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International Council for the Exploration of the Sea

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Contents

Executive summary

The Study Group on Management Strategies (SGMAS) was established with the specific task to *"define a framework based on long-term considerations for management strategy evaluations in a Precautionary Approach context"* and to *"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"*.

The report is the combined work of two meeting in Copenhagen from 31 January to 4 February 2005 and 23-27 January 2006 at ICES Headquarters under the co-chairmanship of Dankert Skagen (Norway) and John Simmonds (UK).

The report is organized in sections. Section 2 describes the conceptual issues that surround management strategies including the role of the different parties in the fisheries system. 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. In particular in addition to "main stream" stocks advice is provided for short and long lived species and for stocks where the data is poor. 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, elements of which are developed further in Section 7 where simulation is described in detail. Section 5 gives fourteen examples of management strategies that are in the process of evaluation or are already in use. There are some specific types of management measures that present their own specific challenges for evaluators. Several of such types of management action are identified in Section 6. Section 7 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 simulation and how they are documented. Methods that are still under development are also noted. Section 9 notes briefly similar developments in areas outside ICES. Section 10 briefly documents current links with other ICES study and working groups and Section 11 provides suggestions for the future.

1 Introduction

This report is the combined work of two meeting of the Study Group on Management Strategies (SGMAS). The Study Group met in Copenhagen from 31 January to 4 February 2005 and 23-27 January 2006 at ICES Headquarters under the co-chairmanship of Dankert Skagen (Norway) and John Simmonds (UK), the participants list is provided in Annex 1 and the terms of reference for both meetings in Annex 2

The report is organized in sections. Section 2 describes the conceptual issues around management strategies[1] including the role of the different parties in the fisheries system. 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. In particular in addition to “main stream” stocks we provide advice for the evaluation of strategies for short and long lived species and for stocks where the data is poor. In this context “main stream” refers to stocks where catch options are derived from F values according to a harvest rule assuming analytical assessment. 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 such management strategies, detailed computational aspects of which are developed further in Section 7 where simulation is described in detail. Section 5 gives fourteen examples of management strategies that are in the process of evaluation or are already in use. There are some specific types of management measures that present their own specific challenges for evaluators. Several of such types of management action are identified in Section 6. 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 simulation and how they are documented. Methods that are still under development are also noted. Section 9 describes briefly similar developments in areas outside ICES. Section 10 briefly documents current links with other ICES study and working groups and Section 11 provides suggestions for the future.

Some of the terminology used in this report is explained in a glossary provided in Annex 3.

1 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.

2 Conceptual issues

ICES is increasingly being asked to evaluate harvest control rules or management plans as a step to move from away from short term crisis management towards long term management. A harvest control rule is a component in a wider management strategy which 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 a knowledge system, a decision-making system and an implementation system (Figure 2.1, WGFS: ICES 2001, ICES 2004d). The fleet adaptation system and the underlying resource system represent 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.

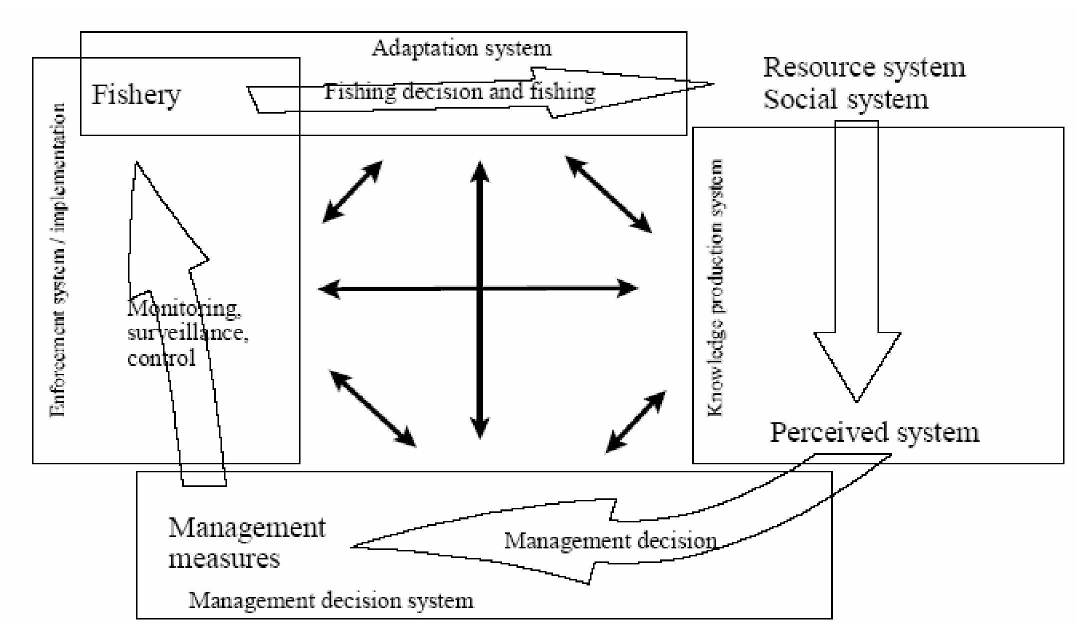


Figure 2.1 The fisheries system. The management strategy identifies the knowledge production system, the management decision system and the implementation system. The adaptation of the fleets and the natural changes in the resource system are external constraints. (ICES, 2001)

The fishery system can also be conceptualized in the form of an onion where each outer layer encompasses one of more inner layers. This onion model can be applied to the (rational) contents of a fishery system (Figure 2.2) or to the processes of a fishery system (Figure 2.3).

The rationality based version of the fishery system consists of (from inside to outside):

- 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 Blim reference point and two trigger points (Bpa and Fpa).

- 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.

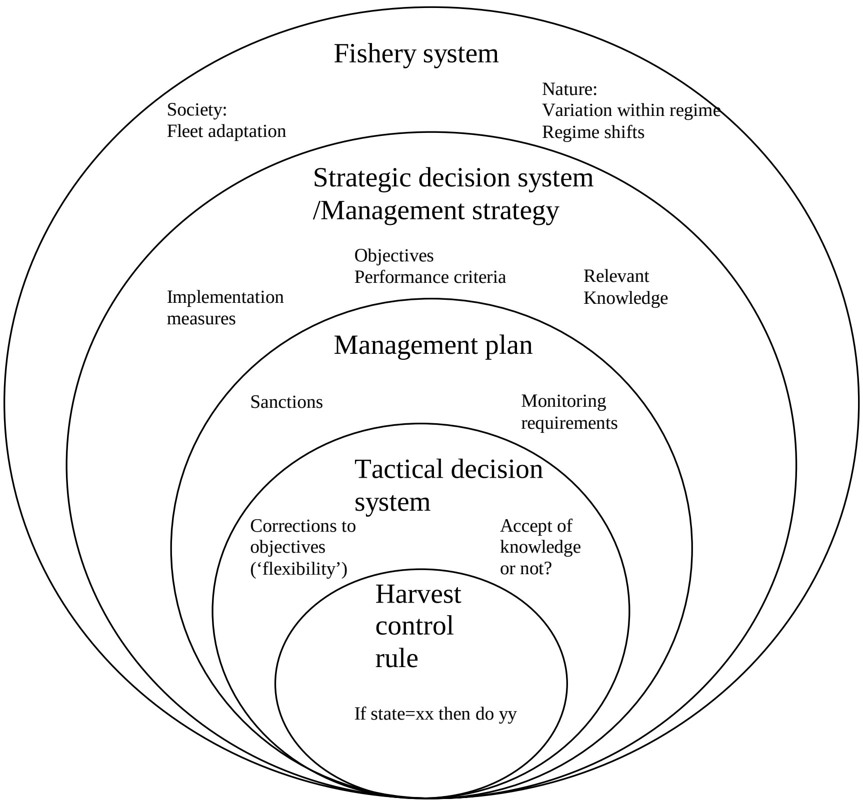


Figure 2.2 The management strategy onion: contents oriented version.

The **process oriented** version of the fishery system (figure 2.3) is based on Ostrom's model of commons decision rules (Ostrom 1990) which distinguishes the fishery system into:

- constitutional choice rules: who gets to participate
- collective choice rules: how they get to participate
- operational rules: what they have agreed, e.g. the 'HCRs'.

An example of the process oriented aspects of fishery systems is the establishment of Regional Advisory Councils (RACs) in the EU. The RACs have been set up within the context of the new Common Fishery Policy ("the management strategy"). In the process of setting up the RACs there have been long debates on **who** should participate in the RACs (including the number of members from different stakeholder groups). After the RACs had started, the focus changed to **how** they were going to participate: how would the role of RACs be, vis-à-vis the decision making system and how the roles would be of the different members within the RAC. Of course there are different arrangements with regards to how groups participate and the RAC is presented as an example only.

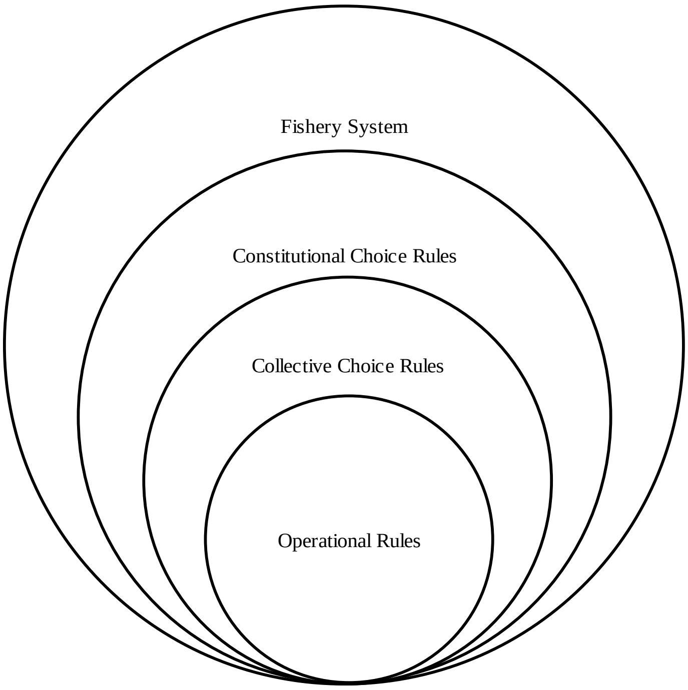


Figure 2.3 The fishery system onion: process oriented version.

2.1 Developing management strategies

The development of fisheries management strategies is a long and complex process where many fisheries managers, politicians, stakeholders and scientists participate. Management strategies are often at a multi-national level and relate to overarching international agreements (e.g. Rio declaration, FAO code of conduct, Johannesburg summit). If we take the EU Common fisheries Policy (CFP, ref) as an example of a management strategy, the development of that strategy took a number of years and involved an analysis of the previous strategy, a hearing process of stakeholder groups, the formulation of an initial proposal, a commenting process by stakeholder groups, a final proposal and the political agreement.

2.2 Evaluating management strategies

The evaluation of management strategies is not a simple task. In general, the evaluations of management strategies are likely to involve analyses that go beyond the natural sciences which traditionally have defined ICES's role. ICES should either attract this wider disciplinary perspective or should seek cooperation with other organizations.

2.3 Developing harvest control rules (operational rules)

The development of harvest control rules is also likely to be an interactive process which involves fisheries managers, politicians, stakeholders and scientists. The different aspects of the process that is needed to arrive at the definition of harvest control rules are described in Section 4.2.

2.4 Evaluating harvest control rules (operational rules)

An evaluation of a harvest control rule would in principle require the incorporation of all the important elements of the outer layers of the fishery system. 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 deteriorates, 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 harvest control rules to these processes may in some instances be illustrated by robustness testing.

2.5 The focus of SGMAS

The primary focus of SGMAS has been to develop a framework for the design and the evaluation of operational rules (harvest control rules) within the wider context of management strategies. In the short term, this is 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. The wider context in which these harvest control rules operate can partly be incorporated through robustness testing (exploring how sensitive the outcome of HCR simulations are to e.g. implementation bias, data uncertainty and natural dynamics).

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.

WGECO has suggested that SGMAS incorporate wider aspects of ecosystem components in development and evaluation of management strategies. These issues are further discussed in Section 10.

3 Options for management strategies

3.1 The dimensions of the problem

3.1.1 Introduction

As discussed in Section 2 above 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 targeting 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 may all call for different management strategies. Finally management strategies need to take into account limitations to obtain timely crucial information on which to base decisions and area- or stock-specific objectives or problems.

This section gives an overview of the relevant types of management objectives which can be addressed, different types of fisheries they can apply to, biological features which should be considered, knowledge requirements, and potential management measures. Further attention is given to available HCRs for single species and specific problem for multiple species issues.

3.1.2 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 “Maximize 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 takes 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.

3.1.3 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 point to different attributes that relate to fisheries and that may need to be taken into account when implementing or evaluating a management strategy. These attributes are:

- directivity: to single species or mixed species, spatially/temporally mixed or distinct
- mobility of the fishery: local or highly mobile
- scale: small - large; artisanal - industrial
- international status: national – multi national
- gear: single gear - multi gear
- legal structure: company owned – fisher owned
- economic status: comfortable vs. desperate

It should be noted that it is not always possible to address management actions to specific fisheries without additional measures which ensure that the actions would affect the intended fishery. For an example see Section 6.2.

3.1.4 Stocks & range of biology

Here we point to the biological attributes 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, but also to answer the question: "Is the proposed strategy appropriate for this kind of stock?" The following biological characteristics should be taken into account:

- natural lifespan: short – long
- stock movement: sedentary and local – highly migratory
- distribution: wide - localized
- productivity: low – high
- aggregation behaviour: schooling – non schooling
- commercial interest: low – high
- recruitment variability: low – high/spasmodic
- ecosystem: trophic level

3.1.5 Information base

The information base (or knowledge production system) is an important element of fishery systems. Given a choice of 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. However, also unbiased empirical indicators of stock size such as relative stock estimates from surveys or CPUE could be used as a basis for tactical decisions. 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: survey data and its precision
- availability/reliability of fishery dependent data: CPUE data and its utility
- 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
- availability of expertise/competence to run the strategy
- 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.
- availability/reliability of relevant biological information
- availability/reliability of relevant ecosystem information

3.1.6 Management measures

Management measures are the mechanisms (tools) the fishery manager has available to regulate the fishery and the utilisation of resources. These mechanisms aim to control the quantity of fish caught, when and where they are caught and the size at which they are caught (Cochrane 2002). The most common tools used here are:

- Quota regulations
- subsidies and tax regulations
- Vessel licensing (including decommissioning)
- Effort regulation (days at sea)
- Technical conservation measures, i.e.
    - Gear regulations
    - Area closures
    - Seasonal closures
- Minimum landing size (MLS)
- Discard regulations
- Bycatch rules

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

3.2 Development of management plans and tactical choices.

As discussed in Section 2, a management strategy includes a hierarchy of elements, illustrated in Figure 2.2. Thus, it is far wider than a harvest control rule. The design of most elements of a management strategy will have to be adapted to specific situations, to account for the characteristics outlined above (presently 3.2-3.6). These adaptations are needed because of the diversity in management objectives, in the information that is available and how that can be verified, in the criteria that form the basis for management tactical decisions, in the instruments that managers can use to implement the strategy, and to the need to adapt to the biological characteristics of the stock. Therefore, there is no universal management strategy, and no universal recipe for how they should be developed.

Below, some aspects of the design process, in particular on management plans and tactical choices, are outlined for some commonly encountered cases. The discussion of these cases is not exhaustive, and the experience so far is limited, but it should give at least some suggestions for those who are involved in the development or evaluation process. Some problems have not been dealt with because of lack of expertise or time constraints. One example is where there are problems with stock identity. Experience obtained so far in developing and evaluation of HCRs and their tactical approach is illustrated in the examples in Section 5. The report of EU Norway meeting in 2004 and AGLTA in 2005 has strongly emphasized this need for each case to be treated individually.

3.2.1 Development of HCRs for assessed 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 the fishing season. 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 (Figure 3.1)

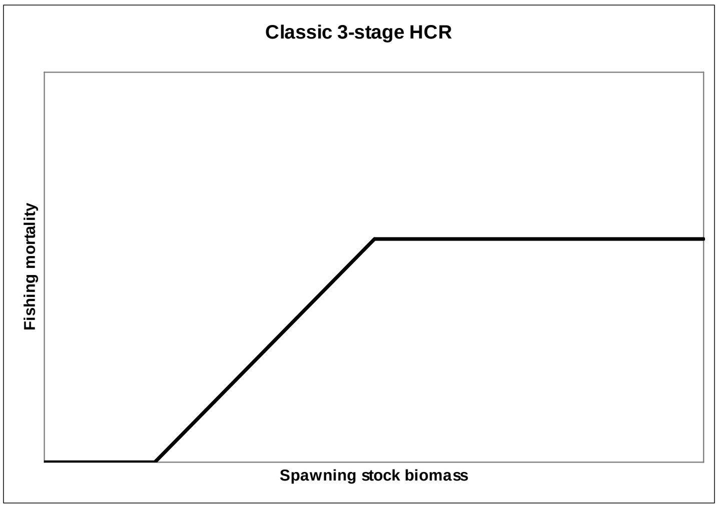


Figure 3.1 "classic" three stage HCR with specified, usually fixed, values for F when B is below the lower trigger point or above the upper one, with a smooth transition at biomass values between the two trigger points

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 perceived to increasing or decreasing.

The evaluation of these types of HCRs is relatively well understood and involves simulation. Currently a number of simulation tools exist to evaluate HCRs for such stocks; the main examples are documented in Section 8 on computer software. This area is developing fast and the current report contains only a snapshot of the current situation.

