evidence of density-dependence pointed to Ricker model as the appropriate one. Effect of increasing sea temperature on recruitment was tested. The S/R relationship covered the range to be simulated.

The basis for limit and target reference points was examined. A slightly reduced Fpa was used in the HCR as target F.

Selection at age was based on an average of the most recent 3 years' estimate. However, it is possible that the fishery could target strong year classes and that was not simulated.

Performance of HCR to trends in weight-at-age was tested.

The fleets involved in the fishery were modelled individually.

5.4.4 The Robustness of the HCR to uncertainty and bias in informa tion

Precision and bias in the assessment were measured and used to simulate the assessment in the simulation framework. No evidence of auto-correlation in numbers-at-age in the catch was found in the data. The HCR can therefore be considered robust to historical levels of uncertainty and bias.

The HCR was to be applied to derive multi-annual TACs. The rule was tested for periods of different length and appeared to perform well for 3-year TACs.

5.4.5 Simulation of Technical Measures

New technical measures were not introduced when adopting multi-annual TACs. The existing measures were not evaluated by simulation.

5.4.6 Implementation failures considered in the simulation

In addition, robustness to what was called a loophole in the management of the stock was tested. At the time, the TAC only applied to the drift-net area therefore only that fishery could be closed when the TAC was met. This situation could easily result in exceeding the TAC. Implementation of a 3-year fixed TAC with 40% constraint in TAC variability and a slight reduction in target F to protect the stock in the case of overshoot seemed appropriate given that the stock was within safe biological limits and the strategy compared well in terms of yield and risk with the existing approach of annual TAC revision.

The possibility of misreporting has not been taken into account in the simulation framework.

5.4.7 Items that should be provided in the conclusions of the HCR study

Given a very weak market a conservative TAC based on the most recent assessment was put into place for three years in the 2003 – 04 fishing season. The 3-year period was defined as experimental with a commitment to maintain existing levels of sampling and monitoring. Likewise, an update assessment was to be performed every year with the purpose of data checking and to provide early warning if problems occurred. It was agreed informally that if the TAC were regularly exceeded beyond the level seen in recent years (16%) the multi-annual TAC strategy would be revised.

A number of scenarios related to the stock dynamics, environmental effects on recruitment levels, and compliance were formulated. The base case represents the most likely scenario or the one that corresponds to historic conditions. The remaining scenarios were formulated by replacing a condition in the base case by an alternative but also plausible one. These scenarios form the basis for sensitivity tests to evaluate the performance of the management options if conditions depart from those assumed in the base case. A summary description of the base case and alternative operating model scenarios for conditions regarding stock dynamics, environmental effects on recruitment levels, and compliance is presented in the following Table:

	Base case	Alternative scenarios
Initial SSB (April 2002)	High (711 t)	Low (501 t)
Weight-at-age	Constant	Declining trend (-1% per annum)
Autocorrelation in R	Negative (-0.2)	No autocorrelation (0)
Stock/Recruitment	Ricker (1962-2000)	Increase in SST (+2% per annum)
TAC compliance	Catch=TAC	TAC overshoot (historic data)

Conflicting objectives such as maximising catch and reducing variability in TACs were identified. Stability took preference given weak market.

Can we point out management issues that may be helpful

Some questions that where addressed to interested parties in a dialogue process were:

Is there a minimum catch level that needs to be guaranteed for the fishery to break even?

What level of constraint in TAC variability would be desirable?

What is the maximum uptake that can be marketed?

Under conditions of a strong herring market, would it be feasible to close both the driftnet and the trawl fishery when the TAC was met?

Other HCRs were tested by simulation and the one selected seemed robust and able to deliver effectively the management objectives.

5.5 Evaluation HCR for NEA cod

5.5.1 New harvesting strategy and corresponding HCR

At the 31st session of The Joint Norwegian-Russian Fishery Commission in autumn 2002, the Parties agreed that the new harvesting strategy for Northeast Arctic cod and haddock should incorporate the following considerations:

- to prepare the basis for a long-term high yield of the stocks
- the desirability to obtain a high degree of stability in the TAC from year to year
- full utilization, at all times, of the most recent information available on the stock development

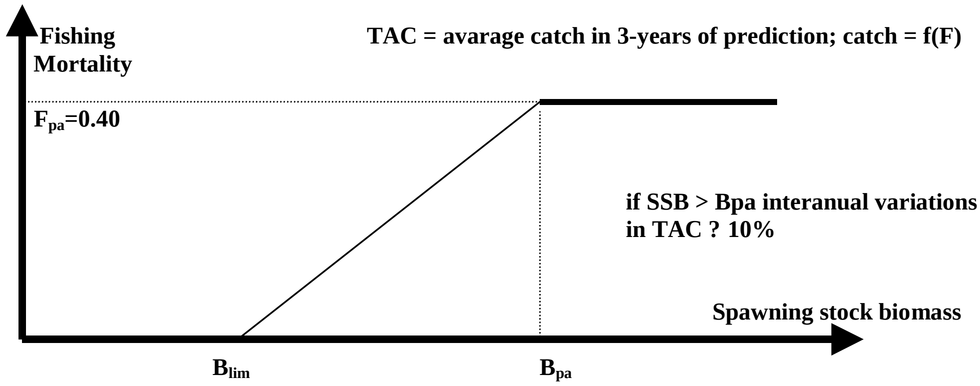
On this basis, the HCR for setting the annual fishing quota for Northeast Arctic cod was developed:

- estimate the average TAC level for the coming 3 years based on $\mathbf{F}_{pa}$. TAC for next year will be set to this level as a starting value for the 3 years period
- the year after, the TAC calculation for the next 3 years is repeated based on updated information about the stock development, though such that the TAC should not be changed by more than +/- 10% compared with the previous year's TAC.
- if the spawning stock falls below $\mathbf{B}_{pa}$, the Parties should consider a lower TAC than according to the decision rule above.

In 2003 the ICES was requested to evaluate the HCR. This work takes more than a year because of necessity to develope an appropriate procedure and a specific computer programme for evaluation. The evaluation of the new harvesting strategy have been performed during intercessional work of group of scientists from Norway and Russia and was finalised on AFWG in 2004 (ICES 2004c). The rule was incomplete in the last part and for performing the evaluation it was amended by ICES assuming the procedure for rebuilding the stock:

- if the spawning stock drops below B_{pa}, the fishing mortality is reduced linearly to zero at B_{lim}. No limitations on the year-to-year variations in TAC in that area.

The amended HCR has the following structure:



5.5.2 The approach used for HCR rule evaluation

The general modelling approach taken is the same as described by Skagen et al. (2003). Results of long-term stochastic simulations were given in report of AFWG (ICES, 2004c).

5.5.3 Model description

The simulation model was developed for testing the harvest control rule for Northeast Arctic cod. Simulations were carried out using the PROST software for stochastic projections (see section 8.2.4).

The biologically detailed population model for cod for use in the evaluation was developed. Several variants of the population model were tried. The model used in evaluation included following elements:

- Density-dependent weight at age in stock (average for 1946-2002 used for age groups where density-dependence was not found).
- Weight at age in catch is a function of weight at age in stock.
- A recruitment model using a segmented regression approach, as well as a periodic term (describing autocorrelation in recruitment) and a trend term including the mean weight of spawning fish.
- Time series (1946-2002) average used for maturation for age groups without density-dependent model.
- Cannibalism not modelled directly because stock-recruitment relationship is based on a time series of spawning stock and recruitment (1946-present) where cannibalism is not included.
- Exploitation pattern: 2000-2002 average used for all years.
- Assessment error CV 0.25, normally distributed. This value is large enough to account for the most extreme assessment error experienced, which is about a factor of 2 both for F and SSB.
- No uncertainty in weight at age, maturity at age or natural mortality at age.

Catch was implemented using the fishing mortality derived from the HCR and the given exploitation pattern. In all cases, 1000 simulations for the period 2003-2103 were performed and the results for the last 80 years of this period were considered. The stock size for 2003 (initial data) was taken from the 2003 assessment.

A possible influence of implementation error was tested using 20% higher F=0.5 in

HCR. It was stated that in this situation the rule is still consistent with the precautionary approach.

The simulations indicate that, when the rule has been established for a number of years, the probability of SSB falling below Bpa or Blim is very low. The amended HCR was considered by ICES as consistent with the precautionary approach.

5.5.4 Reality check of model

In order to do a reality check a run was made with fishing mortality equal to average fishing mortality for the period 1946-2002. The average stock size, catch and recruitment for this run were compared with the average values for 1946-2002 from the 2003 assessment. The comparison indicates that the model performs reasonably well.

5.5.5 Further work on Northeast Arctic cod HCR evaluation

The new version of HCR for cod

At the 33^{d} session of The Joint Norwegian-Russian Fishery Commission in autumn 2004, the results of HCR evaluation were reviewed and Parties agreed that the rule should be amended for situations when stock rebuilding is needed. The last point of the rule was changed by the following consideration:

- if the spawning stock falls below Bpa, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from Fpa at Bpa, to F= 0 at SSB equal to zero. At SSB-levels below Bpa in any of the operational years (current year, a year before and 3 years of prediction) there should be no limitations on the year-to-year variations in TAC.

The request to evaluate this rule was sent to ICES in 2005.

5.5.6 Maximising long-term yield for NEA cod

The 32nd meeting of the Joint Norwegian-Russian Fisheries Commission requested an analysis of maximum long-time yield from the most important commercial species in the Barents Sea, based on existing knowledge. The starting point shall be the dynamics of the Northeast arctic cod and account should be taken of the interactions between cod and other species that influence the yield of cod. The investigation shall include all ecosystem elements that are available for investigations, including natural and human-generated effects on reproduction, growth and mortality.

A time schedule for this work is under preparation. This work will be done by Norwegian and Russian scientists, and will build upon the work on management strategies presented here.

5.6 Icelandic cod

5.6.1 Original work

Management of the Icelandic cod fishery has been a hot topic in Iceland since the early 1990's. At that time the spawning stock was predicted to fall below historic minimum except major reduction in effort (TAC) occurred. In 1992 the minister of fisheries appointed a working group that had the role to advice on the “exploitation of fish stocks in Icelandic waters so maximum yield from Icelandic waters would be reached in the long run”. The group consisted of 3 econometrists from the National Economic Institute, two fishery scientists from the Marine Research Institute and two members came from the fishing industry.

The working group looked at 3 species cod, capelin and shrimp. Harvest Control Rule for the cod fisheries was the main goal of the working group but capelin and shrimp were included as they are important prey species of cod, but at the same time important for the commercial fisheries.

The working group delivered a preliminary report to the minister of fisheries in 1993 and a final report in 1994. Their work was published in Baldursson et. al (1996).

5.6.2 Management Objectives

The group looked for the fishing mortality that maximized current value of profit from the fishery using a discount rate of 5%. Stability of catches was not explicitly modelled but

different values of floor in the TAC were investigated. The probability of stock collapse (SSB < 200 kT) was not explicitly put in the objective function but was an important criteria in selection of a candidate HCR.

5.6.3 Simulation work.

The working group used age disaggregated models for cod and capelin but a biomass model for shrimp. Stochasticity of recruitment was implemented for all stocks but a stock-recruitment relationship was only implemented for cod, but the models for capelin and shrimp were considerably simpler than those for cod. Assessment error was considered to be log-normal with CV of 0.15. Implementation error was not explicitly included.

The simulations were done in Excel using the @Risk add in.

The biological model was coupled with and economic model that included price for the products and the cost of fishing. Reduction of price with increased supply was modelled. Regarding cost the assumption used was that cost per effort unit was fixed. The relationship between available biomass and catch per effort unit in the cod and the shrimp fishery was such that doubling of available biomass lead to 63% increase in CPUE. It turned out to be this reduction in cost of fishing that was the most important factor for location of the optimum. The work included interesting consideration on what to include in the cost function, depending on social circumstances and what interest rate to use to calculate the current value of the profit. The option of maximizing an utility function where uneven income got negative penalty was investigated instead of having floor in the TAC .

In their work the group investigated a number of different fishing mortalities as well as different levels of the floor in catches both with regard to the current value of the profit as well as risk of stock collapse.

5.6.4 Proposed Harvest Control Rule

The results of the work were that the optimal HCR for cod was very similar whether capelin and shrimp were included or not. The group originally put their recommendation in terms of percent of spawning stock but later changed to a percentage of what they called ”catchable biomass” which is the number of age groups 4 and older in the beginning of the year multiplied by weight at age in the catches in the same year. The recommended percentage was 22% and was supposed to lead to $F_{5\text{-}10}$ of 0.35 with the selection pattern used in the simulations. The proposed rule included a stabilizer so the TAC for the next year was the average of the TAC for the current year and 22% of the catchable biomass in the beginning of current year.

The suggested HCR did not have any biomass trigger point and included a floor in the catches that leads to increased fishing mortality when the stock becomes small. No technical measures were proposed.

5.6.5 Implementation of the Harvest Control Rule

The government took notice of the recommendation of the working group, but increased the ratio harvested from 22% to 25%, which according to the working group results did not lead to much increase in risk of collapse. Also a catch floor of 155 kT was adopted because it gave an acceptable risk of collapse. The catch stabilization proposed was not included but instead the TAC was 25% of the average of the catchable biomass in the beginning of the current year and in the beginning of the next year.

The HCR was applied for the first time for the fishing year 1994 -1995. The first 2 years the TAC was 155 kT but landings were 10 – 15 kT higher as part of the fleet worked in and effort control system and their catch was not properly accounted for. The reduction of effort by the trawler fleet was on the other hand substantial, possibly because the fleet migrated to fisheries outside the Icelandic EEC.

One thing that was done following the reduction in cod quotas was to compensate for the reduction by increase the haddock and saithe quotas. This lead to fishermen complaining about unavoidable cod by catch when they were trying to fish their haddock and saithe quotas and this discrepancy in harvest rate of different species is not in line with current recommendations which call for balance in fishing mortality of species in mixed fisheries.

5.6.6 Changes to the harvest control rule.

Soon after the HCR was adopted CPUE started to increase and the estimated stock size grew much faster than predicted in the simulations done in 1994. Fishermen claimed that the stock was much larger than the MRI estimates. There was substantial high grading as exemplified by increased mesh size of gillnets and there were stories about substantial discard of small (4-6kg) gillnet fish.

But apart from these problems everything seems to be going well until the year 2000 when the assessment indicated much worse state of the stock than previously considered and the TAC would have been reduced from 240 kT to 180 kT in one year. There were even indications that the stock might still be overestimated and the following year these indications turned out to be correct.

In this course the minister of fisheries changed the HCR or amended it by limiting interannual changes in TAC to 30 kT but removing the TAC floor. This amendment lead to very high exploitation rates in the following two years. The most severe problem was that the amendment came when large overestimation was noticed and the stock size was below any reasonable candidate for B_{lim}. If both catch stabilization and action to be taken below a trigger biomass had been included in the HCR the situation in the year 2000 would teach us that it has to be defined whether catch stabilization is effective independent of the state of the stock. The amended catch rule has not been approved by ICES as being precautionary while the original HCR was accepted.

Much discussion has been going on about what happened in the years 1997 - 2000 and most fishermen believe that there was much more cod around in 1997 - 1998 than is now considered but it was either discarded or migrated away. The official explanation by the MRI is that most of the discrepancy is overestimation caused by increased availability of cod and analysis of the data indicate that the overestimate should have been around half of what is was, and that the remaining was half caused by use of multiple fleets for tuning in the assessment. The problem was aggravated by the fact that the 1996 yearclass was the smallest one for at least 50 years and the yearclasses 1994 – 1996 probably the worst three in row in the 20th century.

As described earlier high grading became a problem after the implementation of the HCR. This high grading has lead to depletion of big cod, but in recent year fishing effort towards large cod has been limited by extensive closures of spawning areas and now mesh size of gillnets has been limited to 8”, but 9” had become the most common mesh size.

Area closures to protect juveniles have been used in Icelandic waters since the late 1970’s. Soon after fishing effort was reduced in 1995 the number of closures was substantially reduced indicating the fleet was avoiding areas with small fish when larger fish was available. The number of closures increased again in the year 2000.

5.6.7 Further work on HCR.

The working group that did the work leading to the original HCR was reconvened 3 years ago and took another look at the HCR for the cod stock. The group took notice of results from earlier work that had shown that inclusion of the capelin and shrimp stocks in the simulations did not have much effect on the proposed HCR.

The model used by the working group was an age structured assessment model written in AD-model builder using data from 1955 – 2003, simulating into the future using various HCR. The model included relatively complicated stock –recruitment relationship where both time trend in R_{max} and increased importance of older fish in the spawning stock were considered. CV of the residuals from the stock-recruitment model was allowed to depend on stock size. The simulations included assessment error and random variations in weights at age, both with serial autocorrelation. In the economic model the dependence of price on the size of cod was added. Extensive discussions were in the group regarding inclusion of bias in implementation and assessment but the final result was to include neither of those in the simulations but the discussions are reflected in the report to the minister of fisheries.

The result was that fishing mortality around 0.3-0.35 (18-25% of the catchable biomass) maximized current value of the profit and the group recommended the original 22% advice from 1994. The group did not give any specific advice on biomass reference points but advised that the MRI should be consulted regarding those points. The minister of fisheries has not adopted the results of the working group.

5.7 Evaluation of HCR for North Sea herring

North Sea herring had showed signs of over fishing and there was a strong decline in SSB and a rise in fishing mortality in the early 1990s. In 1996 a reduction in TAC was implemented in year and in 1997 an HCR was agreed and had been in operation every since. The HCR was reviewed in a joint EU Norway ad hoc scientific meeting held in Brussels in June 2004. We provide a very brief overview of some of the issues here, for full details of the review readers should consult the main report (Anon 2004).

5.7.1 Management Objectives

The precautionary approach to management was used as a major broad objective and taken as a 5% risk of SSB falling below B_{lim}.

Operational objectives were taken as maximum yield and yields stability, as two fleets were involved, one fishing for adults the other for juveniles, trade-off between fleets was also evaluated.

5.7.2 HCR conformity to management plan and strategy

The general form of the HCR had already been in use since 1997 and had proved to be useful for the recovery period. Three further modifications were tested, a year on year restriction in catch, a catch ceiling and a linear decline in catch below B_{trig} as an alternative to a step change.

5.7.3 Stock simulation parameterisation

Generally starting numbers and stock data were taken from the most recent ICES assessment. The Stock/Recruit relationship was taken from the assessment data and was considered to be generally robust and to cover the range of SSB required for a 10-year evaluation. Selection at age was taken from the assessment and robustness was not evaluated. Dependence of growth and maturity was not included though this was thought to occur, due to limitations of the available software. Natural mortality was taken from the assessment and had originally been derived from MSVPA from the North Sea. Sensitivity of the HCR to the choice of M was not evaluated.

5.7.4 The Robustness of the HCR to uncertainty and bias in information

The precision of the starting values was taken from the ICA assessment variance covariance matrix. Precision of the assessment for simulated assessments was taken from ICES quality data on the past performance of the assessment and implemented as a fixed bias of 10% and a standard error of 20%.

5.7.5 Simulation of Technical Measures

No technical measures were evaluated

5.7.6 Implementation failures considered in the simulation

Historically implementation errors had been observed at about the +20% level and they were included in the underlying data used to establish the S/R relationship. There was no evidence to suggest the level would change so most scenarios were evaluated assuming this level of TAC overshoot. To exclude these would be suggest sudden compliance with the regulations that could not be anticipated.

5.7.7 Items that should provided in the conclusions of the HCR study

The report suggested reviewing the state of the stock after between 3 to 5 years with the selected HCR. The study was conditional on the implementation error, an example with no error was included for comparison. Tradeoffs between the two fleets were shown and it was noted that for the same level of risk to SSB higher overall yields occurred when juvenile fisheries were reduced and the adult fleet expanded.

6 Specific issues related to different management measures

Specific types of management measures will present their own specific challenges for evaluators that will need to be considered. The types of management measures that may be considered within management strategies or HCRs are presented below:

- Quota regulations.
- Vessel licensing
- Effort regulation
- Technical conservation measures, i.e.