The tactical decision, choosing the HCR and the method/data to be used in the HCR has to be selected based on the expectation that the data will be available in the future. The first requirement for testing an HCR is an operating model. The development of such HCRs in this way does not require an assessment for the stock in the current year but implicitly assumes some reasonable level of knowledge with which to parameterize an operating model of the stock dynamics. Then if the assessment is available into the future it can be used as the major source of information on the state of the stock and be used in the HCR. If however, the assessment subsequently breaks down, in particular for recovery stocks where the assessment may become unstable, then an alternative tactical approach using different data may need to be considered.

However, an alternative to the tactical approach of an SSB based formulation is an HCR decision rule on the basis of other parameters and/or in-year information. In this context other parameters could include for example: fishing mortality that the stock can sustain; and in the case of in-year information: surveys or early catch rates from the commercial fishery. Such HCRs are presently used for short-lived stocks like anchovy and capelin but could also be applied to longer-lived stocks.

An exclusively effort-based tactical approach has not yet been put into practice in most of the ICES area. Where these have been used or where there are regimes already in existence which incorporate elements of effort control in a TAC fishery, for example NS Cod, these have not yet been evaluated as a component of an HCR.

HCRs can be used to take either annual or multi-annual decisions that fix fishing opportunities for several years.

SSB may form only part of the HCR, 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 rules based on a set of indices of stock abundance and catch rates.

3.2.2 Development of HCRs for short lived species

3.2.2.1 General population considerations

Short-lived species are usually considered as those that have high natural mortality at all ages and because of that the main part of the catch and the population are 1 or 2 years old. Generally they are important prey species and therefore ecosystem considerations could and should be taken into account when defining objectives. They often exhibit a weak stock recruitment relationship which may be intrinsic to the biology or undetected due to the very high variability in recruitment. Also the natural mortality may vary considerably. Because of the fast turn over of the population there are large chances of stock depletion in case of recruitment failures. The high natural mortality makes these species very sensitive to recruitment variability and therefore even without fishing there are possibilities of the SSB falling below Blim.

3.2.2.2 Key points when choosing tactical approaches for short lived species

Within a management strategy for short lived species, management at a low fishing mortality is an option for managers. This reduces the need for detailed information on the stock. However, because of the high natural mortality this option is associated with low yields. The cases where no fishery at all is allowed can also be considered as a management option if for example eco-system considerations were to be paramount. For fisheries, the main requirement is to anticipate or evaluate the following factors.

- the level of recruitment
- the biomass surviving to spawn (escapement)
- the provision of sufficient forage for the predators in the ecosystem.

When a fishery is to be carried out then for the above reasons a precautionary spawning biomass is usually defined as the primary target threshold for management objectives. This may be an explicit escapement biomass or may act as a Blim to be avoided with a chosen probability.

Because of the population features described above, standard ways of calculating biomass reference points that are used for longer lived fish may not be valid, or reliable. However, in order to provide a basis for precautionary management criteria, a minimum spawning biomass is often needed and defined.

The other key action in management of short lived species fisheries is timely reactive management. Advice based on traditional backward assessment are not usually very useful since the population to be managed (and fished) is usually derived from the one just recruiting year class and this can only be estimated from direct surveying or very early monitoring of the initial weeks of the fishery. So a recruitment survey (O group survey) before the fishery starts is usually the most powerful tool to provide advice for management.

3.2.2.3 Experience of short-lived species management in the ICES areas.

The cases of anchovy in the Bay of Biscay and sandeel in the North Sea are presented below in Section 5.11 and 5.13 respectively. In addition to these two cases there are two capelin stocks (Icelandic and Barents Sea) which are managed with in-year acoustic surveys (ICES 2001 and Gjosaeter et al. 2002) but are not included in the examples given here. In the case of anchovy, simulations show that a recruit survey would notably reduce the risk of falling below Blim. For sandeel, this conclusion has also been reached but has not yet been tested. Similarly for capelin early surveys are key elements of management. While this factor in management is in common to all the examples, however, the fisheries are not similar; the anchovy is mobile schooling fish, of a high price per kilogramme, targeted by purse seines and pelagic trawlers, where commercial CPUE for purse seines has not been found to be informative, and surveys for monitoring fish abundance are already set up. Recruitment surveys have started which, if successful, could provide information within an HCR framework for TAC advice just before the fishery starts. Sandeel differs from anchovy in that it' spatial distribution is strongly associated with the benthic habitats. It is captured by pelagic trawlers when moving up for feeding. Sandeel has a low price as it is used for fish meal, and the commercial fishery CPUE is used for monitoring relative age class abundance, which is then used for immediate management of the fishery for the rest of the year. For short-lived species, these are the types of factors need to be considered in the evaluation of the management strategies.

3.2.2.4 Conclusions for short lived species

Where short lived species are to be exploited in a fishery SGMAS concludes that for a successful management of short-lived species the following attributes are important considerations for HCRs:

- Early recruitment estimation, from fishery or from survey.
- Rapid evaluation of the data to present advice to managers.
- A decision making process that is timely.
- An effective implementation process that responds swiftly.
- In practice, experience has suggested that in-year management is more successful when initially there is a restrictive fishery which is expanded when relevant information becomes available rather than an open fishery which is restricted when the information is obtained. This approach also conforms to standards of good risk management.

3.2.3 Data poor situations

In this section we consider cases where a traditional analytic assessment and prediction is out of reach for some reason. Hence, a tactical decision system that needs regular updates of the stock numbers at age and fishing mortality cannot be applied. There is a large variety of 'data-poor' situations, covering the range from where regular assessments have been the rule, but have broken down due to unreliable data or methodological problems, to cases where there are few measurements related to the stock. One should also be aware that the status of stocks may change: a regular stock may become data-poor, or changes in data availability or assessment methods may mean that analytic assessments can be completed for previously data poor stocks.

In almost all cases there will be some kind of information. This includes qualitative information about biology and fishery that can be useful in the right context. Typically, management plans guided by such data have to be different to the standard form. Therefore, the first task when considering plans for such stocks will be to get an overview of what information can be made available, and consider what can be inferred from such information.

For example, it will be important to know if the species is short lived or long lived, and lightly or heavily exploited, because that gives an indication of the rate of change in stock abundance that can be expected. Likewise, some indication of recruitment variation is valuable, because regimes with relatively stable quotas perform best when the recruitment variation is low. With a high recruitment variation, the loss in average catch needed to ensure that the stock is within precautionary bounds, will be greater. In some cases, length based analytic assessments may be an alternative. In this case, it will be extremely useful to have enough age information to establish sensible growth parameters, even if regular age sampling is out of reach. It may also be worth considering kinds of information that could be collected, as guidance to the information base part of the management plan. The development of a plan should not be restricted to the data that are currently available.

It is very likely with a data poor stock that the average catch will have to be lower than the maximum yield that could be achieved if the state of the stock was known more precisely. Frequent changes in quotas or other management measures should be less relevant, since the information that should guide such changes is missing. This is likely to lead to a lower but more stable fishery where less management actions are needed. However, it is essential that managers are prepared to take effective and possibly drastic action if there are indications that the situation gets out of control.

Evaluation of the plan should consider the quality of the data, the link between data and stock, and the performance and robustness of the HCR. The latter can be done by simulation, but the other two requires more pragmatic and direct consideration of the data, and sometimes more common sense than quantitative information. In particular, one should be aware that subjective indicators of the state of the stock may be influenced by self-interest.

3.2.3.1 Fisheries indicators

Management of fish stocks in data-poor situations is likely to require some form of ‘indicator’ that acts as a proxy for the status of the stock. It is important to differentiate between different forms of indicator. An “empirical indicator” is calculated directly from a specific set of raw data and, in the process of calculation, may use one or two parameters that can be easily defined. In contrast, an “estimated indicator” represents a fishery variable of interest that is derived from a range of data sets and is dependent upon additional parameters that may or may not be easily defined (see Scandol, 2005). For example, raw commercial CPUE and mean age are empirical indicators, while biomass and fishing mortality are estimated indicators.

Traditional ICES VPA-based assessments and management procedures make use of estimated indicators to evaluate the state of the stock and to set reference points. In data-limited situations, the calculation of estimated indicators may be unreliable or not possible, and standard assessments may be rejected (e.g. WGNSDS 2005) causing subsequent problems for the implementation of management plans. If a stock is known to be ‘data poor’ then the initial focus should be upon empirical indicators.

Possible empirical indicators for single-species fisheries management are listed below, although the list is not exhaustive and many possible empirical indicators are likely to exist. Several indicators are likely to be correlated, e.g. mean age and age proportion.

Empirical indicators of stock status:

- raw catch;
- raw catch per unit effort;
- mean age of population samples;
- mean length of population samples;
- age structure of population samples:
    - recruitment fraction;

    - mature fraction of population;
    - 'old age' fraction of population;
- absolute recruitment measures;
- total mortality;
- area distribution;
- underwater TV abundance surveys (e.g. *Nephrops* burrow densities);
- fishery-independent surveys, etc.
- interview information and other subjective sources.

In the above list, indicators calculated directly from population samples could be fishery independent (e.g. data from surveys) or fishery dependent (e.g. data from catches). Several of these indicators may also be suitable for management in multi-species or ecosystem approaches but we do not consider these cases in detail here.

3.2.3.2 Choosing indicators for use in management

The choice of empirical indicator(s) to be used in the management process is likely to depend on a number of factors:

- Data availability: clearly indicators will only be of practical use if the required data are available, or could be made available, either from fishery dependent or independent sources.
- Stock specificity: the choice of applicable indicator(s) will require a careful consideration of the particular stock characteristics.
- Cost: many 'data poor' stocks are also of little commercial value (although this is by no means exclusive) and the expense involved in collecting data for an indicator should be considered.
- Variability / stability: the expected annual variation in the indicator should be considered.
- Long term data availability: some consideration also needs to be given to whether the data that the indicator is based upon will always be available. For example, if the indicator is based upon survey data and the survey fails to take place then no information will be available to use in the management process. In all cases a 'back up' plan will be useful, but indicators that are likely to have fluctuating data availability should perhaps be avoided.
- Fishery independent/dependent: several indicators (e.g. mean length) can be calculated from either fishery dependent or independent data (or both).
- Form of HCR: ideally the management process and corresponding HCRs should be designed around characteristics of the available indicator(s) and not vice-versa, but this may not be possible. If a pre-designed HCR is to be used then the most appropriate indicator(s) should be selected based on the form of the HCR and the considerations in the above points.

3.2.3.3 Using indicators in the management process

The most basic way to use and interpret indicators in the management process is simply by 'eyeballing' the available data (i.e. looking for patterns or signals in the data by eye alone) and making a subjective judgement based on prior knowledge and experience (and using this judgement in the subsequent management process). This approach should not be rejected out of hand as there may be no other option due to lack of further data or management resources. However, this approach is not transparent and is easily open to criticism.

The next step in complexity is to use the raw indicator data (historical and recent) 'as is' in the management process or HCR. The advantage of this approach is that it is clearly objective and transparent, and does not involve any further manipulation of the data. However, using the raw indicator data may cause problems in the management process if, for example, the indicator fluctuates rapidly from year to year. These transient signals may obscure any persistent system changes and, depending on the stock and HCR in place, could cause unnecessary management actions to be implemented. Indicators do not need to be used independently, and it may be useful to compare the apparent signals from a variety of available indicators, before making an objective judgement on the state of the stock. Designing a method to combine signals from different stock indicators is a non-trivial open-ended problem, although quality control methods may prove useful, giving greatest weight to indicators with the most relevant information and the lowest noise.

The most complex way of using and interpreting the indicator information is to use some form of quality control mechanism. This technique is used in process management in areas such as manufacturing and health. A good review of these methods in relation to fisheries management is given in Scandol (2005).

3.2.3.4 Development of a tactical decision system in the case of data-poor stocks

The general guidelines of what is required for development of a management plan still apply to data-poor stocks:

- A description of the fishery, especially its current status and user rights.
- Management objectives.
- How the objectives are to be achieved.
- How the plan is to be reviewed and the associated consultation process.

In the case of data-poor stocks, reliable biological indicators are generally limited and a tactical decision needs to be taken to make the best possible use of the information available (e.g. use of the egg abundance data in a HCR for horse-mackerel, as described in Section 5.12). Existing data may need to be supplemented by literature references or expert knowledge related to similar species. The stakeholders themselves can also be used as a source of secondary information about the stock and the fishery. The cost and availability of resources (expert knowledge, data collection, implementation, enforcement, etc.) associated with choosing between tactical options should also be considered.

3.2.3.5 Reference points for data poor stocks

In the particular case of data-poor stocks, the reference points will be specific values of the indicators that are used to monitor the fishery and apply decision rules. . Indicators for data-poor stocks are unlikely to be based on F and SSB, and reference points will therefore be different to the traditional ICES reference points (B_{lim}, F_{lim}). A key point is that, to be in accordance with the precautionary approach, these reference points must be able to trigger management action to protect the stock from depletion.

3.2.3.6 Flexibility and Robustness

In the case of data-poor stocks, the supply of indicators is more likely to be discontinued. Alternative indicators or decision rules should also be considered as a ‘back-up’ as part of the management plan. For example, in the case of North Sea cod, the existing management plan failed when the assessment was considered unreliable and no alternative was in place.

3.2.3.7 Evaluation of the tactical decision system

When evaluating a HCR for a data-poor stock, the simulated operating model may be a standard population model, but may need to be extended to allow for calculation of indicators used in the HCR (i.e. length distribution). The crucial problem in interpreting the results from simulation testing is to ensure that the observation model is sufficiently realistic. This is not a trivial problem and needs to be addressed relative to the specific indicators used in the HCR (e.g. indicators such as fishermen's opinions of stock status are likely to be difficult to simulate realistically in the observation model). A further non-trivial problem due to the limited availability of data is the initial parameterisation of the operating model to ensure that the simulated dynamics are realistic. However, progress can still be made, as it is likely that essential dynamics are qualitatively known and the necessary parameters may be estimated by making use of existing knowledge of the dynamics of similar stocks.

3.2.3.8 Suggested tactical decision systems for data-poor stocks:

Quota regulation with semi-fixed quotas

Quota is kept fixed unless the indicators suggest that the quota needs to be adjusted. Several variants of this general framework can be considered. For example:

- Upper limit to quota; quota reduction with indicator signal; subsequent quota increases cannot exceed upper limit.
- As above, but limited flexibility to increase upper limit of quota with strong indicator signal, over long time intervals.

This kind of approach is appropriate when the stock is relatively stable and recruitment variation is modest. Simulation studies indicate that such a regime may be dangerous if the stock is in a heavily exploited state. In this situation, risk can be reduced if the quota is set far below recent average catches or if a robust decision rule is in place to react to stock depletion.

Relative changes in quota

If there is information about relative trends in stock abundance or level of exploitation then this information can be used in HCRs to set TACs or to adjust effort (See Section 5.12). Catch or effort levels can be directly adjusted according to the change in the relative index. Any changes in quota should be implemented with caution and take place slowly over time since the signal is based on a relative trend and the absolute status of the stock is unlikely to be known.

Recruitment driven stocks

For a stock which is recruitment driven, an indicator of recruitment is required if maximising yield is an objective (see Section 3.2.2). A semi-quantitative or relative indicator of recruitment could be used, but would necessitate a more cautious response. A step-wise response could be appropriate to minimize risk of stock depletion.

Long-lived species

In the case of long-lived, low fecundity species, a very conservative version of method (1) should be considered (see Section 3.2.4). Close monitoring of trends in relevant indicators is also likely to be necessary. In particular, for deep-water species, the fishing effort should not be highly aggregated as local depletion could then occur.

3.2.3.9 Examples of data-poor stocks and management plans

As discussed above, the 'data-poor' situation is a relative concept linked to the data requirements of the available assessment models. Many of the ICES stocks could be classified as such when a traditional analytical assessment (e.g., VPA based assessment models) cannot be carried out. However, it may be perfectly possible to design management plans for these stocks and define HCRs.

Explicit management plans are only defined explicitly for a few ICES stocks, while reference points are undefined for a number of stocks. In such cases, ICES adopts a precautionary approach to advice using historical biomass trends. This is not always appropriate for data-poor species where other considerations need to be taken into account to provide medium and long-term advice.

Some examples of data-poor stocks in the ICES are described below:

- An attempt to apply standard advisory procedure where there is no analytical assessment for Norway lobster (*Neprhops norvegicus*) in management area L (area 7). In these Nephrops stocks there is no age data, limited length data, and only catch and effort series are available. Management advice takes into consideration the historical catch and effort series with the objective of maintaining the stability in catches observed in the past. Since the effort has increased recently, the ICES advice was to reduce catch to the stable level deployed in the period 2000-2002. Recent developments in underwater TV surveys (e.g. in Irish waters) may allow the use of a relative empirical indicator based on burrow density as a proxy to stock status.

- Attempt to derive a HCR from a production model in the case of Anglerfishes (*Lophius spp*.) in Divisions VIIIc and IXa. These stocks are assessed by surplus production models (ASPIC) since no age data are yet available. The CPUE fleets used in the assessments also gave conflicting trends, making the assessment very uncertain and only useful for identifying trends. B_{MSY} and F_{MSY} are considered as the lowest allowed level for biomass and highest allowed level for fishing mortality. Based on the historical trend of the ratio B/B_{MSY} and F/F_{MSY} the ICES advice in the period 1999-2003 was to reduce F with the aim of driving the stock above B_{MSY} level. The TAC level was set accordingly. Recently, a recovery plan has been proposed for these stocks.

- The Western horse mackerel (*Trachurus trachurus*) stock, where fishery independent data is sparse and the state of the stock is uncertain. This is an example of where the analytical assessment is not considered to be reliable, and the stock is assessed by an “ad hoc” age structured model (SAD). The model is tuned with the tri-annual egg survey time series. Unresolved problems with estimating fecundity mean that it is not possible to estimate SSB (and consequently F) exactly, and therefore the assessments are only useful to look for trends. As a result of the SSB decreasing trend, the ICES advice was to reduce the TAC level to meet the precautionary approach (at least until a new strong year-class enter to fishery). Currently, innovative possible HCRs are being explored; see Section 5.12 for further details.

3.2.4 Long-lived Species

3.2.4.1 General population considerations

There is no explicit accepted definition of the term long-lived species. For the purposes of this report we consider species such as deep-water fishes, elasmobranches, *Sebastes* redfish and Greenland halibut as falling into this category. Many of these species live to ages in excess of twenty years and some may live more than 100 years.

Common characteristics of these species with relevance to their management include:

- Low natural mortality
- High age at recruitment into the fishery
- High age at first maturity
- A variety of reproductive strategies, generally characterized by low fecundity.

3.2.4.2 Key points when choosing tactical approaches for long-lived species

There are a number of key areas in which management strategies for long-lived species are likely to differ from those for other fisheries.

- Changes in exploitation patterns in the fishery take longer to detect
- Following depletion stock recovery is likely to take longer
- Sustainable exploitation rates are likely to be much lower.
- Inter-annual variability of abundance is likely to be lower
- The productivity and resilience of the stock may be poorly understood.

Given the long life span of these species, precautionary exploitation implies low F and slow change in abundance or biomass with time. Detection of changes in the stock therefore requires either high precision or data collection over a long time period. Unless care is taken to ensure standardization in data collection there may be confounding between the changes within the monitoring program and the changes in the stock. Technical development in commercial fisheries (technical creep) makes commercial CPUE series particularly sensitive to these problems. This means that basing the tactical approach on information from the fishery alone is not the preferred option, a scientifically controlled survey will suffer much less from these problems.

The majority of the species under consideration here (e.g. deep-water fishes and elasmobranchs) can be classified as data poor and as such will be subject to many of the considerations discussed in Section 3.2.3. Others such as Greenland halibut and redfish are relatively data rich and tactical approach can be defined in terms of SSB and F as with the majority of stocks. Many long-lived species are caught in mixed species fisheries and this is likely to cause particular problems, especially where the target species of the fishery are relatively short lived species and where the long-lived species is effectively bycatch. In some cases, effort based management and technical measures may be the most appropriate approach.

Because of the greater time taken to detect change and low inter-annual variability, in many cases it may be appropriate to assess the stocks and set management measures at longer time intervals than every year.

In view of their low population productivity, ACFM in 2005 recommended a ban on the catching of large female spurdog as a minimum requirement for population rebuilding. Such management strategies, taking account of specific life history characteristics, may be appropriate for some long-lived species.

Example: recommendations from ICES for Harvest Control Rules for deep-water fisheries.

The 2005 report of ACFM made a number of recommendations for the definition of HCR for deep-water fisheries. ICES advised that the management of deep-water fisheries for which state is poorly known must be guided by indicators which include pressure, state, and impact indicators. This is similar to the framework of biomass (state) and fishing mortality (impact) indicators used by ICES in the standard advisory framework.

For deep-sea species, state and impact indicators are difficult to measure and because of their life cycle length, it may take a long time for responses to exploitation to become apparent. Consequently, ICES recommended that pressure indicators such as effort be used to supplement state and impact indicators in the management of these stocks.

ICES recommended that survey-based indices would be the most appropriate state indicator for target species, however, in most cases the only abundance indicator available is commercial CPUE. Changes in commercial CPUE may be confounded by shifts in fishing regimes (changes in target species, sequential fishing and technical creeping).

3.2.4.3 Biological reference points (BPRs) for long-lived species

ICES and NAFO in 1997 proposed BRPs of U_{pa} = 0.5* U_{max} and U_{lim} = 0.2*U_{max} for data poor species. For the slow-growing late-maturing species, (e.g. orange roughy, roundnose grenadier and deep-water squalids) ICES was of the opinion that thresholds should reflect the specific vulnerability of these species to exploitation and their capacity to recover. Two different options were suggested:

1. The thresholds should be higher than those suggested for the quick-growing early-maturing species and their values should be decided by managers;
2. The thresholds should be set provisionally at 75% and 50% of the virgin biomass for U_{pa} and U_{lim} respectively, to accommodate the precautionary approach in a data-poor context.

In the longer term, a long-term MSY-based positive target strategy, rather than the current risk avoidance strategies was recommended.

3.2.4.4 Harvest Control rules for long lived species

Where U_{max} is known, ICES proposed a three stage HCR For example:

- If $U < U_{lim}$, fishery should cease;
- If $U_{max} < U < U_{pa}$, exploitation should be reduced until $U > U_{pa}$;
- If $U > U_{pa}$, exploitation should be set so that U remains above U_{pa}.

However, for the present situation where U_{max} is unknown for the majority of species, ICES proposed an interim approach.

When **new fisheries** develop or existing fisheries spread into new areas, U_{max} and relevant indicators should be established on the basis of small, initial fisheries. Fisheries should be allowed to expand only when indicators and reference points have been identified and a management strategy implemented.

For **existing fisheries**, fishing pressure should be reduced to low levels and should only be allowed to expand again very slowly until reliable assessments indicate that increased harvests are sustainable, indicators and reference points for future harvest have been identified, and a management strategy implemented.

Both these rules should be supplemented with relevant pressure indicators to insure that effort is maintained within sustainable bounds.

3.2.5 Species interaction

Currently management plans are often given species by species without taking technical or biological interactions into account. This section deals with the specific problems of HCR implementation and HCR evaluation when species interaction is handled explicitly.

3.2.5.1 Technical interaction – mixed fisheries considerations

Many demersal fisheries operate as mixed fisheries were multiple species are caught in the same fishing operation. The management of mixed fisheries poses specific problems because the actual mix of species is difficult to foresee, due to dependence on the distributions of the stocks and fleets and the gears used. Fishing fleets adjust their gear riggings and fishing techniques to increase catchability of the desired target species, while desired catch rates are often dictated by the current species TACs. Fleets thus have the options to select the metiers, which in combination determine the pattern of fishing mortality on target species and by-catch species. The direct management of fishing mortality in a mixed fishery requires management on the metier level.

Harvest control rules for mixed fisheries have to account for the combined effect of all the fleets exploiting a collection of stocks. What is good for one stock may be bad for another stock. What is good for one fleet may be bad for another fleet. Thus, HCR for mixed fisheries will contain compromises which optimize an overall objective.

Management on the metiers level requires an understanding of the mechanisms behind the fisher's choice of metier. Choice of metier involves the choice of fishing techniques and fishing grounds by season. The modelling of fishers behaviour with regard of metier choice has been dealt with by the EU project TECTAC, which finished in 2005. TECTAC suggest two alternative models

(1) Random Utility Model (RUM) (2) Dynamic programming

The RUM is a discrete multiple choice model, allocating probabilities to a finite number of choices. The RUM is a well-established model used mainly by economists and sociologists to describe the many different types of human behaviour. The RUM, however, is a new method in the ICES community, and considerable work remains before it can be used as a basis for routine management advice. Dynamic programming is a technique for solving optimality problems for individuals. It allows for calculating the response of individual vessels, taking into account meeting individual quota for a number of species, given the realized catch in a sequence of decisions on spatial effort allocation and discarding. The model takes into account both the degree of uncertainty of future catches, and the realized landings.

HCR for management of mixed fisheries combined with TACs has been implemented in the EU in recent years by the STECF. The MTAC approach (Vinther et al. 2004) is a method to generate candidate TACs which takes mixed-fishery effects into account and thus represents a compromise between the individual single-species TACs. The MTAC, does thus not depend on direct effort control, and is sort of a compromise solution which attempts to minimize the damage caused by single species management.

The TEMAS model (see Section 8.8 presented in the report of TECTAC considers the problems of combining TAC and HCR for mixed fisheries in combination with the RUM (fisher's behaviour model). The TEMAS model however, rather illustrates the HCR problems than suggesting solutions for them. The current theoretical state of HCRs accounting for mixed fishery, is rather weak. For example, there are a long suite of unresolved problems of both scientific and political nature in HCRs for mixed fisheries in combination with TAC

The work shop on mixed fisheries (WKMIXMAN, January 2006), discussed a suite of models aiming at short term forecast for mixed fisheries. The so-called Fleet and Fisheries Forecast (F^3) model was considered a promising approach by WKMIXMAN. The F^3 method was developed within the larger development of the multifleet multi-species bioeconomic simulation framework TEMAS (DIFRES, unpublished; Marchal et al, 2006), where forecast simulations of stocks and fleets dynamics are performed in order to evaluate the consequences of various management scenarios. This simulation framework is built on the explicit description of fleets' flexibility, allowing vessels within one fleet to share their activity on several métiers. In this regards, various modelling hypotheses were tested, in order to best capture future effort allocation schemes under changing TACs conditions. The F^3 method was developed from these hypotheses.

3.2.5.2 Biological interaction

Management of multi-species resources also calls for considerations on the interaction between species caused by predation and food competition, so that changing fishing mortality on one stock may influence the production of other stocks (prey or competitors). These ecosystem aspects are studied by the EU “BECAUSE” project

A first step of including biological interaction in the evaluation of HCR has been taken by the ICES multi-species assessment study groups for the Baltic (SGMAB) and the North Sea (SGMSNS). These groups are dealing with estimation of fish predation and do as such just cover a small part the ecosystem. The multi-species groups have shown that the performance of the single species HCRs is often very different when evaluated in a single species or multispecies model (4M-HCR, see Section 8.2.1 of SGMAS report, 2005).

A presentation on multispecies modeling was made to the SGMAS “Fish population rebuilding framework to control multispecies, multistock, and/or multiarea fisheries for medium to long-term management purposes” (Gröger & Rountree). This paper outlines the fundamentals of a stock rebuilding framework with clear optimality by controlling fishing effort (or fishing mortality) and maximizing landings (or economic value) based on nonlinear optimization using algorithms from economical control theory.

The selection of appropriate ways of handling species interactions is currently an area that is in need of further development. While developments in mixed fisheries evaluation have included multispecies catches (see Section 5.9), inclusion of biological interaction explicitly in management has not been well developed. In most cases current strategies allow for little more than extending the use of single species biomass limits to modified values including of multispecies considerations, and the inclusion of regular reviews to ensure that the stock dynamics that are assumed are still valid under new circumstances. Further development of multispecies evaluations including both biological and fishery interactions is an important requirement.

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 HCRs 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 technical justification 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 HCRs 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 HCRs 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:
    - o are 'black' landings known or suspected to be sufficient to distort cause and effect of the rule;
    - o is there non-compliance with technical measures sufficient to hinder the achievement of their intended objective;
    - o 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 counterproductive?
- 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

The examples given here are a mixture of what has been already been done or is work in progress. In some cases they detail evaluations that have subsequently formed the basis of agreements, in others they are first attempts to provided advice on HCRs. They are provided to illustrate how processes so far have conformed (or not) with the standards we are establishing. Not everything in the past examples given here is what we would recommend today nor have all the examples deal sufficiently with all the known uncertainties. We anticipate that our understanding of the importance of each source of variability or error will increase over time leading to more complete view of the relative importance of different aspects for different situations. Readers should use these to stimulate ideas but the gudlines in Section 4.4 remain the current standard.

5.1 Southern Hake (ICES Div. VIIIc and IXa)

5.1.1 Management advice

Since 2002 ACFM has recommended for the Southern Stock of Hake (ICES Divisions VIIIc + IXa) that fishing mortality should be zero or if this is not applicable then a recovery plan should be implemented in order to rebuild the spawning stock biomass.

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 Norway lobster stocks in Iberian waters (SGMOS, 2003). The Group considered that it was difficult to set up realistic targets in terms of spawning biomass and proposed a F strategy based on $F_{0.1}$ (0.15 as estimated in the assessment carried out in 2002) to recover the hake stock. Two tactics were analysed, namely (i) an annual decrease of fishing mortality of 10 % each year and (ii) an inverted parabola F strategy, with high decreases of fishing mortality in the beginning of the period and small decreases in the end. The simulations performed indicated that an effort reduction scheme, based on reducing effort by 10% each year, would achieve a high probability of recovery of the Hake stock within ten years.

This report was evaluated and adopted by STECF in July 2003 through a fast track procedure by correspondence. In November 2003 (STECF, 2003) the STECF agreed with the results presented in the report and recommended the proposed recovery plan to be implemented.

5.1.2 Legislated recovery plan (December 2005)

Since 2003, several revisions were presented by the Commission and finally in December 2005 a recovery plan was approved and published in 28.12.2005, in the Official Journal of the European Union (L 345/5, Council Regulation (EC) No 2166/2005 of 20 December 2005). This regulation is applied to the southern stock of hake and to the Norway lobster stocks in ICES Divisions VIIIc and IXa and shall enter into force on the 20th day following its publication.

Objectives of the recovery plan

- To rebuild the stock to within safe biological limits.
- To achieve a spawning stock biomass of 35 000 tonnes in two consecutive years or increasing the quantities of mature individuals within a period of 10 years so that values are reached equal to or higher than 35 000 tonnes.

Harvest control rules - procedures for setting the TAC and Fishing mortality

- If the annual fishing mortality rate for the stock has been estimated to be above 0.3, the TAC shall not exceed a level of catches which will result in a reduction of 10 % in the fishing mortality rate in the year of its application as compared with the fishing mortality rate estimated for the preceding year.
- If the fishing mortality rate for the stock has been estimated to be equal to or below 0.3 per year, the TAC shall be set at a level of catches which, will result in a fishing mortality rate of 0.27 per year in the year of its application.
- The maximum change in TAC between years should not be greater than 15% of the preceding year

The measures approved are different from those proposed by SGMOS and STECF in 2003 and to our knowledge have not been evaluated yet.

At SGMAS meeting in 2006 a working paper was presented (Cardador, Azevedo and Jardim) with a preliminary evaluation of the management rules of the approved recovery plan. This section intends to present some results of the evaluation together with some comments from the SGMAS.

5.1.3 The approach used for HCR rules evaluation

The simulations were performed using CS5 and CP2 (CP was revised to allow uncertainties in more parameters). The main differences in these two models concern the uncertainties (CVs) in the population and in the fishing mortality. In CS5, CVs are attributed to the population at age and in CP2 uncertainties are set in both the population and fishing mortality at age. The input data and CVs for the simulations were the same used in the 2005 by WGHMM (ICES, 2006) for the medium term predictions, with some new assumptions:

- Fishing mortality at ages 0 and 1 are considered to be underestimated because discards are not included in the assessment, and these are mainly comprised by these age groups. It was assumed that F at ages 0 and 1 are similar to the F age 2, e.g. 0.40;
- SSB/recruitment relationship adopted in CS5 was the Ockham´s razor estimated by WGHMM;
- SSB/Recruitment relationship assumed in CP2 was considered to have a random distribution with a median recruitment of 55 500 with a CV of 0.6.
- CVs for F at age were assumed to be: (i) 10% for all ages and (ii) 30% for ages 0, 1, 2 and 10% for ages 3-8+ in CP2.

The simulation of the performance of the plan was done according to the rules established in the approved recovery plan:

- An annual 10% decrease in fishing mortality until the target level of 0.27 is achieved. The variation on TAC of more or less than 15% variation of the preceding year was not defined when running CP2, however the variation of the predicted catches was calculated for detection of the accomplishment of this rule.

The results of these experimental evaluations indicate that the SSB do not achieve the level of 35 000 t in 10 years period with a probability of more than 100%. B_{lim} (15 000 t) is expected to be reached in 2009-2010 (Figures 5.1.1 and 5.1.2) with a probability of about 50%.

Figures 5.1.3 and 5.1.4 show the predicted evolution in the catches, recruitment, F and SSB estimated by both methodologies.

5.1.4 Comments on the evaluation

This evaluation was considered to be a preliminary and exploratory analyse which has been performed to understand if the objectives of the recovery plan are possible to achieve with the rules defined. The results of the models may be sensitive to assumptions used in the models, especially the SSB/R relationship and the CVs applied to the population and fishing mortality at age. A sensitivity analysis will be considered in further evaluations.