- o Gear regulations
- o Area closures
- o Seasonal closures
- o Minimum landing size (MLS)
- o Discard regulations
- o Bycatch rules

Some of the specific issues that refer to management measures are discussed below. The different measures are addressed at varying levels of detail and additional issues need to be considered to achieve a more uniform and comprehensive coverage., This has not yet been achieved by the SG but the further development of this section is expected to be an accumulative process over the coming years.

6.1 Quota regulations

Quota regulations only apply to landings and not to total removals. Implementation issues (black landings, area misreporting, high grading) are known to occur.

6.2 Effort regulations

In implementing effort regulations there is a need to distinguish between nominal & effective effort; regulation needs to control the latter to be effective. However, it is difficult to measure effective effort precisely and constant technological developments and improvement in skills result in on-going increase in efficiency of fishing operations, leading to continuing increase in effective fishing effort.

Where the primary purpose of an effort regulation is to control fishing mortality, this requires a link between effort & F. Effort regulations are less relevant where this link is weak, e.g. for shoaling pelagic species. The change in targeting behaviour of fishing fleets under effort restrictions are not well known

6.3 Vessel licensing

Not yet addressed.

6.4 Gear regulations

Gear restrictions and regulatory measures may include several basic types of management measures. These include specifications on mesh size, specifications on mesh shape, required use of selectivity devices (grids, panels) and of biodegradable devices, and controls on construction materials. There may also be management measures and protocols related to the operation of the gears, such as the amount and types of different gear eligible to be used, soak times and towing speeds.

The purposes of this class of management actions might variously be to affect catchability (selectivity by size), to control species selectivity, and to mitigate environmental/ecosystem effects. In a developed management strategy, specific objectives, for each of these that are relevant, should be available to provide a basis for evaluation.

A number of issues related to evaluating these types of management actions should be noted. The following list should be augmented as necessary, and on the basis of accumulated experience.

Effectiveness of implementation. It is important to consider the degree of compliance that has been achieved during the evaluation period, in order to more accurately attribute effects to their causes. Lack of compliance may driven by competing or conflicting objectives (ie: socio-economic, cultural, …). It is also important to consider if it has been able to diminish the effectiveness of management measures by legal means, such as adaptive operational behaviour.

Specific knowledge requirements. Evaluating these activities requires specific knowledge of how selectivity is affected by gear characteristics, and by the characteristics of both targeted and incidental catch. This knowledge is not often available from regular assessment studies, is quite case specific and can be operationally difficult to attain and maintain. Distinguishing signal from noise may require robust sampling and analysis.

Unaccounted mortality. This issue can be a special challenge in a comprehensive evaluation, owing to the difficulty in quantifying hidden, though possibly substantial, effects (ie; ghost fishing and escapement mortality).

6.5 Evaluation of seasonal and area closures

Management actions to apply seasonal and area closures to fishery activities may be of a temporary nature or may be permanent. In either case, they are applied in space or time, or in combination.

Seasonal and area closures may be applied for a variety of purposes; including to protect certain parts of a resource(s), such as juveniles, or prime reproductive individuals; to protect key biological features such as spawning or aggregation; or to protect habitat that is considered important.

A number of issues related to evaluating these types of management actions should be noted. The following list should be augmented as necessary, and on the basis of accumulated experience.

Effectiveness of implementation. It is important to consider the degree of compliance that has been achieved during the evaluation period, in order to more accurately attribute effects to their causes.

Quantifying effects. Being in position to evaluate time and area closures requires advance planning to ensure baseline information from the period prior to the application of measures is collected, or that it can be mined from existing knowledge bases. It also requires that control situations be created to help distinguish the effects of measures under evaluation from other effects. Isolating the benefits of these measures for evaluative purposes can be a challenge.

Extended effects of the measures. Controlling activity in a space or time may well have effects beyond the immediate area or time and the evaluation should consider these. These types of extended effects include; redistribution/concentration of effort to adjacent areas or times, redirection of effort to other species, and replacement of effort by other (derogation) fleets. It should be considered as well that time and area management may have unintended and/or incidental effects on non-target species.

Distributional shifts. It may not be appropriate to assume routinely that the original distributional characteristics of the target species (of the measure) are stable over time.

6.6 Minimum landing size

Historically minimum landing size regulations have been implemented to protect juvenile fish. Effects of minimum landing size regulations are variable and depend upon the inter-relationship between gear characteristics and the size range of the target species. One consequence is the discarding of under-sized fish.

6.7 Discard regulations

Measures to influence discarding practices can range from gear regulations intended to reduce the capture of undersized fish to banning of discarding in order to discourage the practice. It is not possible to evaluate the effect of discard regulations without knowing the extent of discarding.

7 Standards for simulations

7.1 Introduction to simulation

WGMG (ICES, 2004) identifies the evaluation framework approach based on simulation as the appropriate method to use. Simulation tools can be used to conduct experiments that evaluate the response of the fishery system to the strategy. The evaluation framework includes mathematical representations of both the *true* and the observed systems (data collected, assessment model used and reference points used to guide HCRs and their implementation) and so attempts to investigate the robustness of management strategies to both the intrinsic properties of the natural system and to our ability to understand, monitor and control them. Examples of factors that can be investigated are long-term fluctuations in productivity (Ravier and Fromentin 2001), errors in estimating fishing effort, choices of assessment models, biological reference points and data collection strategies. Importantly, such a framework has the advantage of considering the interactions between all these components and provides an integrated way to evaluate the relative importance of system components for the overall success of management (Wilimovsky 1985, De la Mare 1998, Holt 1998, Kell *et al*. 2003).

SGMAS emphasizes that simulation tools are important aspects of evaluating management strategies, but also notes that the wider context in which the harvest control rules operate may not be amendable to simulation approaches. This can partly be incorporated through robustness testing and by exploring how sensitive the outcome of HCR simulations are to e.g. implementation bias, data uncertainty and natural dynamics. The wider context can also be incorporated by adding qualifiers to the outcome of simulation based on the analysis of the past performance of the fisheries or of fisheries elsewhere.

7.2 Elements of simulation models

Figure 7.1 shows a representation of the conceptual evaluation framework recommended by WGMG (ICES, 2004). The framework comprises everything that is needed for conducting simulations to evaluate management procedures.

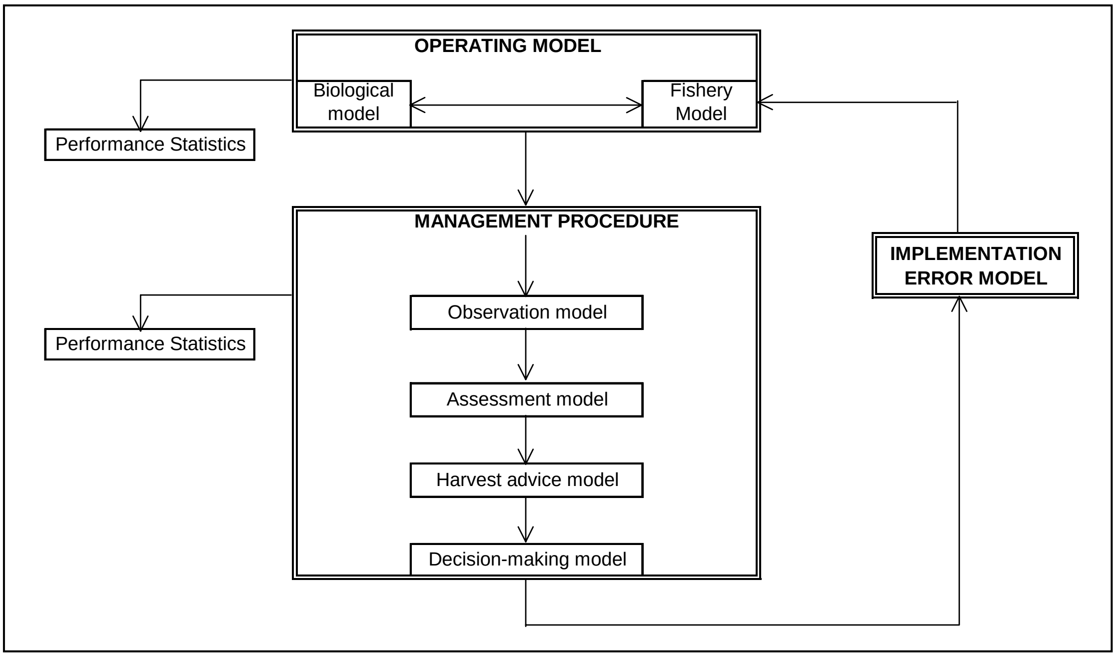


Figure 7.1. Conceptual framework for the evaluation of management procedures, recovery plans and harvest control rules.

In this framework, the management procedure should not be more complex than the underlying operating model. For example, the evaluation of management schemes involving closed areas cannot be carried out without spatial structure in the biological and fishery models. However, even if the initial underlying model is relatively simple, the software should be structured so that further levels of complexity can easily be incorporated at a later date.

This section expands on Figure 7.1, giving more details of models and sub-models that could be incorporated in the software. Whilst it is intended to cover most options, it is not intended to be exhaustive. Stochasticity could be incorporated in most models, and is discussed in Section 7.2.5.

7.2.1 Operating model

The operating model is an attempt to reflect reality. However, no model reflects reality exactly, but the operating model creates a virtual world, which represents the *true* system in the evaluation framework. The applicability of the results to the real world depends on how well the operating model conforms to reality.

The evaluation framework will be used to perform experiments, the outcomes of which rely critically on the underlying hypotheses about this *true* system contained within the operating model. These hypotheses should therefore be considered carefully, and should either be conditioned on available data or have a strong theoretical basis or justification. In addition, the choice of assumptions underlying the state of the system that is created by the operating model will usually pre-determine many of the results of the simulation. Therefore, as in any experimental set-up, the set of assumptions (implicit or explicit) employed needs to be kept in mind when drawing any conclusions.