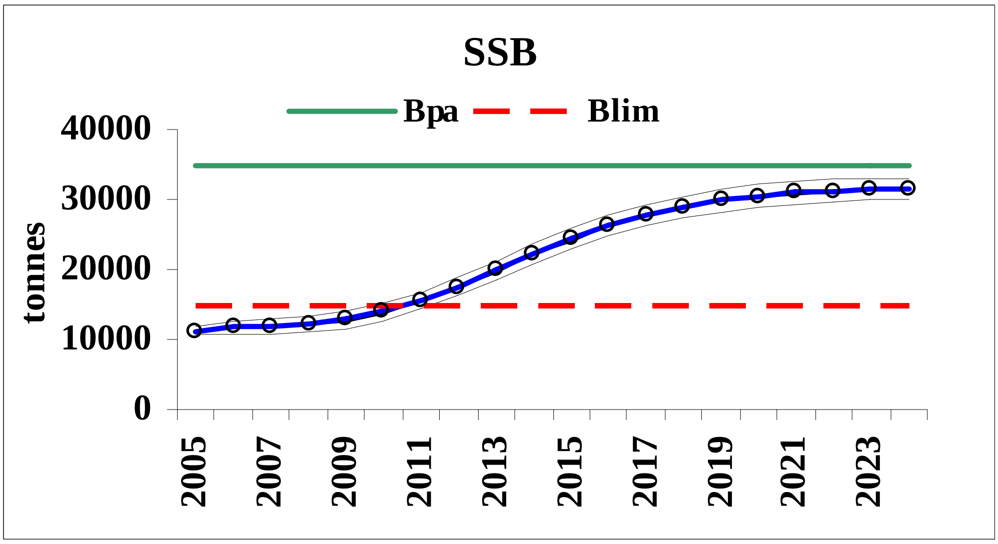


Figure 5.1.1 **Southern hake - Evaluation of the recovery plan (CS5-soft)**

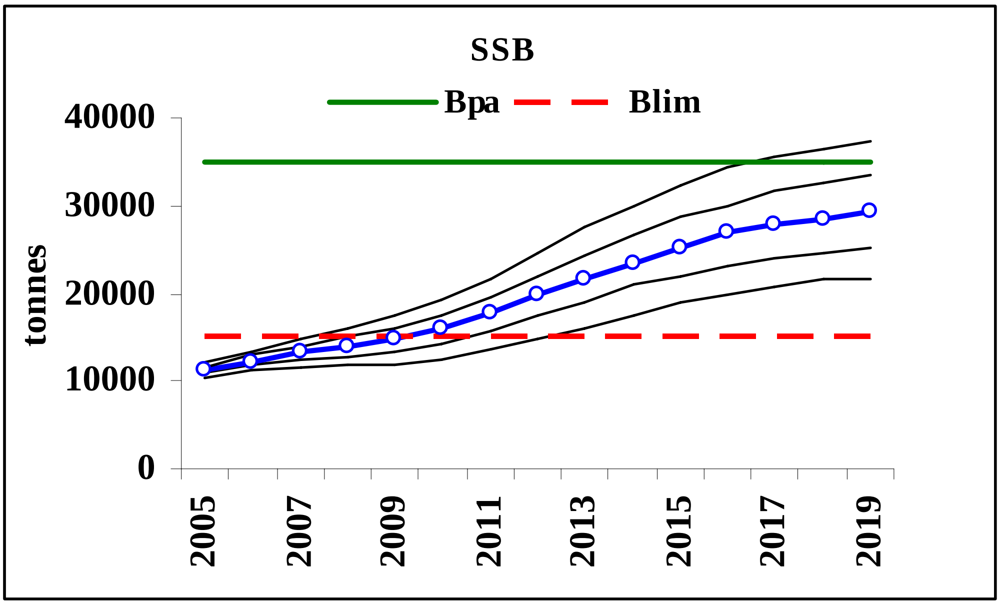


Figure 5.1.2. **Southern hake - Evaluation of the recovery plan (CP2-soft)**

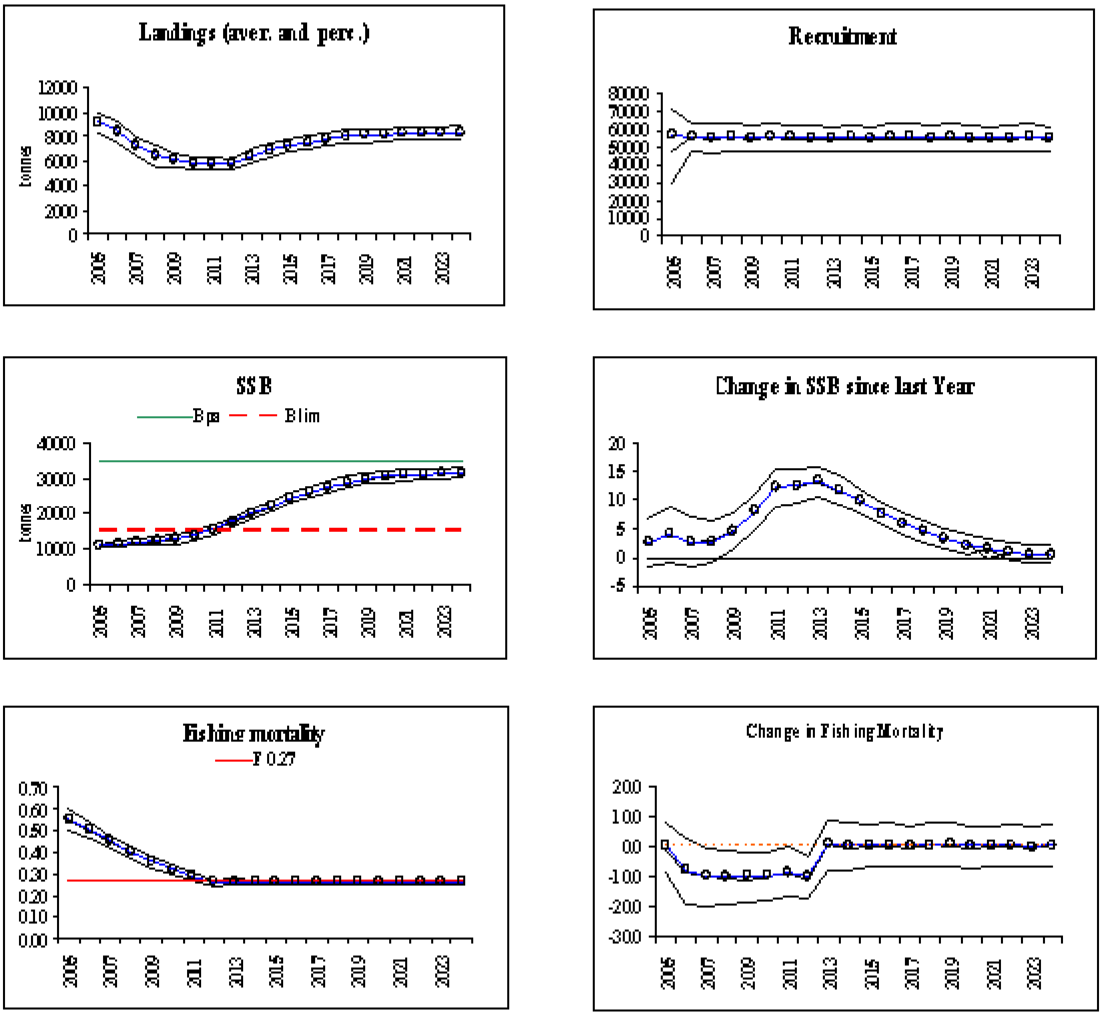


Figure 5.1.3 **Hake Southern - Projections using CS5– 10% reduction in fishing mortality until F = 0.27 (Recovery Plan).**

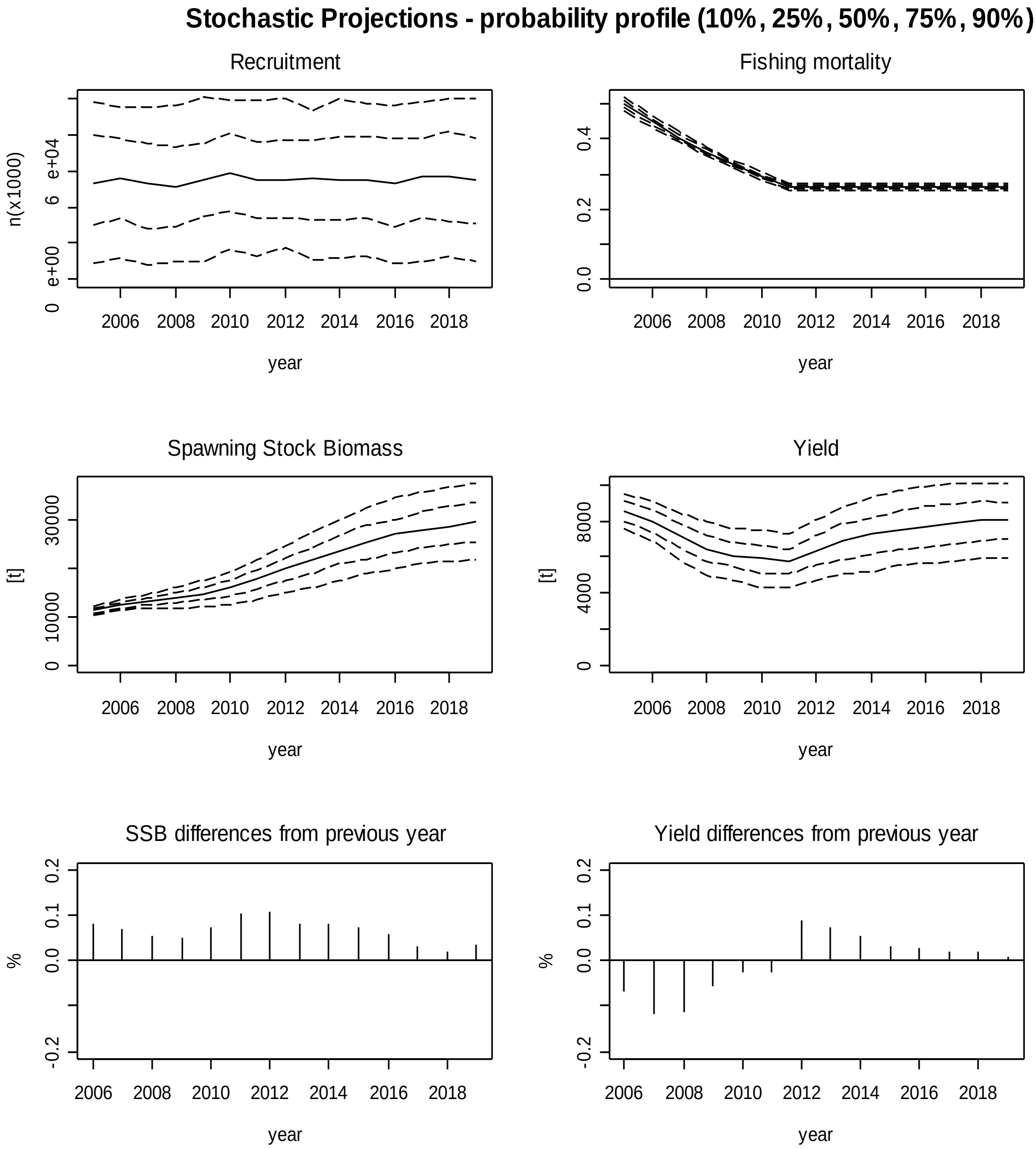


Figure 5.1.4. **Hake Southern Stock – Projections using CP2 – 10% reduction in fishing mortality until F = 0.27 (Recovery Plan) – option (i).**

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 and fishing mortality based harvest control rules 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 information

There are several sources of uncertainty for this stock and 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.

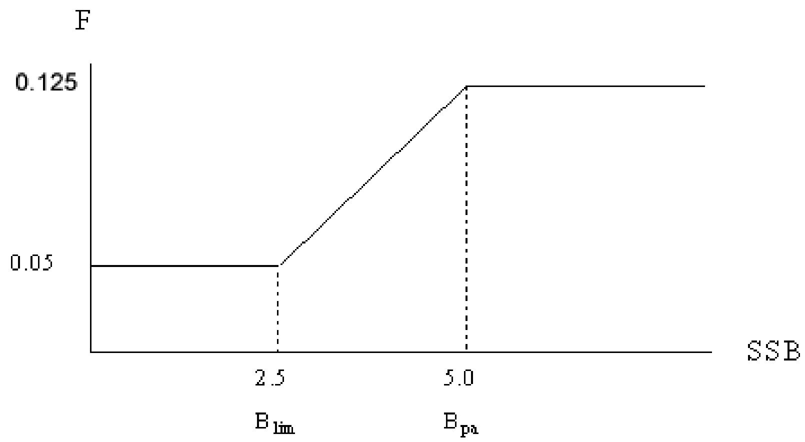
5.2.8 Items that should provided in the conclusions of the HCR study

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, Faeroe 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 information

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 have not been any serious considerations or any major revisions of the HCR from the industry or management agency.

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 precautionary 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 Variable (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 information

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

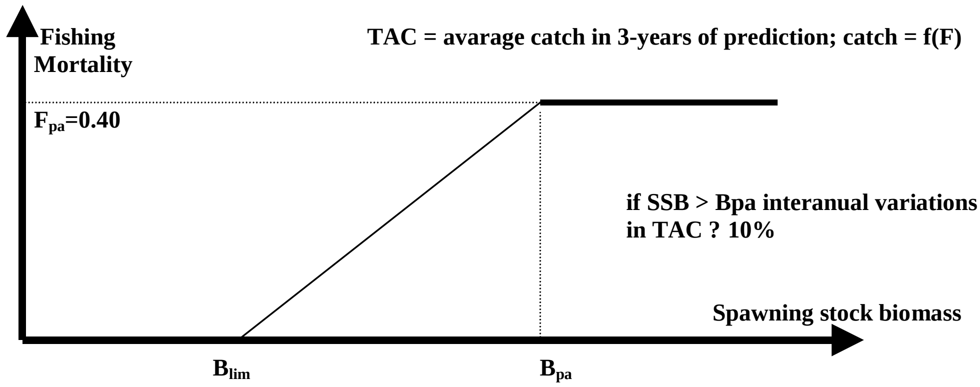
On this basis, the HCR for setting the annual fishing quota for Northeast Arctic cod was developed:

- 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 develop 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 the 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 lognormal 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 a utility function where uneven income got negative penalty was investigated instead of having a 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.

5.8 Evaluation of HCR for West of Scotland herring

The following is taken from an evaluation of the operational elements of an HCR for West of Scotland (VIa north) herring. The evaluation was carried out by HAWG in March 2005 (ICES 2005 ACFM:10) and followed the guidelines contained in Section 4.4 of this report. The review concentrates on management options for medium term exploitation of herring in this area and considers in detail the implications of the productivity of the stock, or more explicitly the possible range of stock relationships that may explain the observed recruitment and their influence on the choice of the operational aspects management for this stock.

A.a Broad objectives

There are no explicit management objectives for this stock but the implied objectives are to obtain maximum stable yield within the precautionary approach.

A.b Operational Objectives

The operational objectives are to keep the stock above B_{lim}, which is currently estimated to be 50,000 t (see Section 5.8). Yield requirements include consideration of year-to-year stability and maximising long term yield.

B. Conformity of a HCR to the management strategy

The stock is currently managed with a TAC. It is thought that this type of management, backed up with enforcement is applicable for this fishery.

An HCR with an F target and year on year restrictions on changing TAC would therefore be an appropriate choice of HCR.

The current assessment provides a reasonable basis for evaluation of an HCR.

The stock was depleted in the 70s and has never recovered to the SSB seen in the 1960s. The stock recruit relationship observed in recent years may be different from the one describing the full time-series. For management there is a need to consider if there is a requirement to allow the possibility that the stock will recover to biomass levels seen in the 60s. If this option is selected as a management objective, this will then require selection of a long term F that will allow this to happen. In this context an explicit biomass target for the stock may not be appropriate because the biomass levels seen in the early 60s may be unachievable. In addition to this criterion, management should be based on currently observed levels of recruitment and annual growth.

TAC implementation and management control in for this stock is variable, the main problem is area misreporting of catch in such a way that catches have often been less that the TAC and rarely more. Discarding in the herring fishery is low through some discarding of herring may occur in the mackerel fishery in the same area and there may be some high grading in the freezer trawler fleets.

C. HCR simulation parameterisation

C.a Biological operating model

The simulation was carried out using STPR3 and S3S (Skagen 2004) as a simulation program. The chosen model consists of three stages.

1. Depleted stage with fixed F (F1) less than or equal to intermediate F for biomass below Blim of 50,000 t.
2. Intermediate stage with a fixed intermediate F (F2) when the biomass is above Blim but below Btrig (B2)
3. Long term stage long term F (F3) above a biomass trigger (B2)

This may collapsed to two stages if F1 and F2 are equal (combining stages 2 and 3). The rule may be modified with an option of a year on year constraint on the change in TAC.

C.a.a Selection of Stock / Recruitment relationship.

Data on the state of stock is available from 1957 to 2004, the recruitment in the last 4 years is still uncertain so has been omitted from the study. The stock experienced heavy fishing in the 1960's and the fishery was closed in 1979 / 1980. The SSB during the period 1957 to 1975 is greater in every year than the SSB during the subsequent period 1976 to 2000. This could be due to a number of possibilities

- reduced productivity in the area,
- the average fishing mortality at mean F = 0.35 is too high to allow recovery.
- The stock depletion removed some important component of the stock.
- Area closure of 50% of the spawning grounds may have caused excess pressure on the remaining 50%

The stock (SSB) and recruitment data are plotted together with fitted models for the period 1976 onwards and for the complete period in Figures 5.8.1 and 5.8.2 respectively. The parameters of the fitted stock recruit relationships are given in Table 5.8.1.

Within each data period, the different models (Figures 5.8.1 and 5.8.2) do not give major differences in perception of the stock. Though there are considerable differences between the stock recruit relationships depending on whether the whole period is considered to be representative of the current situation (statistically / biological stationarity) or if the recent period is regarded as different. The model that fits best in both periods is the Shepherd, as the AIC value is lowest in both cases, implying the increase of parameters is helpful in functionally describing the observed recruitment data. In addition to the low Akaike Information Criteria (AIC) the pattern of residuals around the Shepherd model is perhaps slightly better behaved than for the other models (see Figure 5.8.3 and 5.8.4) but the difference is small. There is however, a biological problem with concluding that the Shepherd reflects the truncated series correctly as this implies reduced recruitment at higher biomass. We know from the longer time-series that increased recruitment at higher biomass has been observed. In order to model the short time period both Shepherd and Change Point models have been used in management exploration. The latter model is preferred as it gives recruitment that does not decrease at higher biomass, and may thus be regarded as compromise option between the Shepherd model for long and truncated data series.

For the simulated recruitment Figures 5.8.5 to 5.8.7 show the comparison of the simulated probability density functions (pdfs) expressed as a cumulative probability distributions and observed recruitment. In all three cases the simulated pdfs area a reasonable representation of the observed recruitment.

C.a.b Natural mortality;

Natural mortality used in the assessment is taken from the assessment of North Sea herring, the adjacent area. This is based on MSVPA run for the North Sea. (Table 5.6.5)

C.a.c Growth;

Growth is obtained as observed weights at age from annual acoustic surveys of the area and is available as individual estimates of growth for each year since 1991and is used as a stochastic variable in the simulation, taking each year as a single set of observations. (Table 5.6.4)

C.a.d Maturity;

Maturity is obtained from annual acoustic surveys of the area and is available as individual estimates of fraction adult for each year since 1991and is used as a stochastic variable in the simulation, taking each year as a single set of observations. (Table 5.6.6).

Maturity and weights at age are selected as an annual set from the same year in the stochastic simulations. So while cohort dependent growth is not fully simulated correlations between weights at age and maturity are included in the simulation.

C.a.e Other issues;

There are no other major issues included in the simulation. There are no major multi-species interactions. There have been some limited spatial restrictions with a spawning area closure, however, it has not been possible to show any benefit to the stock and the extent to which this restriction has actually been operational is unknown. There are no density or growth dependent effects observed with this stock. With the exception of weights and maturities all the variables are treated as independent without correlation or auto-correlation.

C.b The fishery

The fishery is a mostly a directed pelagic trawling fishery which is currently dominated by two fleets of trawlers. There is occasional discard or slippage of herring and limited high grading. Some herring are caught as a by-catch within a seasonal mackerel fishery and either landed or discarded depending on availability of quota. Some of the VIa north herring quota is taken in adjacent areas and misreported as VIa north herring. This aspect has been limited by the use of single area licence restrictions. This was relaxed last year but continuation of this measure is thought to be helpful and is under consideration. The selection pattern for the fishery has been stable for the last 3 years and is taken from the ICA assessment (Table 5.6.15).

C.c Representation of the knowledge and decision process in the simulation

The general error levels in measurement and implementation bias and variability are included. However, not all the elements for management are fully included, for example there is no feedback between implementation and implementation error.

C.c.a Observation error on biological parameters

Observation error on growth and maturity is included and characterized as part of the stochastic variability seen in the observed data.

C.c.b Assessment error

Assessment as a source of observation error is implemented as SD of 30% and a bias of 10%, these values are very slightly larger than the observed values taken from the ICES quality control sheets for the period 1995 to 2003.

C.c.c Advice and decision making.

No systematic implementation error is included in the simulation, although there is some evidence for over-reporting of catch due to area-misreporting. However, including systematic under utilisation of quota that cannot be guaranteed into the future is not thought to be applicable. In 2003 implementation of regulations seemed to be reasonably effective, and last years deterioration may have been due to relaxation of regulations. To model some level of implementation error a 10% stochastic variable is used for implementation to reflect the uncertainty in implementation. This may slightly exceed observed variability but may be used to account for some area misreporting.

D Management measures

Management measures currently consist of, a TAC regime and a spawning seasonal closure covering approximately 50% of the spawning area. As this is a largely directed pelagic fishery with only a small amount of discarding and by-catch a TAC is an appropriate method of setting limits for catch. Only the TAC is simulated.

E The robustness of the management evaluation

The current assessment method is ICA tuned with a single acoustic survey. The assessment is rather noisy, and precision and bias in the assessment has been taken into account in two ways.

i) The current state of the stock is used as a starting point using variance covariance matrix obtained from ICA. As indicated above the historic time-series of assessments suggests that a precision of 30% is appropriate.

ii) The method has been checked for sensitivity to the precision of the estimation by using other error levels (20% and 40%) and although, the level of risk is sensitive to this no major differences in outcome occur.

Sensitivity of the HCR to assessment bias has been examined by using different values, the current bias of 10% slightly over estimates the values observed from about 8 years ago. The assessment bias was more severe in the earlier years (1994-1997) but has been less severe after this (1998-2000). It is possible that the stability of the bias is dependent on stock and regulations applied but there is insufficient data to establish this.

Sensitivity to management failure is considered through examination of recent implementation. Current management is through a role-over TAC and there has been little change in recent years. Implementation failure has been associated with under shooting the TAC through area misreporting rather than over exploitation. Any undeclared landings that are occurring are not included in the data and the simulations assume these will be stable. There are area restrictions due to a spawning season closure but they may not be fully effective and the stock has shown no signs of benefiting from the closure. Stock productivity was higher before the closure was implemented.

F Results

The sensitivity of the HCR to the S/R relationship is the critical aspect of management for this area. Figure 5.8.8, 5.8.9 and 5.8.10 summarise the range of possible yield and risk for different values of long term F from 0.2 to 0.6. Included in this set of evaluations is a full range of values of intermediate and depleted F (F1 and F2), trigger biomass (B2) and year on year constraint on TAC. The colour of the symbol indicates the risk of SSB falling below Blim. Risk is dealt with in 5 classes, 0-1%, 1-2.5%, 2.5-5%, 5 to 10% and >10% risk if SSB falling below Blim at least once in the 10 years of the simulation. For clarity the strategies with risk less than 5% are shown separately in the lower panel of each figure. It is not intended that these plots are examined in detail; it is the broad areas of colour that indicate the main possibilities.

The maximum achievable median yield for each long term F (F3) with a risk less than 5% are given separately for each stock recruit relationship in Figure 5.8.11 to show how the different stock recruitment relationships affect the results. The difference between the two models for the truncated period (1976 to 2000) is small; it is difficult to say which of these models is correct, though there is a small statistical preference for selecting the Shepherd model over the change-point model. However, the Shepherd model implies reduced recruitment at an SSB 150,000 t. This is in contrast to the longer time-series which gives a model delivering elevated recruitment at these SSBs. The Change Point model which gives no reduction in recruitment at higher biomass is therefore preferred though not on statistical grounds.

The implications for management of the long series is illustrated in two ways.

i) Figure 5.8.12 illustrates that all three S/R models explain the current state of the stock quite well. Using historic exploitation: at F = 0.355 with a standard deviation of 0.248. This conforms to the observed conditions for the last 30 years. As can be seen from this figure exploitation in this way delivers a stock at a level close the current SSB. This supports the view that the current state of the stock does not preclude the longer series model being appropriate.

ii) The development of median yield and SSB and median recruitment and SSB are shown in figure 5.8.13a and b respectively for different values of long term F from 0.2 to 0.4. From this it can be seen that the most probable direction for the development of the stock depends on whether F long term is above or below 0.35

The value of long term F 0.35, which is to be used as guidance, should not be regarded as a precise value that can be used as an exact management target but rather as a general indication of where this change in exploitation occurs.

Example Selection of HCR.

1) Potential increase in biomass and yield from a large stock is to be allowed. F long term selected as 3.0 or below. Table 4.7.2 indicates that F=0.3 gives rather low potential increase, a reduction of F to 0.25 gives approximately 1,000 t reduction in catch but a much higher potential increase in SSB. A further reduction to F=0.2 with 2,000 t reduction seems to great. So long term F is chosen to be F=0.25. Some reduction is required in the even for stock decline so F2 is selected as F=0.2

2) Figure 5.8.2 panel b illustrates the trade off between yield, year-on-year given the choice from (1) above F3 = 0.25 an F2=0.2. The risk of SSB falling below Blim in the options illustrated in this panel is always under 1% so all options may be judged precautionary. Maximum yield is seen to occur at two locations on the panel, at

   a. B2 = 75,000 t and catch constraint (CC) of 1,000 t.

   b. B2 = 120,000 t and CC= 2,000t.

At first sight this may seem unusual that there are two maxima, but point (b) occurs with the HCR often giving SSB in stage 2 of the rule and thus F=0.2 where as point (a) is mostly in stage 3. If minimum year-on-year change in TAC is an objective then point (a) gives the maximum yield. Point (a) seems to be the best solution. The chosen HCR becomes:-

F=0.25	if SSB > 0.75,000 t year.	TAC changes by less than 1000 t each
F=0.2	if SSB < 0.75,000t	No constraint on TAC.

G Conclusions

There is one major management option to be considered first. Should management choose a strategy that has some reasonable probability for the stock to expand to the levels observed in the 70s? Exploitation at an F of over 0.35 is thought to have a higher probability of keeping the stock at its current lower level or causing it to decline. Exploitation at F 0.3 or lower is thought have an increased probability of allowing expansion of the stock. So exploitation below this level at say F = 0.25 is recommended if it is considered important to allow the stock to increase. If for biological reasons expansion of the stock is currently not possible then this choice of F<0.3 delivers a yield that is a little reduced from the maximum. Reduction of F below 0.25 would probably produce even lower yields.

Having already selected the long term F (F3) Figure 5.8.14 illustrated the choice among other parameters in the HCR. These panels show yield, risk, and the range in change in TAC for different values of B trigger (B2) and year on year constraint on change in TAC. This figure needs to be considered only after the decision to exploit above or below F=0.35 has already been taken. The main features of these options are summarized in Table 5.8.2 The Following text box contains an evaluation of the choice of HCR parameter for panel a in Figure 5.8.2.

The WG considers that these simulations provide a good basis for managers to decide on the basic form of a HCR for VIa (N) herring. However, experience with the North Sea suggest that rules that use constraints on year-on-year change in TAC need more detailed evaluation than is provided here. In particular the influence of correlation in recruitment should be investigated further. Managers can use this study to decide on the main elements of the HCR they require such as the most suitable long term F. If there is a wish to have a year-on-year constraint on change in the TAC then the chosen scenario can be evaluated in more detail to ensure it is robust.

H Additional information

The study carried out here has examined assessment precision from 20% to 40% and bias of 0, 10% and 20%, though the results shown here are only for 30% precision and 10% bias. In these simulations implementation error was constrained to be within a 10% SD. Currently the TAC is often not fully taken but should management fail to keep catches in line with the TAC, this suggested HCR may need to be re-examined.

Natural Mortality has been assumed to be known and stable.

Recruitment simulations do not include significant autocorrelation, excluding that resulting from the relationship it’s self.

The choices here depend very much on a rather uncertain S/R relationship. Research on the validity of this relationship would be helpful. If the stock continues to provide reduced recruitment at SSBs above 120,000 t the S/R relationship and HCR should be re-evaluated.

Its is suggested that the situation should be reviewed approximately every 5 years.

Table 5.8.1 Herring in VIa (N) parameters of stock recruit relationships fitted to the stock SSB and recruitment data from the 2003 assessment, for full period 1957 to 2000 and a truncated period 1976 to 2000.

	Data from 1957 to 2000				Data 1976 to 2000			
	Change-point	Ricker	Beverton-Holt	Shepherd	Change-point	Ricker	Beverton-Holt*	Shepherd
alpha	7.7625	9.99245	4.57E+03	3.77E+01	1.78E+01	4.09E+01	7.78E+02	2.29E+01
beta	491.5	1.22E-03	3.70E+02	1.04E+01	53.96	1.36E-02	-1.85E+01	9.51E+01
Gamma				4.62E-01				2.63
AIC	82.04	79.37	78.46	74.40	32.13	30.07	31.39	28.22

* This model was biologically implausible for the data and was therefore not used in the evaluation.

Table 5.8.2. Herring in VIa (N) summary of general outcomes for different options of long term exploitation F from 0.2 to 0.4. Showing a small range of harvest options, effect on SSB if the long period S/R relationship holds, and yield options under the short term period S/R relationship. For more details of the latter see figure 5.8.14.

F3 (Long term)	F2 (intermediate)	Stock Recruit period 1957-2000	Stock Recruit period 1976-2000: Range of Median Yield	B2 (B trigger)	Year on Year Constraint	Risk (falling below Blim)
0.2	0.2	Median SSB increases by approx. 95 % over 10 year period	37,300t unless stock increases	Not relevant	Highest yield at 2000 t constraint	0
0.25	0.2	Median SSB increases by approx. 44 % over 10 year period	38,400 to 39,400t unless stock increases	Max yield at 75,000t	Lowest yield at 4000 t Highest at 1000 t constraint	Less than 1%
0.3	0.25	Median SSB almost stable	39,300 to 40,800t	Max yield at 120,000 t	Lowest yield at 4000 t+, Highest at 1000 t constraint	Less than 1%
0.35	0.25	Median SSB decreases by approx. 18 % over 10 year period	40,100 to 41,600t	Max yield at 105,000 t	Lowest yield at 6000 t+, Highest at 2000 t constraint	0.7% to 1.6%
0.4	0.25	Median SSB decreases by approx. 35 % over 10 year period	33,400 to 43,000t	Max yield at 95,000t	Lowest yield at 6000 t, Highest at 2000 t constraint	1.3% to 4.0%

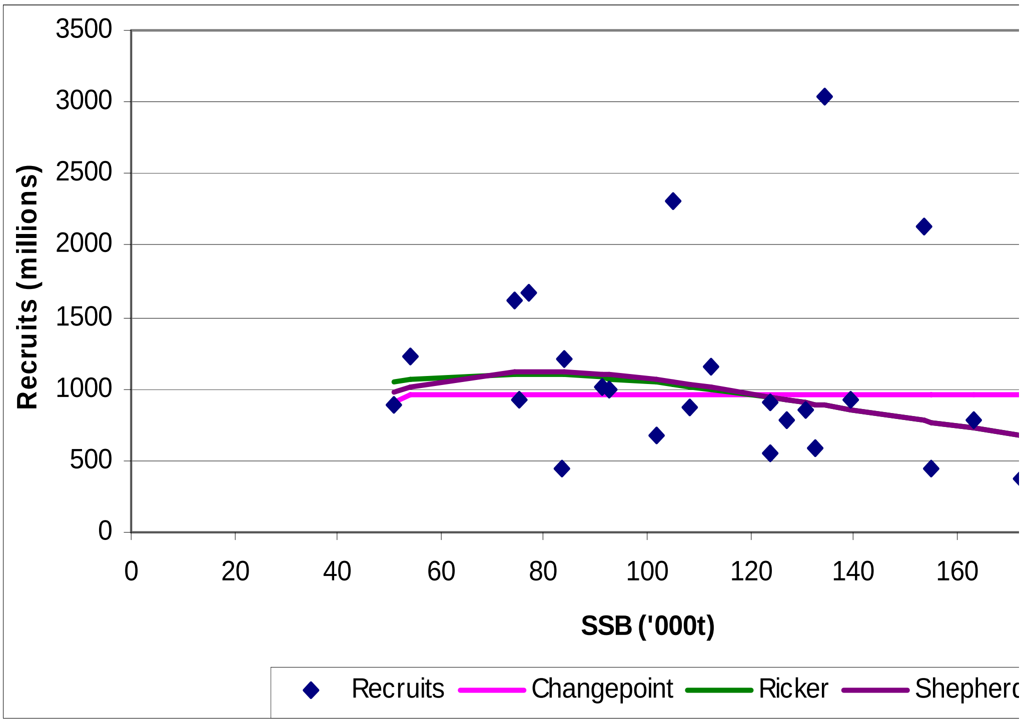


Figure 5.8.1 Herring in VIa (N), stock recruit data and fitted models (Change point, Ricker and Shepherd) using observed stack and recruitment from the ICA assessment for the years the 1976 to 2000. Note that the period 1976 to 2000 has no SSB values above 170,000 t and no overlapping SSB values with those in the earlier period 1957 to 1974 included in Figure 5.8.2.

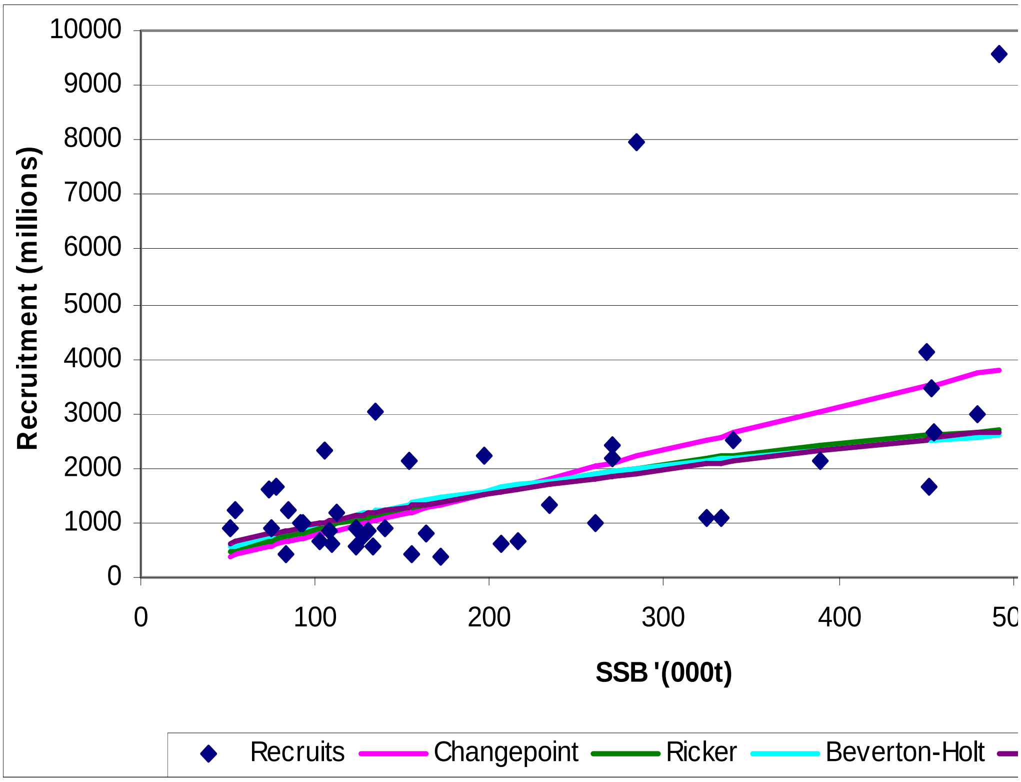


Figure 5.8.2 Herring in VIa (N), stock recruit data and fitted models (Change point, Ricker Beverton and Holt and Shepherd) using observed stack and recruitment from the ICA assessment for the years the 1957 to 2000. Note that the period 1957 to 1974 has only SSB values above 170,000 t and no overlapping SSB values with those in Figure 5.8.1.