The two major components of the operating model are a biological model and a fishery model. A relatively simple operating model could be for a single fishery acting on a single-species, in a single area; the biology of the species could be described by a standard age-structured population dynamics model with a Beverton-Holt stock-recruitment relationship and a von Bertalanffy growth function. More complex operating models could introduce concepts such as spatial structure, length structure, or mixed-species fisheries.

The choice of the level of operating model complexity is a crucial one. On one hand, potential users of the evaluation framework will want an operating model that offers as much realism as possible. On the other hand, a simpler operating model will be easier to define and implement. Therefore, the costs of complexity need to be considered carefully. In general, operating models should capture the characteristics of the underlying dynamics but need not necessarily model the full complexity of them.

7.2.1.1 Biological model

This model represents the development of the stock, which is then acted upon by the fishery, with removals in the form of numbers or fishing mortality output from the fishery model described in Section 7.2.1.2.

Complexity can be included at various stages, however the simplest form is likely to be a single-species age-structured population. This is likely to be generated from a model of the biological development of the stock, which incorporates the main biological processes as separate sub-models:

- natural mortality,
- growth,
- maturity, and
- recruitment.

Further levels of complexity that may be incorporated include:

- several species;
- multi-species interactions;
- cannibalism
- spatial aspects;
- seasonal/temporal aspects;
- density dependence;
- introduce length;
- covariance between variables; and
- auto-correlation in, for example, recruitment.

7.2.1.2 Fishery model

This model takes output from the decision-making model, as modified by the implementation error model. It quantifies the removal (in terms of fishing mortality or numbers) from the stock, which is input into the biological model. At the simplest level, there would be a single fleet, although this could be extended to a multi-fleet model, with a model for each fleet.

Within this model, the following processes may need to be incorporated:

- selectivity-at-age (by fleet/mesh-size);
- relation between effort/TAC and removal (either fishing mortality or numbers); and
- spatial structure.

Furthermore, complexity may be incorporated by having feedback from the biological model. For example, implementation error (see Section 7.2.3) may also be included in this model by increasing discards as the removals approach the TAC.

7.2.2 Management procedure

The management procedure represents the human intervention that attempts to understand and control the system that is described by the operating model. The management procedure can be viewed as the entire package comprised of:

i. data collection (observation);
ii. assessment;
iii. advice; and
iv. decision-making.

Many of the simulation studies conducted to date have focused on the evaluation of *harvest control rules*. These are decision rules that pre-specify what management advice will be given as a function of the perceived status of the stock(s) (item (iii) in the above paragraph). However, other factors may also be of interest to some studies. For example, different levels of data collection, or different types of data in (item i above) will affect the perceived stock status and its precision. Also, the ability to implement technical measures can be an important consideration (see Section 7.2.3).

In order to be amenable to a simulation approach, the various elements of the management procedure should be stable, or at least carefully specified. For example, simulation results of a study in which the assessment model changes every year may be difficult to interpret.

The evaluation of management options is best performed in the context of entire management procedures; that is, the combination of a particular stock assessment technique with particular control rules and their implementation (ICES 1994). For example discarding is a function of management strategy. Discarding in the fishery will causes bias in the assessment that will in turn inform management advice. Alternative management procedures that reduce the reliance on fisheries data will have different biases and even if they give less precise estimates of stock status may perform better. Such alternative management procedures could be based upon surveys alone or tagging data (McAllister *et al*.2004).

7.2.2.1 Observation model (data collection)

The observation model represents the way in which the operating model is sampled. It simulates the collection of data for the assessment model. This will usually involve some type of fishery-dependent statistics, and may also include fishery-independent data or other auxiliary statistics (e.g. tagging).

Each element of the observation model can be defined to varying degrees of complexity. For instance, with a complex operating model, the total catch can be estimated from aggregating samples derived from different fleet components in different areas. Misreporting could also be modelled. Similarly, catch-at-age data or survey data can be modelled with more or less sophistication, largely in a manner that is consistent with the level of complexity in the underlying operating model.

For each element of the observation model, the analyst should carefully consider precision and accuracy.

In the context of the current ICES management approach, increasing degrees of complexity could be as follows:

- *Perfect data collection* - catch-at-age data (and/or other data required for the assessment) is exactly as generated by the operating model.
- Random variation and/or bias is added to the catch-at-age data (and/or other data required for the assessment) from the operating model using simple rules.
- The collection of catch data is simulated in more detail using sub-models for processes such as:

- recording landings;
- estimation of discards;
- market sampling for age-structure.
- The collection of data from surveys such as acoustic, trawl and egg survey for:
- aggregated/disaggregated estimates of population abundance;
- estimates of spatial structure.
- Models dealing with sampling issues can include further sub-models for:
- survey design;
- sample size;
- stratification;
- measurement error;
- length/weight measurement error;
- ageing errors;
- sexing errors;
- maturity errors.

7.2.2.2 Assessment model

The assessment model uses the information from the observation model in order to provide estimates of the status of the stock(s) and fishery. The maximum possible level of complexity of the assessment model will be limited by the level of complexity of the observation model (which is, in turn, largely limited by the complexity of the operating model).

Some simulation studies are said to have *assessment feedback*. This means that a piece of assessment software is actually embedded as part of the simulations. A simulation without assessment feedback is one in which the results of the assessment simply follow some prescribed formula, without all of the computer-intensive iterative computations of a typical assessment. There are trade-offs between these two choices. Simulations without assessment feedback are much easier to implement and run much faster. On the other hand, it is not a simple task to find algebraic formulations to predict the biases and precision of assessment results in relation to the choice of assumptions and data.

The framework design should also take into consideration the frequency of assessments. Generally, the framework should allow flexibility so as to match the timing of assessments with the time scale of decision-making.

In ICES terms, this model simulates the current role of the stock assessment working groups. However, this does not necessarily mean actually implementing one of the current stock assessment methods, as explained below. Increasing degrees of complexity could be as follows:

- The assessment estimates the current state of the stock exactly. This model also requires perfect data collection (no assessment feedback).
- The data are not passed to a stock assessment package, but some random variation, and/or bias is added to the (probably perfect) data to simulate the assessment process (no assessment feedback).
- The data are passed to a stock assessment package, but with pre-set input parameters such as age at constant selectivity or shrinkage (assessment feedback).
- An attempt is made to deal with all the problems and ad hoc solutions that Working Groups face, such as choosing shrinkage or including survey data (assessment feedback). This would be very difficult to simulate fully.

7.2.2.3 Harvest advice model

This component uses the assessment results to compare the perceived status of the stock and fishery against a pre-determined set of benchmarks in order to formulate advice. On many occasions, a harvest control rule will be used (a recovery plan is regarded as being a special case of a harvest control rule). These rules represent pre-agreed actions taken conditionally on quantitative comparisons between indicators of the status of the stock and some sustainability or optimality indicators. For example, a very simple rule may be to fish at $F=F_{pa}$. In this case, this model component will require all of the assessment results that are needed to compute F_{pa} and an algorithm (recipe) for computing F_{pa}. A more complex harvest control rule may prescribe, for example, that F should vary as a non-linear function of SSB.

The advice needs to be expressed into the units that will be used to affect the stock(s). For example, in order to achieve F_{PA} there can be catch controls (advice TACs), effort controls, or other technical measures.

Potentially, harvest control rules may address more than one species at once, e.g. if mixed species advice is implemented according to set rules. Alternatively, taking mixed species fisheries into account could be part of the decision-making process (see below).

This model takes the output of the assessment model, and applies a *harvest control rule*, which is then output as *advice* to form the input to the decision-making model. For example, current ICES harvest control rules generally fall into the following categories:

- F-regimes: direct effort regulation, TACs derived from F, TAC = fraction of measured biomass.
- Catch regimes: permanent quotas plus protection rule.
- Escapement regimes: leave enough for spawning but take the rest.
- Hybrids: F-regime with catch ceiling, F-regime with constraint on catch variation, F-regime with quotas derived from predicted catch several years ahead, additional constraints on variation in SSB.

The output from this model could include recommendations for:

- TAC;
- Allowable effort;
- Closed areas;
- Mesh size regulations.

If the operating model is multi-species, at this point the recommendations may be further revised to account for mixed fisheries, for example by implementing the MTAC software according to pre-specified settings. Alternatively, this may be part of the decision-making process (see Section 7.2.2.4).

7.2.2.4 Decision-making model

The decision-making model is able to alter the advice given by the advice model. In most applications, the decision-making model will have no effect on the output of the advice model (following the example above, setting the advice TAC as that that results in F_{pa}, which may then be adopted as the agreed TAC). However, it is more flexible to design this as a separate model component. This would allow for the examination of control rules in which the management decision is not solely based on assessment results (for example, one that takes inputs from a socio-economic model as well).

Separating harvest advice from the final decision also allows for the making of management decisions for multiple species at once, if accounting for mixed species fisheries is not part of the harvest control rule in the advice.

Increasing degrees of complexity could be as follows:

- advice is unchanged;
- advice is altered with a simple rule (e.g. TAC increased by 10%);
- advice is altered due to taking technical interactions into account, for example by the MTAC software, if this is not part of the advice itself;
- more complex models could be included to take account of other factors which affect management decisions, such as social or economic factors.

7.2.3 Implementation error model

This model provides the interface between the regulations and the fishery. For multiple potential reasons it may be that management decisions are not always implemented exactly. This may include either random noise, or also systematic departures from the intended actions. The implementation error model allows flexibility in the evaluation framework for considering these types of effects.

In a way, this part of the framework can be viewed as an interface between the management procedure and the operating model. It takes the output of the decision-making model and provides input to the fishery model in the form of altered regulations. It is thus the implementation of the regulations rather than the implementation of the fishery, which is dealt with in the fishery model.

In many applications, the implementation error model will maintain the same decisions arising from the decision-making model and the advice model (following the examples above, obtaining a catch equal to the TAC that results in F_{pa}).

Increasing levels of complexity could be as follows:

- regulations are enforced perfectly;
- implementation is modelled with a simple rule (e.g. 90% compliance);
- extent of compliance of the TAC for one stock depends on uptake of the TAC for other stocks because of technical interactions:
  - discarding;
  - reduced mesh size are included as separate models;
- models containing complex models of fishers' reactions taking social and/or economic factors into account.