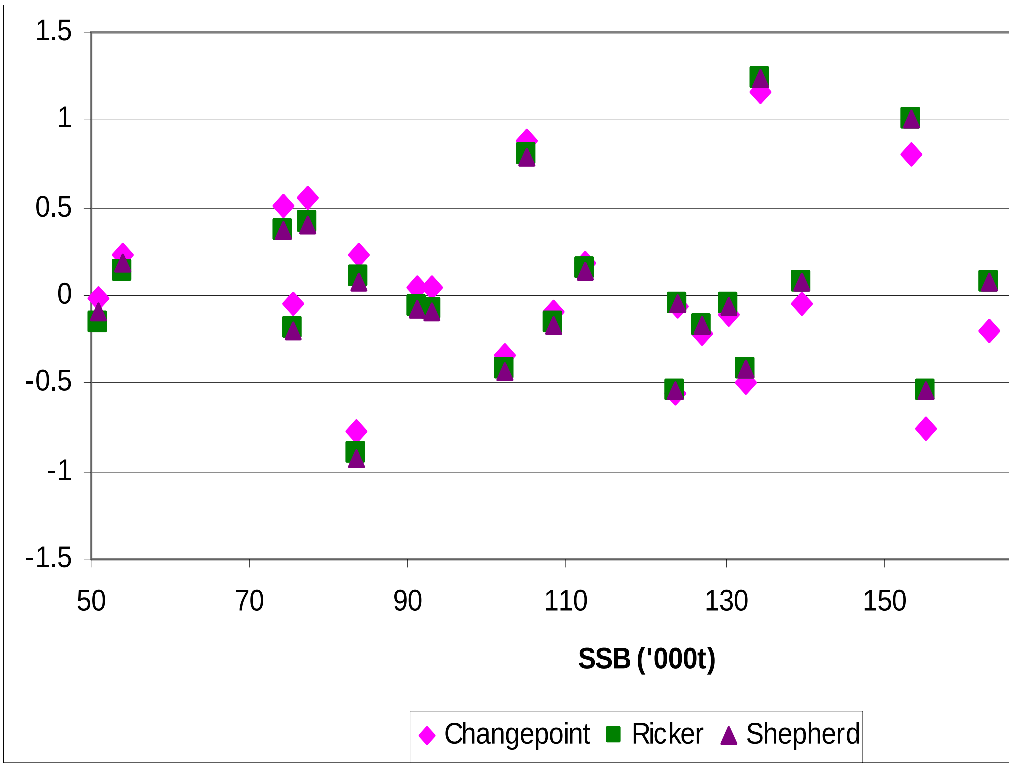


Figure 5.8.3 Herring in VIa (N), residuals around the fitted stock recruit (S/R) models for stock recruit data from 1976 to 2000 using values from ICA assessment.

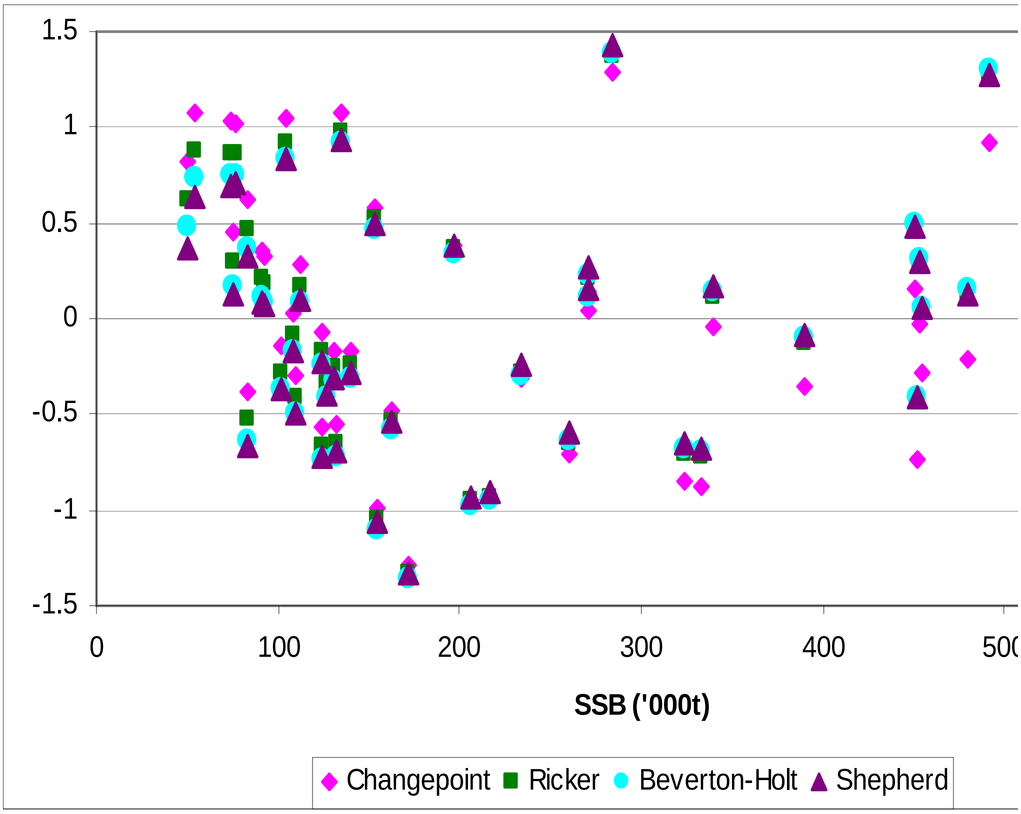


Figure 5.8.4 Herring in VIa (N), residuals around the models for stock recruit (S/R) data from 1957 to 2000 using values from ICA assessment.

Recruitment Curves

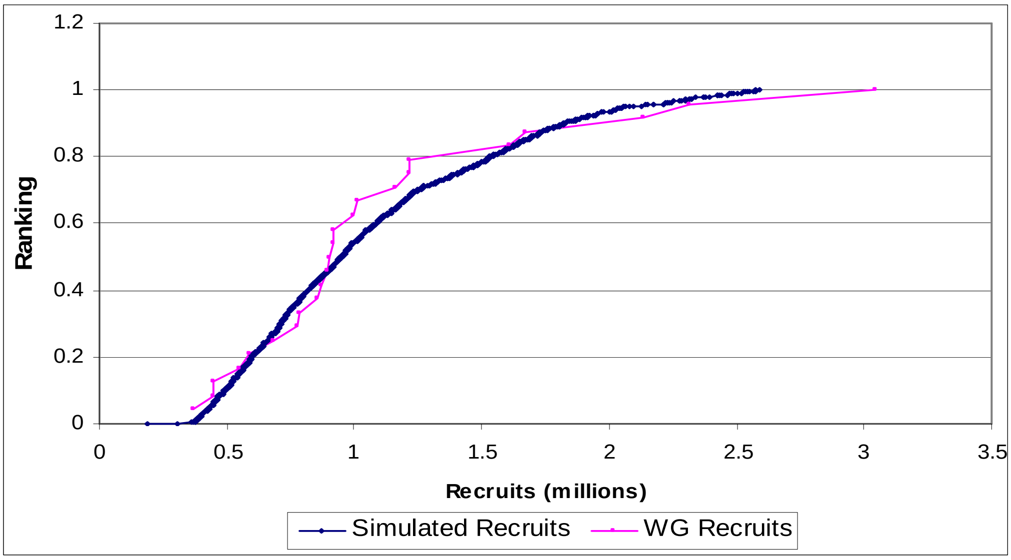


Figure 5.8.5 Herring in VIa (N), comparison between stock recruit data 1957 to 2000 and simulated values for the Change Point S/R relationship fitted to the observations for the long time-series 1957 to 2000.

Figure 5.8.6 Herring in VIa (N), comparison between stock recruit data 1976 to 2000 and simulated values for the Shepherd S/R relationship fitted to the observations for the long time-series 1976 to 2000.

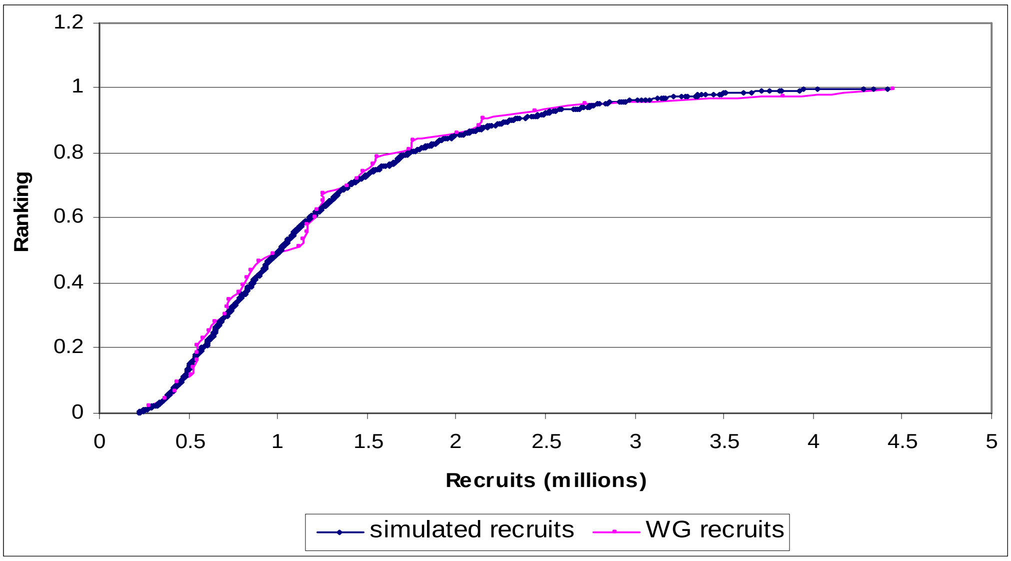


Figure 5.8.7 **Herring in VIa (N), comparison between stock recruit data 1957 to 2000 and simulated values for the Shepherd S/R relationship fitted to the observations for the long time-series 1957 to 2000.**

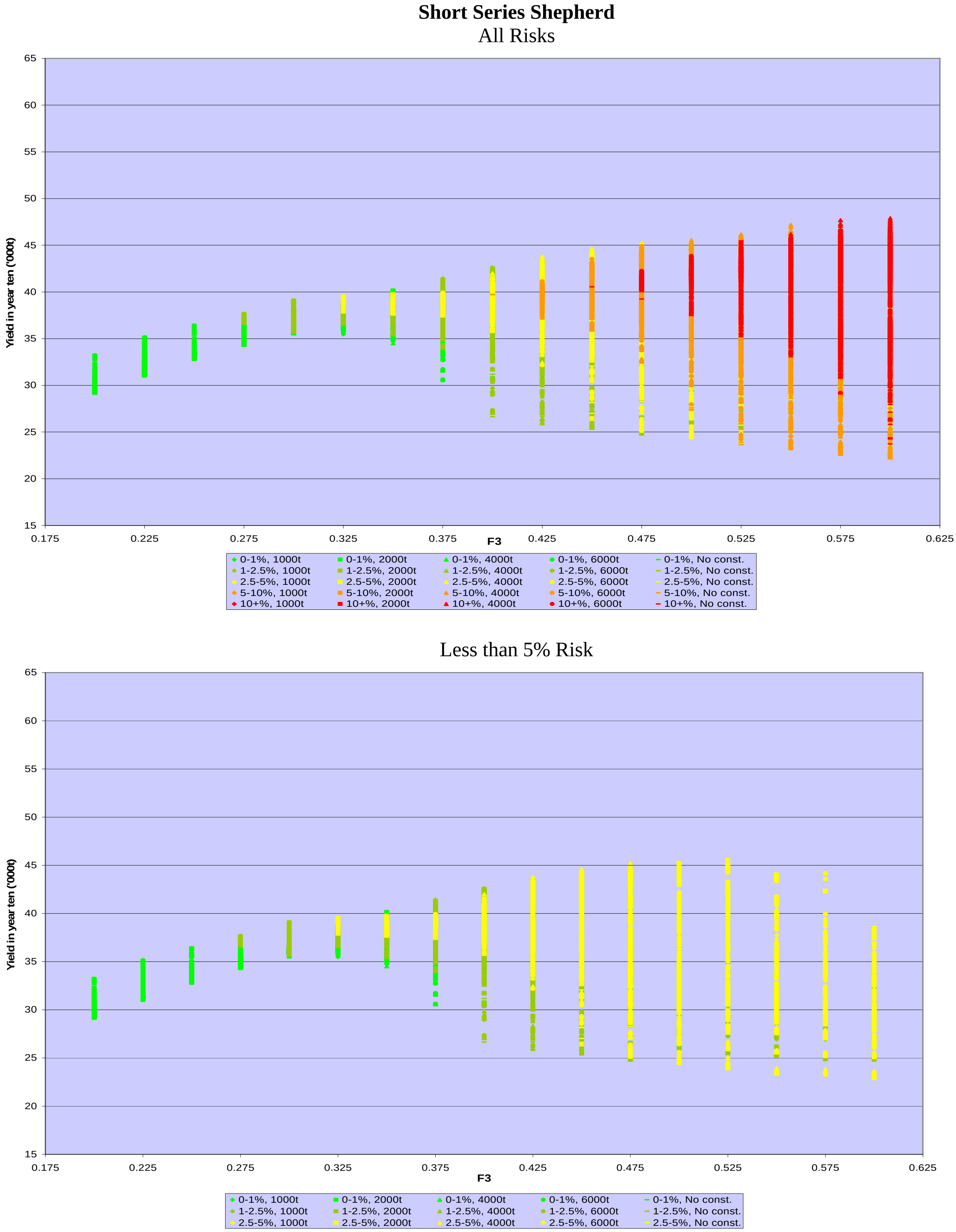


Figure 5.8.8 Herring in VIa (N), median yield in year 10 for short time-series Shepherd S/R relationship; yield verses long term F for the full range of HCRS studied, the colour indicates risk of SSB falling below Blim. Upper panel includes all risks, lower panel shows only risks less than 5%.

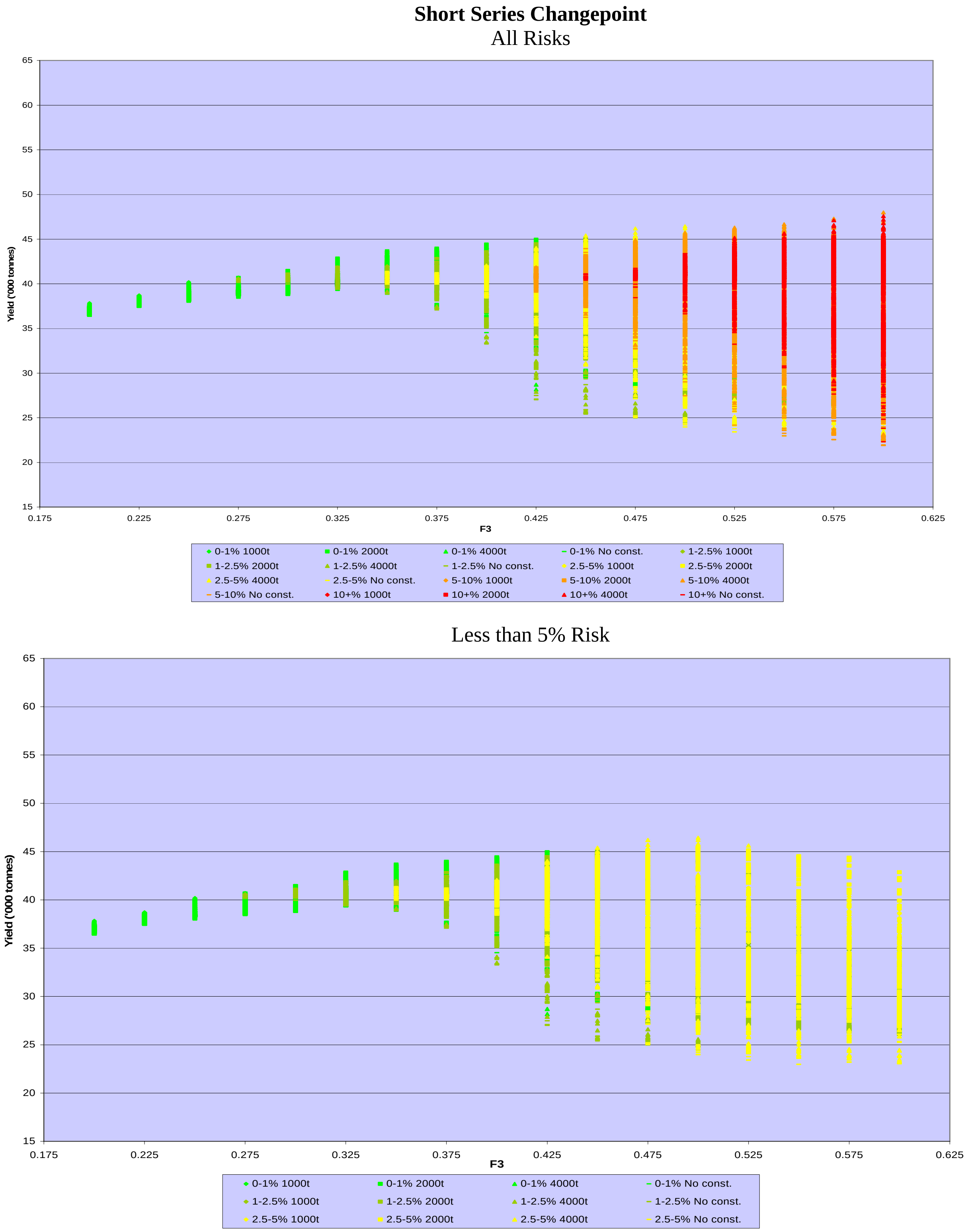
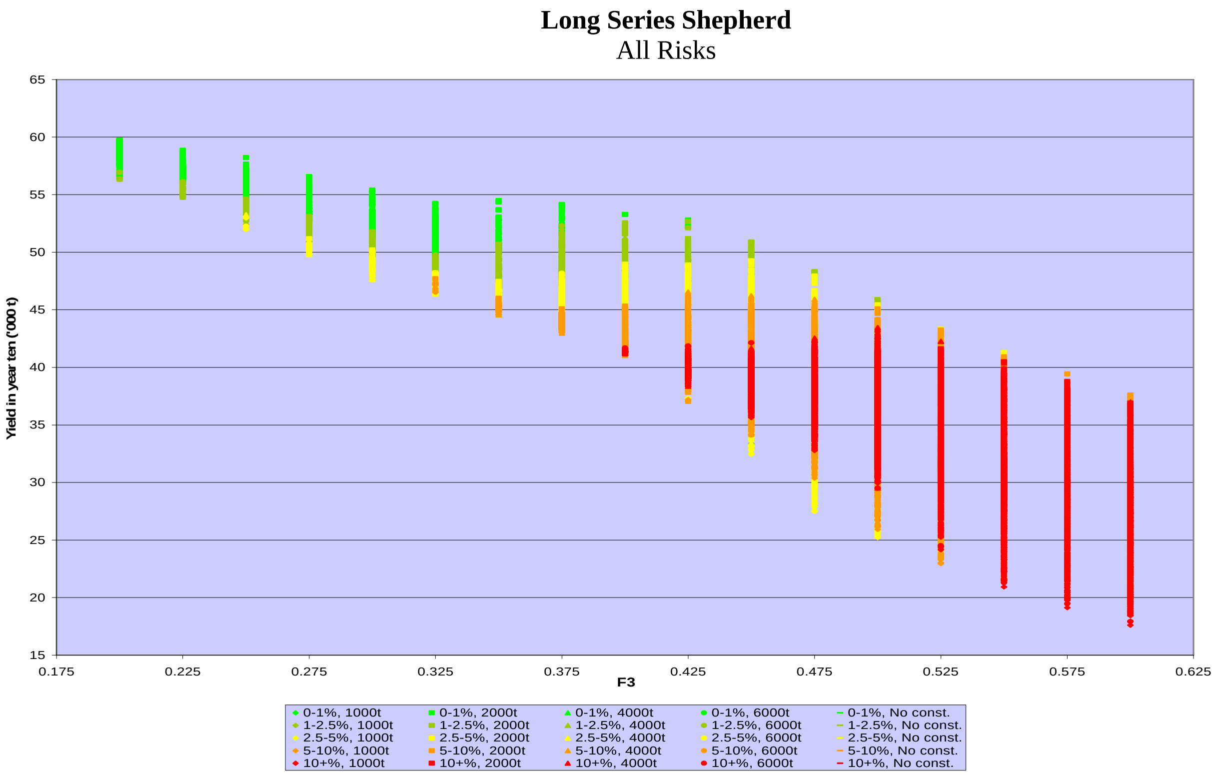


Figure 5.8.9 **Herring in VIa (N), median yield in year 10 for Short time-series Change Point S/R relationship; yield verses long term F for the full range of HCRS studied, the colour indicates risk of SSB falling below Blim. Upper panel includes all risks, lower panel shows only risks less than 5%.**



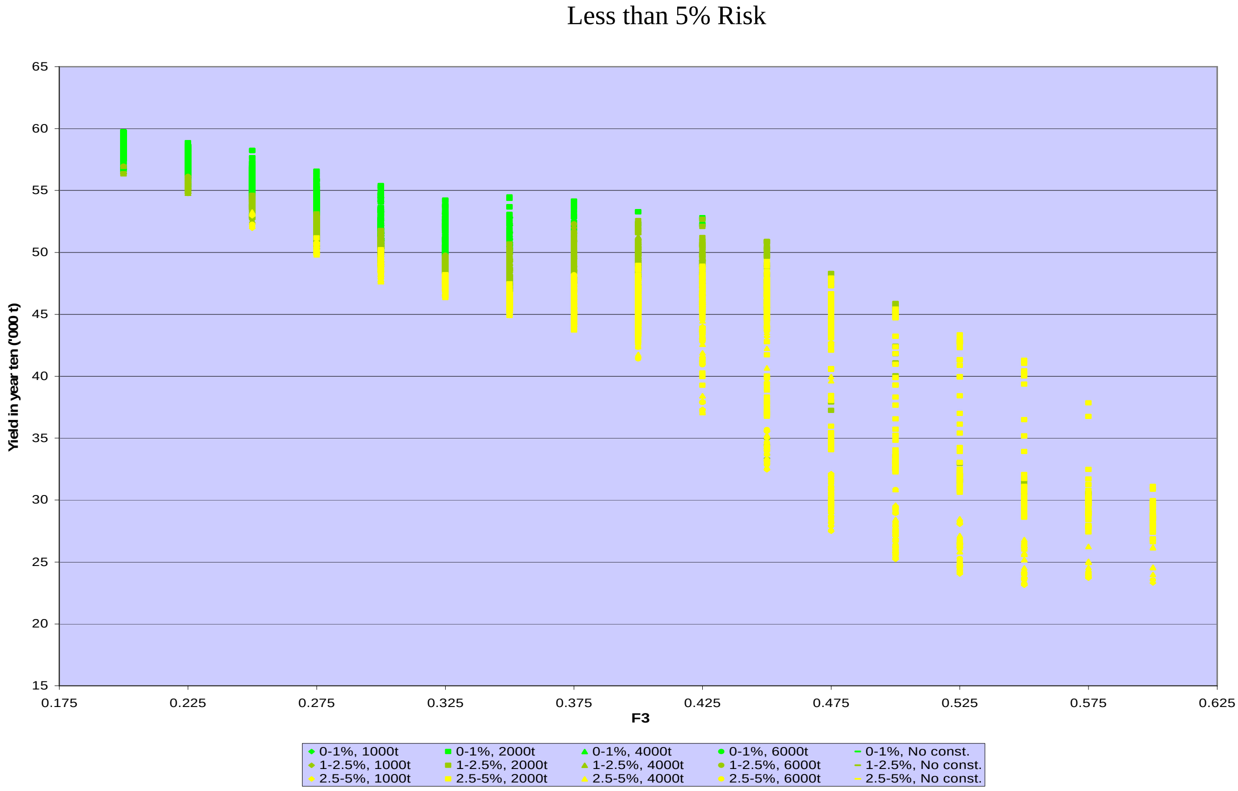


Figure 5.8.10 Herring in VIa (N), median yield in year 10 for long time-series Shepherd S/R relationship; yield verses long term F for the full range of HCRS studied, the colour indicates risk of SSB falling below Blim. Upper panel includes all risks, lower panel shows only risks less than 5%. Note the rise in yield with lower F.

Figure 5.8.11 Herring in VIa (N), the maximum median yield in year 10 obtained for all HCRs with risk of SSB < Blim of less than 5% (Fig 8 to 10 lower panels) plotted against long term F for the three S/R relationships studied.. Showing similarity for the two models for the truncated time-series and the higher yields at lower F for the longer time-series.

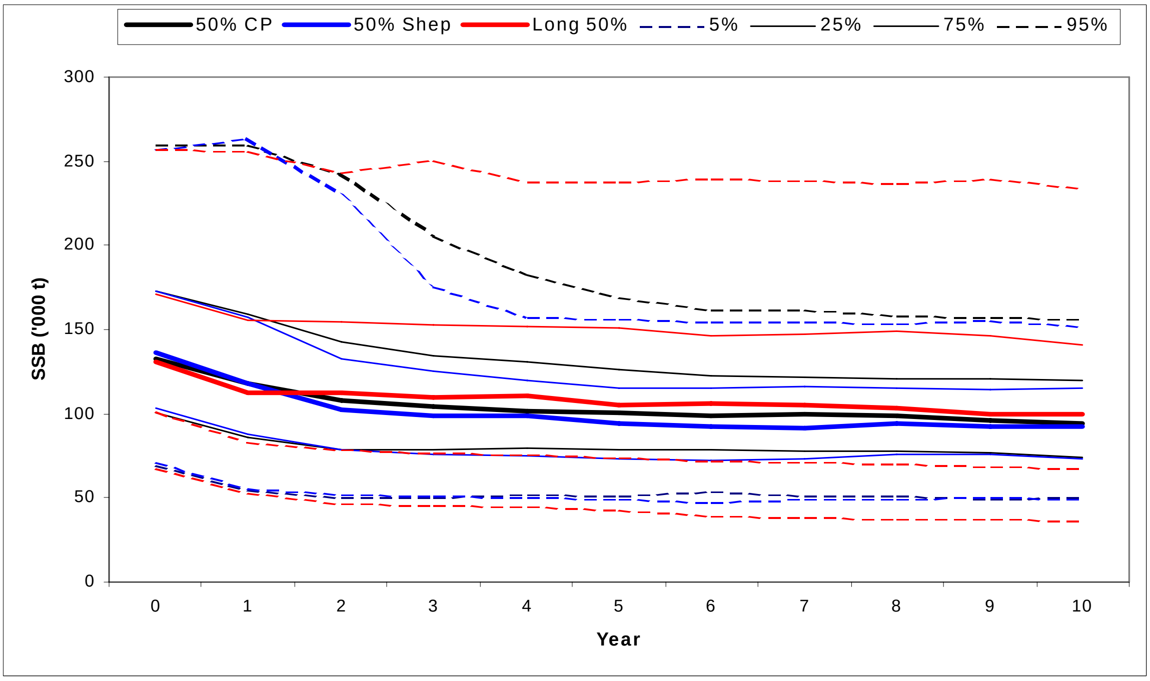


Figure 5.8.12 Herring in VIa (N), comparison of stock trajectory (5,25,50,75,95 percentiles) from current state of the stock assuming exploitation equivalent to the mean (0.36) and standard deviation (0.25) of the exploitation experienced since 1976. For the three main Stock Recruit relationships studied, truncated data series Change Point (CP) and Shepherd (Shep), and long data series Shepherd (Long). Showing that the expected state of stock depends little on the choice of stock recruit relationship if exploitation is at this level.

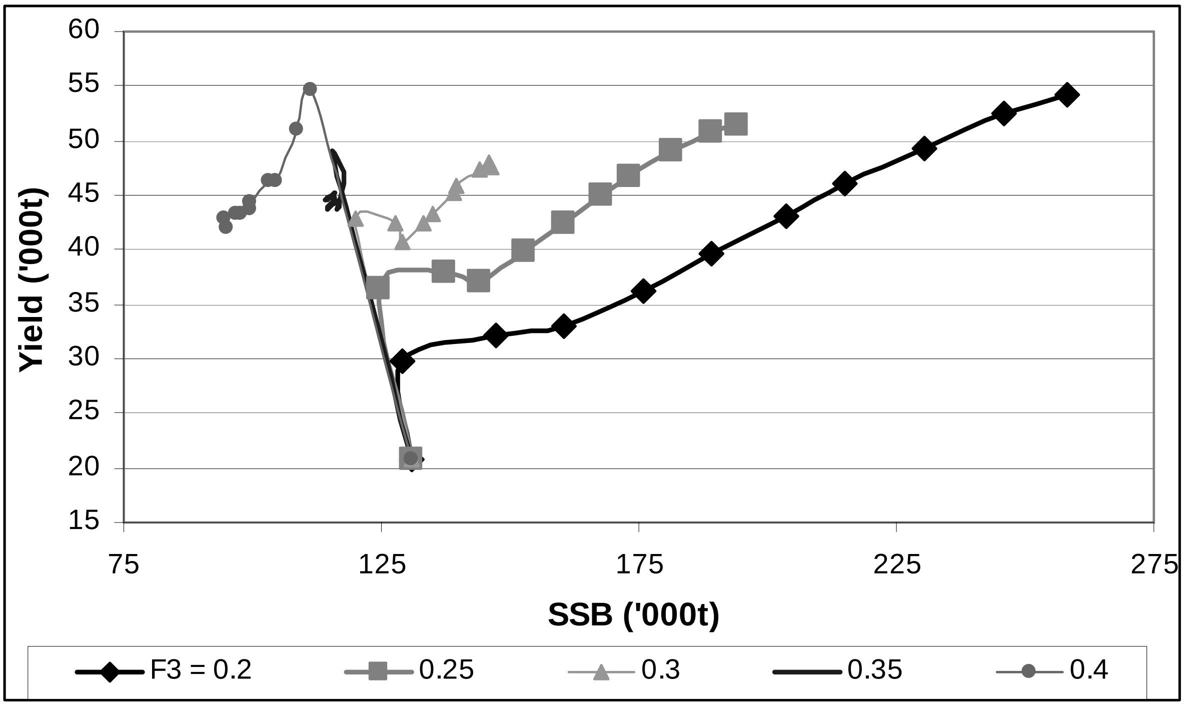


Figure 5.8.13a Herring in VIa (N), illustration of stock exploitation expressed as median yield v. median SSB for different long term Fs assuming the long time-series S/R model. Exploitation at F =0.35 gives approximate stability.

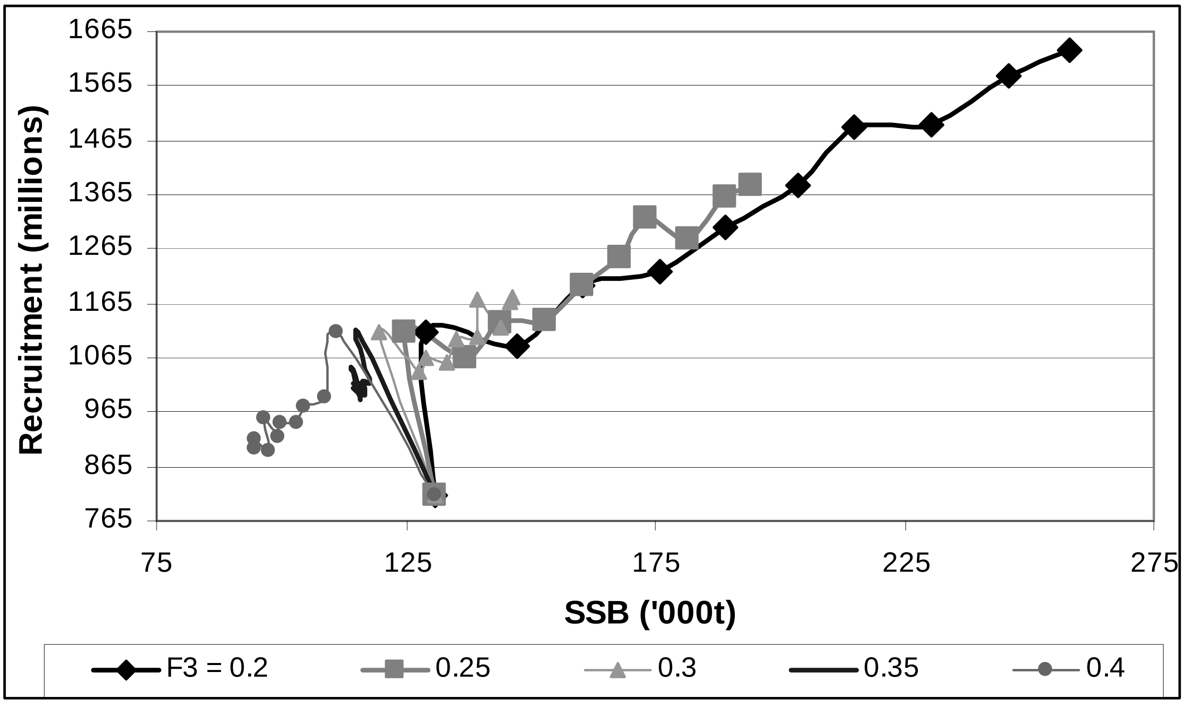


Figure 5.8.13b Herring in VIa (N), illustration of stock development expressed as median recruitment v. median S SB for different long term Fs assuming the long time-series S/R model. Exploitation at F =0.35 gives approximate stability.