Implementation error may also need to be included in the fishery model if feedback from the biological model is required (see Section 7.2.1).

7.2.4 Performance statistics

Performance statistics are summary indicators for the various components of the framework. Summary performance statistics are needed to facilitate the analysis of the simulation results because it is simply not feasible to examine all of the results that can be generated with this type of framework. In addition, performance statistics are the benchmarks that are needed for evaluation of the simulation results.

Examples of performance statistics for single stock trajectories include average variation in annual yield, minimum stock size, time to recovery, average yield. Examples of performance statistics for runs (i.e. many trajectories) include average time to recovery, number of trajectories for which stock size passes below some threshold (i.e. management fails), average discrepancy between assessment output and *true* stock size.

7.2.5 Stochasticity

All simulations will assume that at least some elements are stochastic, to account for the variability or uncertainty in these elements and to evaluate the probability of events occurring. For example, in a simple operating model, this may include variability in initial numbers, weights, mortalities, maturities and selection at age. Likewise, the observations going into an assessment may, and usually should, be stochastic, and if there is no assessment feedback, the simulated assessment output may also be stochastic. The decision-making and implementation error models could also be regarded as stochastic. However, as with other aspects of the models, stochasticity should be introduced with increasing complexity.

Both the operating model and the observation model can, in principle, be very complex. However, adding complexity to the model structure also raises questions as to where stochasticity should be introduced, and whether the probability structure of the various elements has been adequately represented. The output of such models should be validated against available data wherever possible.

In all cases, there are several ways of introducing stochasticity. Three options are to draw from theoretical statistical distributions, to use bootstrapped model output, or to draw randomly from historical values. Obtaining random numbers at the various stages is by no means trivial. Important points to consider include the quality of the random number generator, correlations between variables and trends or cyclical variations, for example in recruitment.

Incorporating random variation, in itself is also not enough, sometimes it may be important to test the robustness of a model fitting method to incorrect assumptions about the distribution of the data. Experience with simple stochastic forecasts with several types of ICES standard prediction software (WGMTERM combined with XSA, ICP and STPR combined with ICA, see Section 7) have shown that the uncertainty in stock abundance, fishing mortality and recommended catches can be under-estimated (Patterson *et al*. 2000). This underlines both that care needs to be taken to ensure that all relevant sources of uncertainty are adequately covered, and the need for validation of methods, for example to confirm that confidence intervals have the correct probability coverage.

7.2.6 The choice of temporal limits for simulation

In order to carry out simulations for stock management evaluation there is a need to consider several temporal related aspects

> Life-span; the duration of the period where the initial year classes still contribute to the stock. This corresponds roughly to the age span of the species assuming only a small +group in the age data.
>
> Episodic nature of recruitment.
>
> Restrictions on year to year change in management parameters to be tested (ie. TAC).
>
> Temporal time steps for management.

Currently these aspects have not been fully evaluated and it is anticipated that further work will refine this advice but a general consideration of modelling issues suggests that the following criteria would be appropriate:

Life-span may be defined as 90% of the age span needed to capture the full range of ages encountered of the species.

Episodic recruitment should be dealt with by providing a period that is long enough so that on average at least two major episodic events are included in the simulation. In such cases, managers may want to consider how they want to make best use of an outstanding year class (cf.

Section 5.3), and specific simulations to elucidate that should at least cover the period until such a year class has disappeared.

When restrictions on year to year variation in catch are considered, the simulations should at least cover the time it takes to implement a 50% cut. This would be 0.7/(fractional year to year change in TAC) and would be 7 years for 10% annual restriction or 14 years for 5% restriction. This factor is sometimes described as the time constant for change.

The time step should be sufficiently small to capture the stock development and the time scale for management decisions and be the smaller of the two measures. (Years for annual management of medium to long lived species or months or weeks for short lived in year management)

It is considered that the first three criteria are additive. However, shorter simulations could be used to investigate long-term equilibrium yield separately from the choice of optimum year on year limits on change. The first being evaluated through equilibrium from an out of equilibrium start and the latter being dealt with by forcing an equilibrium start point.

7.3 Communication of results

The output produced by a comprehensive simulation study can be quite overwhelming. To communicate this amount of information in an understandable way is not a trivial task, and great attention should be given to communicating the results in an efficient way. A common mistake by scientists is that the time spent preparing communication of results is far too small in relation to the time spent on the simulations.

Outputs can be considered to fall in to one of three types:

- Diagnostics needed when conditioning the simulation model;
- Summaries and results for communication between scientists;
- Summaries for communication of results to managers and lay-persons.

For scientists detailed outputs allowing understanding of how results were generated, statistical measures of performance etc. are relevant. For this purpose, tables and numerical results are often better than graphical presentations. However, even in this case, attention should be paid to making the output limited to communicate the essentials for the purpose.

For the broader public and managers, it essential to present the outcomes in a way that promotes communication. Graphs showing the time course of fractiles are not necessarily understood the way they are meant, sometimes it may be more informative to illustrate variability by a bundle of trajectories, and risks by cumulated distributions. Tools like fuzzy traffic lights, radar plots etc. may be considered. Sometimes, animation presentation tools may be useful. The choice of what to present is crucial. In that respect, one should be aware of the risk of distorting the message when highlighting presumably essential points, i.e. the focus should be primarily on ensuring that message is correctly understood. Likewise, the choice of information to present should be guided by the purpose and the main interests of the recipient. In some cases this is specified in considerable detail by the customer, in other cases communication with the customer may be necessary. A manager will often search for very specific information of interest in the material that is presented, and it may be necessary to consider carefully that other crucial information also is conveyed. Developing good ways of communicating results is an integral part of the dialogue process with managers and other interested parties.

7.4 Validation and quality control

7.4.1 General principles

Gentle (2003) pointed out that a simulation that incorporates a random component is an experiment and that the principles of statistical design and analysis apply just as they do to any other scientific experiment. Such studies should therefore adhere to the same high standards as any scientific experimentation. The reporting of a simulation experiment should receive the same care and consideration accorded to the reporting of any scientific study and Hoaglin & Andrews (1975) outlined the items that should be included in a report of a simulation study. For example, the journal *Computational Statistics & Data Analysis*, the official journal of the International Association for Statistical Computing includes relevant reporting standards in their guide-lines for authors. Therefore, descriptions of simulation studies must:

- clearly state the hypothesis under study;
- be thorough with regard to the choice of parameter settings;
- do not over-generalize the conclusions;
- carefully describe the limitations of the simulations studies;
- be easily reproducible;
- guide the user regarding when the recommended methods are appropriate;
- indicate why comparisons cannot be made theoretically and why therefore simulations are necessary;
- provide enough information so that the quality of the results ca be evaluated; and
- give descriptions or references of pseudo-random-number generators, numerical algorithms, computer(s), programming language(s), and major software components that were used.

7.4.2 Validation of simulation

The particular question to be addressed here is do our models provide the best or most plausible representation of reality i.e. Do our (operating and management) models perform as expected? Also to be aware of and specify the limitations of the simulations.

Sub-models can be considered independently to determine whether they are consistent with observations. The models should be considered deterministically, stochastically and including correlations (e.g. is the level of simulated recruitment similar to that observed historically, is the error distribution appropriate such that stochastic recruitment deviates have similar distributions to observed recruitment and are regular patterns in the simulated time series comparable with those observed.

In the management procedure it is particularly important to check that output from the assessment procedure has an error and bias similar to that observed/estimated in reality.

Simulation models may include constraints (e.g. to ensure that F does vary hugely between years), but it is important anyway to check that absolute and interannual variation in such variables remains within reasonable bounds throughout the simulation.

The performance of aggregate models can be checked by carrying out hind-cast analyses initiating the projection in the past and comparing a selection of modelled metrics with our best estimates during this time period.

The expected response of the system to management can explored in the short term by simple deterministic projections and by equilibrium analyses in the long term. Such preliminary investigations can provide valuable insights into the expected dynamics and may save development time in rapidly identifying unsuitable scenarios.

7.5 Complexity

7.5.1 Dichotomy of approach

Some general aspects are considered in 7.5.2, but there is an important dichotomy of modelling approach that needs to be considered first. Two basic types of model can be considered:

e. Full feedback models in which the sub-models of the management procedure and the time lags in implementation are modelled explicitly, with the aim of modelling the processes involved and retaining the mechanisms that produce errors and biases.
f. The alternative approach directly models the management metrics with error and bias of the type considered to arise through sampling and assessment processes. At the present time implementations of this type do not account for the management time lag although control theory exists that could be applied to this problem.

There are advantages and disadvantages to each approach and both have a place in the evaluation of management strategies.

Full feedback models are useful in the wider context including the following cases:

- Data poor stocks where a complex operating model can be used and limited data sampled and provided for management.
- To evaluate the effect of improved or reduced sampling effort on management (e.g. running a survey in alternate years).
- Evaluating the effects of making erroneous assumptions regarding biological parameters for assessment and for assessing the effect of unaccounted mortality.
- Testing assessment software and investigating assessment bias in relation to stock and management scenarios.

They have the advantage that correlations between population variables and the assessment errors are retained through the management process and depending on complexity may provide a better representation of what is thought to be happening. However they are generally complex require extensive development time and expertise and added complexity may introduce new sources of uncertainty and error.

The alternative direct error models are particularly useful for evaluating the effects of a systematic range of assessment error/bias bias on management performance, because they allow direct control of the amount of error/bias applied. They have the advantage of being simpler to develop, implement and apply and are relatively transparent.

7.5.2 General aspects of complexity

In some cases, it is probably sufficient to evaluate the risk of bringing a single stock outside precautionary biomass limits, as a function of assumed deviations of actual removal from the stock from what is intended in the HCR. This can be made with relatively simple projections, but with some caveats. More elaborate models may be needed to account for variations in the productivity of the stock in the operating model. There may also be a need for more specific modelling of the consequences of regulations for the performance of the fishery, e.g. with regard to discarding practises. If management plans include gear restrictions, closed areas etc., the more complex models may be needed to evaluate the effect of such measures on the realised fishing mortality properly. The observation – assessment part of the management procedure may need to be evaluated if it is unclear how current assessments will have other uncertainties than previous ones.

7.6 Guidelines and standards for future developments of software

7.6.1 General guidelines

Software used by ICES is generally written and produced by individual scientists or national laboratories. Attempts at ensuring the quality of such software have been made on several occasions by ICES methods working groups (ICES 2004), and by dedicated ICES Study Groups (e.g., SGFADS: ICES 1998/ACFM:9).

The approach proposed by WGMG 2003 (ICES 2003b) for guidelines on the formal procedures to be adopted by WGMG for the testing, evaluation and validation of software for use by ICES stock assessment Working Groups is still appropriate

For the evaluation of management strategies, it is hard to see a software tool that will cover all sorts of stocks or fishery systems together with any manager's ideas about harvest control rules. It is more likely that many requests will require program development in preparation of an evaluation of a particular HCR related to a specific stock and fishery. Thus, any program produced is likely to need modifying to deal with particular cases. This requires that any software should be able to be modified easily and flexibly by a range of users for a large variety of tasks. The underlying code must be openly accessible and well documented.

WGMG (ICES 2004) considered open source code approaches, in particular the use of R, for the development of fisheries programs and noted that the use of an Open Source approach to software development within the fisheries context would lead to considerable benefits. It is important that development is as inclusive as possible and that resulting software can be implemented without requiring an excessive amount of work and is usable by a wide range of people.

WGMG (ICES 2004) recommended that in order to encourage as many programs as possible (onto the system), there should not be a requirement that all tools be made Open Source. However, in order to take advantage of the benefits of Open Source development contributors to the system should be encouraged to release their code. If this is done, and if common programming languages are used, it would be possible to share code between projects, and thus reduce development time.

The proposed move within ICES towards an Open Source approach leads to a need for a new system of testing, evaluation and validation of fisheries models. Classical validation exercises (e.g., Kraak 2004) are compatible with the Open Source approach, but they can be supplemented by feedback from ongoing use of the models.

7.6.2 Presentation of program code

Due to the anticipated variation in structure of potential management strategies and HCRs, any software set up to evaluate HCRs is likely to need recoding at some point. If this is the case, then in order to allow users to examine and modify the program code, it is essential that that this code is written in as user-friendly a fashion as possible. This includes features such as clearly structured code, comments, and both internal and external documentation such as a technical and user manual. It would help end users if the documentation included an overview of the functionality of the software package in relation to the checklist for evaluating a HCR given in Section 4.

If the final program code is not to be compiled (e.g. code for use on the R platform) then it is already likely to be accessible. If compiled code is used (C++, Fortran) then the original source code should also be presented.

7.6.3 Program structure

The underlying program structure should fit into the conceptual framework for software given in WGMG (ICES 2004) and discussed in Section 7.2.

The modular structure allows for easier extension or adaptation of any software, and also allows for separate programs to run the different operating or management models. A protocol to control the interaction between the separate program modules (or separate programs) is necessary. This could be as simple as saving the system data to an output file at each step (that can then be read by other program modules), or by having standard program objects used by all program modules (this is the aim of FLR). If this protocol is consistent then it should be very easy to edit or extend program modules as required. A modular approach allows for the most flexible implementation of the checklist for evaluating a HCR given in Section 4.

To ensure the software is accessible to as many users as possible, programs should not be developed such that they only run on expensive / obscure platforms or require expensive / obscure libraries.

7.6.4 Validation of program

For any software to be accepted by the fisheries science community it should be fully validated by independent users. Any limitations of the software should be made clear as part of the documentation.

7.6.4.1 Validating new software

As suggested by WGMG (ICES 2004), any new software could be tested and validated against a small suite of standard simulated data sets proposed to be established and held by ICES. In relation to software designed to evaluate HCRs, it may be possible to test against a set of standard HCRs, although this may not be appropriate depending on form of the underlying program model and the form of the HCR.

Within the fisheries context, a peer-review process must involve sharing the results of evaluations of performance of the software in different situations, between both users and program authors.

7.6.4.2 Validating ongoing software development

If a developer distributes his software and receives several bug fixes and code contributions it can be difficult for him/her to integrate and organize all contributions. This will be especially true if the software has been designed for evaluating HCRs, where it is expected that the program code will be extended or edited by a number of users working on different case studies. In a small project, such as is currently typical of fisheries science, with one or two developers and a small number of users, this process can be conducted manually. However, as the project grows in size it may become necessary to automate the process of tracking and managing changes to the code. In any case this will provide a number of benefits in managing the project. One of the most used programs by the Open Source community to deal with these problems is CVS or Concurrent Versions System (http://www.cvshome.org/). Details of this system can be found in the book *Open Source Development with CVS* (http://cvsbook.red-bean.com/) and other documents can be found at the CVS site.

8 Review of available software

8.1 Overview of methods

Currently there exist only a few software packages developed specifically for evaluation of harvest control rules (Table 8.1). STPR and CS4/5 have been extensively used at various ICES and STECEF working groups for HCR evaluation. 4M-HCR was developed for SGMSNS 2003 and used to show the effect of including biological interactions. PROST was originally designed to evaluate the proposed 3-year HCR for NEA cod. The Fishlab toolbox has been used to carry out extensive evaluations of management strategies for flatfish and roundfish in response to requests from the EU Commission. This is now being superseded by FLR. For Norwegian Spring Spawning herring the SeaStar software, that is currently used to assess this stock, is also used for HCR simulation. This software is very adapted to this particular stock, and can not be readily applied universally.

Tables 8.1 and 8.2 give a summary of the tools identified by the SGMAS that are available for stock projections and/or could be adapted to include HCRs and their evaluation Each of these software tools is discussed in more detail in the following text.

Table 8.1 Software designed specifically to evaluate HCRs

Software	Type	Published method	User doc.	Technical doc.	WG usage	Source code	Language	Origin	Last version
4M-HCR	Multi-species multi-fleet VPA & Forecast incl. HCR evaluation	N	Y	Y	Y	Y	C++, R, SAS	DI-FRES,	August 2003
CS4/5	HCR simulation	Y	N	N	Y	Y	Fortran, R	CEFAS,	5
STPR	Medium-termHCR	Y	Y	Y	Y	Y	Fortran	IMR,	2004
PROST	Medium term HCR	N	Y	Y	Y	Y	Java	IMR,	2004
FSSSPS 1.0	Medium term (HCR*)	N	Y	N	N	Y	R	FSS (Ireland)	Jan 2005 (* HCR under development)
Fishlab	Toolbox	Y	Y	Y	Indirect	N	C++, Visual Basic, Excel	CEFAS	1999
FLR	toolbox	In development	In development	N	N	Y	C++, Fortran, R	CEFAS	0.5–1Prototype

Table 8.2 Software that can be adapted to evaluate HCRs

Software	Type	Published method	User doc.	Technical doc.	WG usage	Source code	Language	Origin	Last version
MFDP	Short-term	Y	Y	Y	Y	N	VB	CEFAS	
WGMterm	Medium-term	N	N	N	Y	N	Fortran	FRS	
ISIS-Fish	Spatially explicit, multi-fleet, multi-soecies	Y	Y	N	N	N	Java	IFREMER	2004
GADGET	Age-length multspecies multiarea, multi-fleet	Y	Y	Y	Y	Y	C++	MRI, Iceland & IMR, Norway	2004

8.2 Software designed specifically to evaluate HCRs

8.2.1 4M-HCR

4M-HCR (ICES 2003c) estimates annual factors for the scaling of *status quo* F which are consistent with the harvest control rules contained in a proposal from the European Commission for establishing measures for the recovery of the cod stock (Reg 2003/0090 (SNS)). The rules have been implemented in a generic way such that HCRs can be applied to any number of species. For each species, the target (e.g. for cod, 30% SSB increase per year, but limited to a plus/minus 15% annual TAC change) can be defined individually. 4M-HCR is implemented using the R-package and uses the 4M multi-species forecast program as an external procedure for estimating future stock sizes, catches *etc*. given a set of forecast Fs estimated by the 4M-

HCR program. The evaluation can be done in "single species mode" with fixed natural mortality or with variable natural mortalities estimated by the 4M model. The software is part of the 4M package and requires some skill to use.

8.2.2 CS

The CS program, latest version 5, is a tool for harvest control evaluation. The population dynamics of the fish stocks are represented by a standard age-structured model with fixed, precisely known natural mortality rate, maturation, growth and exploitation pattern. The uncertainties represented in the simulation are recruitment variability, bias and variance in the observation of population abundance at age, at the start of the year in which management measures are to be applied and uncertainty in present conditions. CS5 allows a wide range of HCR to be evaluated. The STPR program includes the functionality of CS5, so that CS5 now seems to be outdated.

8.2.3 STPR3

STPR3 (described in Patterson *et al*, 2000) is a program for making stochastic predictions of fish stocks and for evaluating management decision rules. The program performs stock projections where the probability distributions of the interest parameters that are induced by stochastic input terms, are evaluated by bootstrapping.

Program

- Compiled code in Fortran.
- Source code developed on ad hoc basis.

Operating model

- Single species, dual fleet, age structured, annual time step, 10 years time frame.
- Recruitment are estimated from wide range of functions and may include an autoregressive term
- Stochastic variables: recruitment (function of SSB), weights at age and maturity at age (drawn from historical data), initial stock numbers (point values with variance or bootstrapped).
- Deviation of actual catch from recommended catch can be modelled (implementation error) using stochastic multiplier.

Management model

- Simple HCR can be catch-constraints, F-constraints or combination of both for 2 fleets. Additional constraints on Year-to-year variation in Yield, F and SSB
- TAC for year calculated on projected SSB using HCR.
- No assessment model included. Perceived SSB is taken from a probability distribution dependent on true SSB.
- TAC decision based on this 'faulty' SSB data.
- No implementation model included, but implementation error can be specified as for assessment error.

User considerations

- Easy to configure and run compiled program.
- Source code and compiled version available.
- Non-standard formatted ASCII files for input and run options.

- Output in ASCII files to be used in spreadsheets or similar. R-script available for presentation of results.
- Reprogramming of source code likely to produce bugs and extending the code is not recommended.
- Well documented.

Conclusions/Recommendations:

STPR3 has been developed gradually, more or less *ad hoc* for specific jobs. The latest version of STPR 3 is well documented and rather easy to configure and run. It has been used at the "EU-Norway ad hoc scientific working group on Multi-annual managements plans" (Anon. 2004) for several stocks and no programming bugs were found. The definition of the HCR is quite flexible but the use of other HCRs requires reprogramming of the Fortran source code, which is quite messy, and further extensions imply a substantial risk of creating bugs.

8.2.4 Prost

Program for performing stochastic projections using an age structured population model. The program was originally designed to evaluate a proposed 3-year HCR for NEA cod (see Section 5.5), but is designed to be genearally applicable.

Program

- Java coded.

Operating model

- Single species, single fleet, single area, age structured, annual time step.
- Models recruitment, growth, maturation and fishing (selection). For each process different functions and uncertainty definitions can be selected.
- Weight and maturity can be density dependent.
- Recruitment: fixed, Beverton-Holt, Ricker, Ockham, Ockham with cyclic term.

Management model

- 3 HCRs: constant F, pre-specified TAC, 3-year rule for NEA cod (complex HCR).
- HCR operates on an observed SSB that is given by the real SSB plus an error term (assessment error).

User considerations

- Straightforward to use
- Program extendible by users familiar with Java.
- Documentation available.

Conclusions/Recommendation

Program designed for a specific case study (NEA cod) but the core program may still be useful for other stocks.

8.2.5 FSSSPS

FSSSPS is a stochastic stock projection simulation currently under development. The operating model is completed but management and assessment models are to be added. Stochastic 'noise' is added each year to system parameters to represent uncertainty and variability in the operating model.

Program

- R language – easy to edit / check code.
- Modular structure: simple to add extra functions.
- Program generates full time series data set and compiles several statistics. Sensitivity analysis included.
- Program is yet to be validated.

Operating model

- Stochastic operating model.
- Single species, single fleet, age structured, annual time step.
- Recruitment: fixed, bootstrapped, stochastic Ricker or stochastic segmented regression (‘hockey stick’).
- Natural and operational variability accounted for by adding uncorrelated ‘noise’ to input data parameters (weight, mortality, maturity etc).
- Implementation error currently modelled as ‘noise’ added to F or TAC (normal or truncated normal).

Management model

- No assessment / management model included yet.

User considerations

- Easy to implement program by novice user.
- Straightforward to add simple assessment model / HCR functions (assuming basic knowledge of R). Complex assessment models / HCR functions would require editing the code of the underlying model (requires expert R knowledge).
- Output files in ASCII format.
- Program produces graphical output.
- No documentation yet available.

Conclusions/Recommendations:

Program will offer flexibility and transparency but is not yet complete with assessment / management models to be added (so cannot be immediately used). Easy for end user to run simple projections and (when complete), run and evaluate ‘simple’ defined HCRs. Documentation needs to be produced.

8.2.6 FishLab/FLR libraries

These are (dynamic link) libraries of core routines conceived and developed specifically for the evaluation of management strategies. For a particular (case) study the core routines are assembled taking account of the particular features of the (case) study under consideration. Other sections of the model are implemented in proprietary software. They provide a high degree of flexibility, but this is traded off against the relatively high levels of expertise required to assemble the required core routines.

8.2.6.1 FishLab

Developed during the 1990s the libraries interface with MS Excel and Visual Basic. They have been used for a number of EU studies (MATACS, MATES) and papers (Kell *et al.*, 1999; in press a,b,c) and provided supporting simulations to some early EU Norway negotiations. The libraries are used for reference point estimations carried out by the PA Software package assessment software routinely used by ICES assessment WGs. The package was not widely taken up and received some criticism for lack of documentation, difficulty of implementation and version control. Relatively extensive electronic documentation was provided but it follows the fairly terse style of MS Windows and was not found sufficient by end users.

Program

- Excel/VBA interface – easy to edit implement/ Excel difficult to quality control;
- Modular core structure: flexible mix and match use of functions as required; provision of extra functionality can be achieved through new C++ routines, VB code or Excel
- User constructed implementation: high control of output detail
- Individual tailored applications: difficult to quality assure

Operating model

- Operating model user defined: stochastic implementation where required;
- Most applications single species, age structured annual time step, but user design allows for development of multi-species, multi-fleet, alternative time scales;
- Process errors can be modelled using a parametrically or non-parametrically, some facility to include correlation

Management model

- Management model explicitly modelled: sampling errors modelled, assessment methods explicit, decisions and implementation errors assumed/modelled

User considerations

- Ease of implementation depends on complexity required, but has been criticised as requiring high user expertise
- Limited selection of commonly used assessment available
- Interface allows flexible implementation of HCRs
- Electronic documentation available

Conclusions/Recommendations:

Highly flexible and has been used to carry out major evaluations by collaborating national institutes individually and under contract to the European Commission. Forerunner to FLR, with appropriate expertise can be successfully applied to carry out evaluations of management strategies.

8.2.6.2 FLR

Currently under development the FLR libraries interface with the R framework, which has the advantage of providing a more powerful supporting system for data manipulation and statistical analysis and modelling capability than was available for FishLab. FLR also has/will have a wider range of assessment methods than were implemented in FishLab.

Program

- R interface – easy to edit implement, extensive additional data manipulation and statistical modelling capability;
- Modular core structure: flexible mix and match use of functions as required; provision of extra functionality can be achieved through new C++, Fortran, R routines,

- User constructed implementation: high control of output detail and supplementary analyses
- Under development

Operating model

- Operating model user defined: stochastic implementation where required;
- Most applications single species, age structured annual time step, but user design allows for development of multi-species, multi-fleet, alternative time scales;
- Process errors can be modelled using a parametrically or non-parametrically, facility to include correlation

Management model

- Management model explicitly modelled: sampling errors modelled, assessment methods explicit, decisions and implementation errors assumed/modelled

User considerations

- Ease of implementation depends on complexity required, but has been criticised as requiring high user expertise
- Good selection of commonly used assessment (will be) available
- Interface allows flexible implementation of HCRs
- Developed using Concurrent Versions System (CVS) to insure integrated development
- Documentation will be available

Conclusions/Recommendations:

Highly flexible, with appropriate expertise will be suitable to carry out full evaluations of management strategies. Not expected to be fully developed for several years, prototype versions expected in 2005.

8.3 Software that can be adapted to evaluate HCRs

8.3.1 MFDP

Can be extended for several years with variable F and TAC control in each year, but deterministic so of little relevance to full evaluation of management strategies.

WGMterm

Stochastic medium term projection program. Uses fixed F multipliers to project an age structured population forward. Would require modification to implement HCRs and model errors in the knowledge acquisition system. Has been criticised in the past for lack of documentation.

8.3.2 ISIS-Fish

ISIS-Fish (Mahevas & Pelletier, 2004) is a software tool that evaluates the impact of management measures on the dynamics of a complex fishery. The simulation model is generic in order to be used for different types of fisheries. Existing knowledge about each fishery is stored in a database included in the software, and may be easily modified. This includes the parameters describing each population and each fishing activity. Furthermore, the software allows for flexibility in several model assumptions. Both management measures and behaviour of fishermen in reaction to these measures may be interactively designed through a Script language. The simulation tool thus enables one to compare the respective impacts of conventional management measures like catch and effort controls, and measures more recently advocated like marine protected areas. The software is implemented through a graphical user interface and is thus straightforward to use. However, the program is self-contained and no source code is available so that it is not possible to edit or add to the program directly.

8.3.3 GADGET

Age and length structured modelling system developed from Bormicon (Stefánsson and Pálsson, 1997) and Fleksibest (Frøysa et al, 2002) under the EU project DST_2.(Development of structurally detailed statistically testable models of marine populations) Specifically designed to take account of multi-species, multi-fleet and spatial effects. The model uses a hierarchy of data files for input. Generating those data files can be time consuming for complicated models but documentation is excellent (www.hafro.is/gadget) and examples are available. The model can be used for testing management procedures but does then need to be linked to programs written in R (or similar software) to generate data files for stochastic simulations. Program code is complicated but well organized and well documented. Getting familiar enough with the model to be able to change the code takes some time. GADGET is not the recommended model where ordinary age structured models are sufficient, but might be useful where spatial effects, multi-species effects, multi-fleet effects or length based processes are important.

8.4 Software functionality in relation to the checklist for evaluating a HCR

Section 5 includes a checklist for evaluating a HCR that should be considered when developing software for this purpose. The software discussed above has been developed prior to the checklist being produced, but a number of the suggestions on the checklist are likely to be already covered by the software available.

All of the above software should be able to produce the required criteria for judging a HCR, namely the yield of the stock(s), variability of yield, final state of stock(s), and risk to stock(s). However, no one piece of software is yet available that covers all the points suggested on the checklist.

8.4.1 Operating parameters

The software tools that are either already set up to evaluate HCRs (CS, STPR, Prost) or would be easy to adapt (FSSSPS, MFDP, WGMterm) are based only on an age-structured model, include no spatial elements, an annual time step and include only 1 or 2 fleets.

4M-HCR includes variable time steps, multi-fleet, and also biological interaction but requires a huge input data set and skill to use. ISIS-Fish includes spatial elements and is easy to use but it is not possible to edit the underlying code so it may not be possible to evaluate complex HCRs.

From the group “toolbox” software, FishLab can, and FLR will be able to, be applied to a wide variety of situations with the required level of user expertise. GADGET includes spatial elements or variable time scales along with multiple fleets.

8.4.2 Stock dynamics

All the projection software listed above include at least one recruitment function. ISIS-Fish includes a special recruitment model, while any software that has the source code available would be easy to adapt to include other recruitment functions. Similarly, all programs that have available source code could easily be modified to include stochasticity in natural mortality.

Most of the software above is designed for a single species. 4M-HCR and GADGET can deal with several stocks simultaneously and can model biological interaction.

Growth is explicitly modelled in Prost, ISIS-Fish and the 'toolbox' software GADGET. Some density-dependent elements are included in Prost and could also be added to the 'toolbox' software.

Variability in stock parameters such as maturation is explicitly included in FSSSPS and GADGET, while it would be straightforward to add variability to programs where the source code is available.

8.4.3 Management measures

As discussed elsewhere, the expected variation in requests for particular HCR evaluations means that no one piece of software is likely to be able to cover all possibilities. Instead, software that is easy to adapt with different HCR rules and fishery systems are what is needed.

ISIS-Fish can't be recoded, although simple decision rules can be entered through the user interface. MFDP and WGMterm may be relatively simple to adapt but are likely to have limited use. FSSSPS and PROST are also likely to be easy to adapt but may not be able to deal with highly complex management strategies or fishery systems. The most flexible software tools are likely to be GADGET, FishLab and FLR (when it is completed). These tools are designed to offer specific modular elements for each part of the simulation algorithm. Each modular element can be recoded as necessary to deal with particular management strategies or fishery systems.

9 Further development of management strategies

The SGMAS considers this report as a first step in establishing guidelines for evaluation of management strategies. The guidelines given in the present report are far from complete, and further development is needed in several fields. The SGMAS does not consider itself as a permanent group, but it clearly needs more meetings to extend the work that has been done so far. Hence, the SGMAS regards this as the first of several meetings.

The field covered by the SGMAS is close to the field of the WGFS. However, the scope of the SGMAS is mainly in developing operational guidelines to enable ICES to respond to managers' request for advice on development and evaluation of management strategies even at present, while the scope of WGFS is mostly on improving the understanding of how fisheries systems work. Clearly, the SGMAS will draw on the insight provided by the WGFS.

For a coming meeting, the SGMAS has identified the following fields where further development is needed and can be anticipated:

- Ecosystem management aspects
- Mixed fisheries
- Incorporating socio-economic insight
- Management strategies for types of stock that are not amenable to the 'mainstream' HCRs, like short-lived species, stocks with a poor knowledge base or deteriorating data.

The SGMAS suggests to have its next meeting late in 2005 or early in 2006 .

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Annex 2: Definition of terminology

Term	Definition	Source
Adaptation system	The Fishery adaptation systems account for actions taken by fishing fleets in response to a number of external constraints, which are related to the social, economical, political, biological and environmental context of the fishery (WGFS, 2000)	SGMAS2005
Assessment model	Part of the management procedure that uses information derived from the observation model in order to provide estimates of the status of the stock(s) and fishery.	WGMG2004
Conditioning	The process of selecting specifications/parameter values for case-specific trials to ensure that they are not inconsistent with already existing data.	WGMG2004
Decision-making system	Part of the management procedure that results in harvest decisions that are largely determined by the harvest advice model.	WGMG2004
Error (uncertainty)	Differences between the "virtual world" (in the operating model) and the perceived one. Several types of errors are: *process error* due to natural variation in dynamic processes (e.g. recruitment); *measurement error* generated in collecting observations from a population; *estimation error* that arises from trying to model the dynamic process (i.e. during the assessment process); and *implementation error* since management actions are never implemented perfectly.	WGMG2004
Evaluation of management strategy	The process of evaluating (parts of) a management strategy against pre-specified objectives. The evaluation can consist of simulations of some elements of the management strategy, complemented with analyses of those elements of the strategy which are not amendable to quantitative analysis. The evaluation of Harvest Control Rules are a special case of the evaluation of a management.	SGMAS2005
Evaluation trial	Trials used for formal comparisons of candidate management procedures.	WGMG2004
Feedback	Effect of one component in the framework on other components. The term is typically used for effects that cannot be described analytically. Assessment feedback refers to the effects of including an actual assessment model within the framework; management feedback refers to the effect of management on the stocks and vice-versa.	WGMG2004
Fishery	The term fishery can refer to the sum of all fishing activities on a given resource, for example a hake fishery or shrimp fishery. It may also refer to the activities of a single type or style of fishing on a particular resource, for example a beach seine fishery or trawl fishery.	Cochrane, 2002
Fishery system	A fishery system includes four subsystems of human decisions and actions and one resource system which is external to the analytical framework. The processes within the subsystems are: knowledge production, management decisionmaking, implementation, adaptation WGFS (2000).	SGMAS2005

Term	**Definition**	**Source**
Fishing capacity	This is a concept which has not yet been rigorously defined, and there are substantial differences of opinion as to how it should be defined and estimated. However, a working definition is the quantity of fish that can be taken by a fishing unit, for example an individual, community, vessel or fleet, assuming that there is no limitation on the yield from the stock. It is also conceptualized in terms of the effective size of a fleet (number of vessels, total engine power of the fleet, etc)	Cochrane, 2002 SGMAS2005
Fishing effort	The total amount of fishing activity on the fishing grounds over a given period of time, often expressed for a specific gear type e.g. number of hours trawled per day, number of hooks set per day or number of hauls of a beach seine per day. Fishing effort would frequently be measured as the product of (a) the total time spent fishing, and (b) the amount of fishing gear of a specific type used on the fishing grounds over a given unit of time. When two or more kinds of gear are used, they must be adjusted to some standard type in order to derive and estimate of total fishing effort.	Cochrane, 2002
Fleet	Used broadly (…) to describe the total number of units of any discrete type of fishing activity utilising a specific resource. Hence, for example, a fleet may be all the purse seine vessels in a specific sardine fishery, or all the fishers setting nets from the shore in a tropical multispecies fishery.	Cochrane, 2002
Harvest advice	Part of the management procedure that compares the assessment results against a pre-determined set of benchmarks in order to formulate advice. Typically, a harvest control rule will be used.	WGMG2004
Harvest control rule	An algorithm for pre-agreed management actions as a function of variables related to the status of the stock. For example, a control rule can specify how F or yield should vary as a function of spawning biomass. Control rules are also known as “decision rules” or “harvest control laws” in some of the scientific literature.	WGMG2004
Implementation error model	Model that represents how implementation of decisions will differ from intended ones.	WGMG2004
Implementation system	The implementation system covers agencies and organisations that are concerned with implementing, monitoring and enforcing the various management measures that has been negotiated in the decision management system WGFS (2000).	SGMAS2005
Initial conditions	The set of conditions (assumptions and events) that result in the historical data that are needed to start the simulations.	WGMG2004

Term	Definition	Source
Interested party Interest group	Refers to any person or group who has a legitimate interest in the conservation and management of the resources being managed. This term is more encompassing than the term stakeholder. Generally speaking, the categories of interested parties will often be the same for many fisheries and should include contrasting interests: commercial/recreational, conservation/exploitation, artisanal/industrial, fisher/buyer-processor-trader as well as governments (local/State/national). The general public and the consumers could also be considered as interested parties in some circumstances.	Cochrane, 2002
Knowledge production system	The knowledge production system consists of all processes by which observations are generated from other subsystems and how these observations are made understandable for management purposes or to any other system where this knowledge may be used (e.g. in the Adaptation system). WGFS (2000)	SGMAS2005
Limit reference point	Benchmarks used to indicate when harvests should be constrained substantially so that the stock remains within safe biological limits. The probability of exceeding limits should be low.	WGMG2004
Management evaluation framework	A framework for evaluating (parts of) a management strategy against pre-specified objectives. The evaluation framework can consist of simulations of some elements of the management strategy, complemented with analyses of those elements of the strategy which are not amendable to quantitative analysis.	SGMAS2005
Management measure	Specific controls applied in the fishery to contribute to achieving the objectives, including some or all of technical measures (gear regulations, closed areas and time closures), input controls, output controls and user rights.	Cochrane, 2002
Management plan	A management plan includes the decision-making processes (harvest control rules, tactical decisionmaking) and the sanctions on implementation and the requirements for monitoring and reporting. Management plans may also exist in the form of rebuilding plans or recovery plans.	SGMAS2005
Management procedure	A simplified representation of the set of human actions that attempt to understand and control the fish and fishery systems. The procedure can be comprised of: observation, assessment, harvest advice, harvest decision, and implementation of those decisions.	WGMG2004
Management strategy	Management strategies consist of objectives with associated performance criteria, the implementation measures (e.g. input or output control) and what is considered a relevant knowledge base for decisions.	SGMAS2005
Objective	A target that is actively sought and provides a direction for management action. For example, achieving a specified income for individual fishers is one possible economic objective of fisheries management.	Cochrane, 2002
Observation model	Part of the management procedure that represents the way in which the operating model is sampled for fishery-dependent and fishery independent data.	WGMG2004

Term	Definition	Source
Operating Model	A virtual world that is a simplified representation of reality. It's main components are fish and fisheries (adaptation).	WGMG2004
Performance indicator	A specific state, or variable, which can be monitored in a system e.g. a fishery to give a measure of the state of the system at any given time. In fisheries management, each performance indicator would be linked to one or more reference points and used to track the state of the fishery in relation to those reference points.	Cochrane, 2002
Rebuilding plan	Same as recovery plan	SGMAS2005
Recovery plan	A management plan that aims to recover the state of a fish stock to a pre-specified level. This may includes elements of the decision-making processes (harvest control rules, tactical decisionmaking) and the sanctions on implementation and the requirements for monitoring and reporting. Recovery plans are a special case of a management plan.	SGMAS2005
Reference point	Values of parameters (e.g., B_{msy}, F_{loss}, F_{PA}) that are useful benchmarks for guiding management decisions. Biological reference points are typically limits that should not be exceeded with significant probability or targets for management. Reference points are an essential element for parameterizing harvest control rules.	WGMG2004
Robustness trials	Trials to examine the robustness of management procedure performance to a range of plausible scenarios regarding the dynamics of nature, the adaptation of fishermen, the implementation system and the knowledge production system (e.g. bias) .	WGMG2004 SGMAS2005
Stakeholder	See Interested party.	Cochrane, 2002
Tactical decisionmaking system	Management decisions are more than the harvest control rule. Tactical management decisions will always include a critical evaluation of the outcome of a harvest control rule and will be subject to requests for flexibility when politically sensitive issues are at stake.	SGMAS2005
Target reference point	Benchmarks used to guide management objectives for achieving a desirable outcome.	WGMG2004 SGMAS2005

References

Cochrane, K. L., Ed. (2002). A fishery manager.s guidebook. Management measures and their application. FAO Fisheries Technical Paper. No. 424. Rome, FAO.