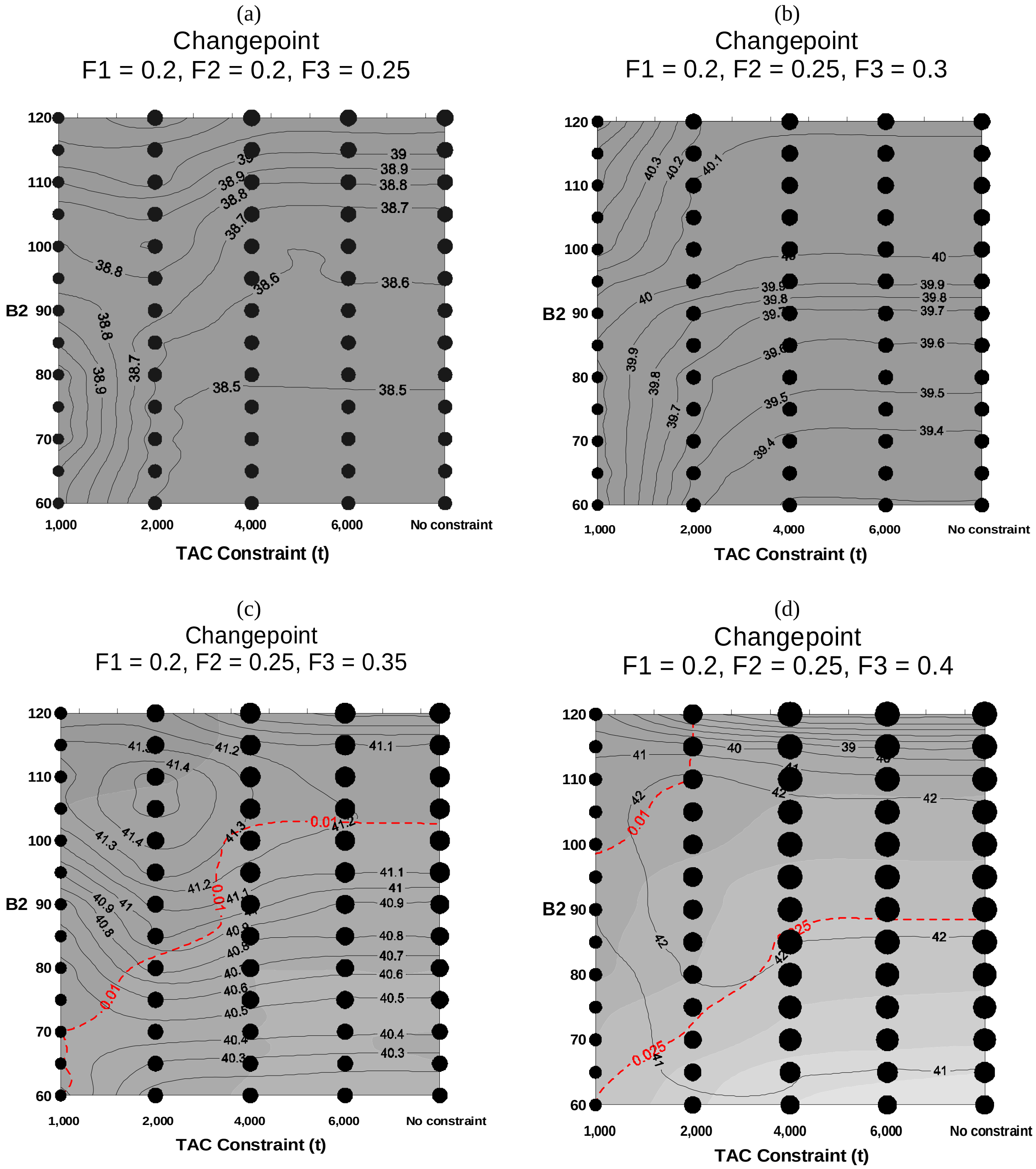


Figure 5.8.14 herring in VIa (N), comparison of yield (black contours), risk of SSB falling below Blim (colour dark grey low (0%), pale grey higher (5%)), and 5% to 95% spread of year to year change in TAC (black circles) for: F3 = 0.25 (panel a), F3= 0.30 (panel b), F3= 0.35 (panel c) and F3= 0.4 (panel d). Each panel is for values of biomass trigger (B2 in '000 t) on the vertical axis and for constraints in year to year change in TAC on the horizontal axis. The dotted contour lines represent risk values of 1% and 2.5%, panels a and b both fall below the 1% risk level, hence no dotted contour line present. There is an increase in risk from the top left corner of the panels to bottom right. This is clearly observed in panel d, where there is a low risk (<1%) in the upper left corner, increasing to 4% in the lower right.

The range of year on year change in TAC (black circles) goes from 1,700 t for the smallest circles up to 3,800 t for the largest.

5.9 NSRAC management plan evaluation

5.9.1 Summary

This evaluation results from a request to evaluate a management plan for North Sea flatfish that was advised by the North Sea RAC in 2005. The evaluation concentrates on the effects of the plan with respect to sole and plaice in the North Sea. The management plan as it was formulated was supplemented by measures and objectives by the fisheries department of the Dutch Ministry of Agriculture, Nature Conservation and Food Quality. The current evaluation of the NSRAC management plan has been restricted to the effects of effort measures. Limitations owing to TACs and the 15% limit in annual TAC changes have not (yet) been tested in this evaluation.

The management plan as it formulated by the NSRAC is does not always clearly state the objectives and measures. This leaves room for interpretation, and results are dependent on this interpretation.

The evaluation has been carried by using the FLR simulation toolbox that is under development in a number of EU funded research projects (e.g. EFIMAS, COMMIT, FISBOAT). The simulation consists of an operating model and a management procedure. The operating model is expected to mimic the true stock and fishery dynamics. The management procedure consists of the process of acquiring data, doing stock assessments and implementing a harvest control rule.

The operating model consists of two species (plaice, sole), two areas (north, south) and two fleets (“NL-type”, “UK-type”). All the relevant processes in the stocks and the fishery have been modelled but at different levels of detail. The operating model has been conditioned on the data from the ICES Working Group on demersal stocks in the North Sea and Skagerak (WGNSSK). The operating model has been “fitted” using a very simple iterative process to estimate catchability, distribution over areas and recruitment levels. The final operating model generates approximately equal stock sizes in both observed and fitted SSB but the predicted landings for sole and plaice appear to be lower than the observed landings. This study shows that the parameterisation of simulation models to evaluate management plans is an area that requires more methodological development.

The probability of achieving the plaice B_{pa} target in 2010 is between 98% and 62% depending on the type of stock-recruitment relationships and whether or not additional measures are taken when a stock is below B_{lim}. The probability of reaching the sole B_{pa} in 2010 is between 82% and 48%. Owing to the low recruitment in 2003 and 2004 that has been measured in the surveys, the SSB in all runs is expected to fall below B_{pa} in the first years after the implementation of the management plan. The assumption on the shape of the stock recruitment relation has a strong impact on the expected success of the plan. The Ricker curve can be interpreted as a favourable environmental scenario and the Beverton-Holt as an unfavourable scenario.

For plaice, the expected landings associated with the management plan remain stable between 65 000 and 75 000 tonnes. For sole, the landings initially decrease in all runs. When a favourable environmental regime is assumed (Ricker curve) the landings are expected to increase again after the initial decline.

The success of effort management is dependent on a clear relation between fishing effort and fishing mortality. At present that relationship is poorly known. The model assumes a much more “responsive” effort-F relationship than observed in recent history, which could give the impression that changing effort will be directly detectable whereas in practice these changes in effort have often not lead to changes in fishing mortality.

5.9.2 Background

The North Sea plaice and sole stocks are managed by TACs, days at sea restrictions and technical measures. Both species are taken in a mixed fishery with by-catches of other species (e.g. cod, whiting, other flatfish species). The plaice stock has shown a decline in SSB after the early 1990s and has been at a relatively low level since the mid 1990s. The sole stock has fluctuated with a trend mainly determined by incidental strong year-classes. SSB in 2005 is estimated above B_{pa}. The two most recent sole year-classes are estimated to be very poor, which has a strong negative impact on the outlook for this stock.

5.9.3 The management plan to be evaluated

Objectives

In 2005, The North Sea RAC advised a management plan for the flatfish fishery in the North Sea to recover the plaice stock. The objective of the plan is formulated as follows:

”The NSRAC advises that a multi-annual management plan should be adopted for plaice in the North Sea with an initial target of reaching an SSB at the B_{pa} level within 3 – 5 years with a re-evaluation after 3 years and with the long term aim of exceeding B_{pa}. The plan should be implemented as of the 1st of January 2006. The management plan is aimed at reducing pressure on juvenile plaice and would comprise structural effort reductions accompanied by stability in the TAC for plaice. The multi-annual plan should be accompanied by a monitoring and evaluation scheme, which would also include the monitoring of social and economic impact.”

The operational objective is to recover the plaice stock above B_{pa} within a defined timeframe of 3 - 5 years. Bpa for plaice has been proposed at 230,000 tonnes by ICES. There is no explicit objective for sole.

Measures

North Sea flatfish are currently managed by a combination of TACs, days at sea limitations and technical measures.

The management measures proposed in the NSRAC management plan are:

“To reach the target of the multi-annual management plan, the NSRAC advises a structural effort reduction of 15% of enforced licensed capacity limits in the international 80 mm flatfish fishery over 2006 and effort to be maintained at the new level for a further two years. The German fishing industry believed that there should be an exemption for German shrimpers in the 80 mm category, which target sole in the coastal waters during part of the year. The NSRAC is willing to consider an exemption for the shrimper fleet if scientific evidence supports the claim that plaice are not discarded in significant quantities in their targeted 80 mm sole fishery”.

“The manner in which different Member States achieve this reduction should be at their own discretion through a national flatfish management plan (NFMP). The following conditions should apply:

1. the NFMP needs to be verifiable and enforceable;

2. the NFMP needs to be submitted to the Commission for approval

3. the NFMP should consist of any or a combination of the following instruments for effort reduction (as measured in kW/days):

a. decommissioning, and/or

b. days-at-sea restrictions

4. in the case where decommissioning is part of the NFMP, the Member State will refrain from taking its decommissioning days under Annex Iva;

5. seasonal tie-ups during the spawning season may contribute to the effort reduction but should be managed by the fleets, not the Commission, in order to keep a flow of fish to the market.

To allow for the management target to be achieved, the management regime should operate throughout the entire multi-annual plan period, i.e., the effort reduction level will be sustained. A re-evaluation will be carried out after three years. Intermediate changes to the management regime as a whole would only be permitted if unforeseen developments took place. In the event of the plaice stock falling below B_{lim} *new measures would be applied. In the event of the plaice stock going above Bpa during the multi-annual management period, the harvest control rule will be that no amendments are made.*

The management measures in the plan consist mainly of an effort reduction. However, the implementation of the effort reduction in the proposed plan is formulated as a capacity reduction. Studies show that capacity reductions do not necessarily results in effort reductions in situations of under-utilisation of capacity.

Intermediate changes to the regime are only allowed when the plaice stock fall below B_{lim}. This rule is problematic to interpret. B_{lim} is currently defined as the SSB below which recruitment is impaired. However, as fisheries management only has a perception of the stock status, generated by stock assessments, the true B_{lim} cannot be know to managers. In the model, we will therefore interpret these words as: “In the event of the plaice stock falling below the **perceived** B_{lim} new measures would be applied”. Furthermore, we have assumed that the clause would apply to both plaice and sole.

The measures that would be taken when a stock is perceived to be below B_{lim} are not formulated in the plan, and thus open to interpretation. We have interpreted this measure as a further decrease of nominal fishing effort by 15% each year until SSB has returned to above B_{lim}. This reduction shall subsequently not be reversed. However, because this implementation in the plan is not clearly defined, we have run models with and without this additional interpretation.

In the NSRAC management plan there is an implicit reference to stability in TACs. The objective of stability of the TACs is not quantified in the original text. The Dutch Ministry of Agriculture, Nature Conservation and Food Quality has requested to include a maximum annual change in TACs of 15%. However, in the present simulation model this has not yet been included as part of the evaluation.

5.9.4 HCR simulation: processes included

Biological operating model

The simulation model consists of “true” underlying plaice and sole stocks (operating model), representing the population dynamics of these stocks. The model is spatially structured, with two areas. The distribution of the species between the areas is estimated from the BTS survey, taking into account different distributions for each of the age classes. In general, sole is distributed mainly in the southern area, throughout its entire life-span, while plaice distribution shifts from south to north during their lifetime.

Data on the development of the stock is available from 1957 to 2004 by XSA assessments, the recruitment in the last 4 years estimated by the last assessment is still uncertain so has been omitted from the study.

From this data, Ricker and Beverton-Holt type *stock-recruitment* relationships were estimated (Figure 1). For plaice, this relation is estimated directly from the WGNSSK2005 assessment data. For sole, the stock recruitment relation is estimated from WGNSSK2005 that is corrected for the absence of discards in the historic period. This correction factor was estimated by minimizing the sum of squares of the (observed – predicted) landings. In the forward simulation, recruitment estimates are taken from the stock recruitment relation, taking into account the variance estimate from the historic relationship.

Stock numbers at age were taken from the WGNSSK assessments. The simulations were initiated in 1995 with the observed stock numbers at age and with all estimated recruitments. Landings, discards and survivors were then calculated from the calculated fishing mortality. From 2006 onwards the simulations would use the estimated stock-recruitment relationship to generate recruitment, survivors and catches.

Natural mortality used in the simulation is assumed equal to the WGNSSK2005 estimates, being equal to 0.1 for all ages in both stocks

Growth in the simulation model is implemented as a Von Bertalanffy growth curve fitted to observed lengths from the BTS survey (Figure 3). A CV of 0.1 surrounds the length-at-age for all ages for plaice, and 0.17 for sole. The weights-at-age are estimated from a length-weight relation estimated from the BTS survey.

Maturity is assumed equal to the WGNSSK2005 estimates for both stocks.

The fishery

Exploitation of the fish stocks under consideration mainly takes place by a multi-species demersal fishery, targeting mainly flatfish species sole and plaice. For the purpose of the evaluation the structure of the fishery has been simplified to the two major fleets that take the majority of the catches and it has been assumed that these fleets take all catches. These fleets are the English beam trawl fleet and the Dutch beam trawl fleet. These fleets allocate effort in both areas, with the Dutch beam trawl fleet allocation most of its effort in the southern area, while the English beam trawl fleet allocates effort equally over both areas (Figure 4). The fishery is allowed to use 80 mm mesh size in the southern area, and 100 mm mesh in the northern area. The 80 mm mesh size in the southern area combined with the minimum landing size of 27 centimetres for plaice causes considerable discarding of juvenile plaice.

During the last 10 years, the nominal fishing effort of the fleets has decreased substantially. However, a recent study has shown that the efficiency of the Dutch beam trawl fleet, one of the major operators in this fishery, has increased between 1.5% (plaice) and 3% (sole) per year. The efficiency increases have been used in the fitting of the operating model and in the future predictions of effective effort, partially counterbalancing the decrease in nominal fishing effort.

Assessment and forecast

Knowledge on the status of the stocks is generated through the explicit inclusion of a stock assessment and forecast model in the simulation. This process encompasses recording the catches and landings of both fleets in the model, and having a survey that covers both areas. The assessment method is XSA based on the landings (sole) or catches (plaice). The implementation of the XSA stock assessment to in the knowledge process explicitly takes into account the assessment error generated by the stock assessment, including potential biases that are dependent on the stock developments. The implementation of a two-year catch prognosis explicitly takes into account potential errors in the advisory process by assuming stable exploitation rates in the intermediate year.

The WGNSSK assessments are tuned with multiple research surveys (plaice) or a combination of surveys and commercial CPUE data (sole). The assessment data are rather noisy, especially the discards estimates of plaice which make up a considerable part of the catch-at-age data. This lack of precision in the assessment has not been fully taken into account in the simulations so far. At present an error of only 10% has been applied to the simulated landings, discards and survey catches. The sensitivity of the results to the assumed error still has to be investigated.

Biological parameters of the stocks in the assessment process are assumed to be equal to the "true" biological parameters set in the operating model. No observation error on growth and maturity are included in the simulation model.

Simulation of the management plan

In the evaluation, nominal fishing effort was reduced by 15% in 2006 compared to 2005. The level of effort was maintained in the following years.

With regards to the Blim trigger, we have interpreted the management plan as: "In the event of **a stock** falling below the **perceived** B_{lim} new measures would be applied".

The measures that would be taken when a stock is perceived to be below B_{lim} are not formulated in the plan, and thus open to interpretation. We have interpreted this measure as a further decrease of nominal fishing effort by 15% each year until SSB has returned to above B_{lim}. This reduction shall subsequently not be reversed. We have run the models both with and without the extra 15% interpretation.

In the NSRAC management plan there is an implicit reference to stability in TACs. The Dutch Ministry of Agriculture, Nature Conservation and Food Quality has requested to include a maximum annual change in TACs of 15%. However, in the present simulation models the TACs are not constraining the fishery. We have not yet implemented the behaviour of fishermen when a TAC is reached but the effort quota is not yet reached. This needs to be done in a future version of the model.

The decision process in each year is based on the prognosis of the remaining spawning stock after the year to which the management action applies. This prognosis is compared to the B_{lim} trigger points from the management plan.

No systematic implementation error with respect to misreporting or black landings is included in the simulation.

5.9.5 Conditioning of the operating model

Conditioning of the operating model refers to the way in which the dynamics in the operating model reflect the current understanding of the biological and economic dynamics. The simulation model has been set up with two fleets, two areas and two species. The operating model was constrain to generate the observed dynamics of plaice and sole in terms of landings, discards, SSB and fishing mortality. Given the multiple dimensions in the model (fleet, area and species) it was difficult to choose process parameters that gave a close match between the model estimated landings, discards, SSB and F and the values taken from WGNSSK for the period 1995-2005. This is because the parameter values, functional forms and the area-fleet divisions in the operating model may be different from the true processes which are taken here as the WGNSSK realization.

5.9.6 Robustness testing

Robustness testing is the process whereby the robustness of the management strategy is tested to the variability in the operating model (nature, fleet dynamics) and the uncertainty in the knowledge generation process (stock assessment, forecasts).

The management evaluation has not been finalized yet. Therefore, the results are still preliminary, and not all robustness testing has been carried out. The robustness of the evaluation to two different hypothesis have so far been tested in several runs (Table 1), each with 50 iterations:

- sensitivity to the implementation of the 15% effort reduction when the stock falls below the B_{lim}. The implementation of this rule has a large effect on the risk of failing the objective, because the present poor state of the sole stock results in further effort reduction, reducing fishing mortality for both sole and plaice.
- sensitivity to the stock recruitment curve (either “Ricker” or “Beverton and Holt”). The median recruitment is higher using the Ricker stock-recruitment curve compared to the Beverton-Holt curve (Figure 6), so that the Ricker curve can be interpreted as a favourable environmental scenario and the Beverton-Holt as an unfavourable scenario.

5.9.7 Results

The results of the simulations are still preliminary, as a number of additional simulations are in the process of being carried out.

1. The fitted landings for both plaice and sole are lower than the observed landings in the historic period (Figure 7). This result indicates that it is difficult to get a good fit of the selectivity and catchability parameters in the model and that in general it is difficult to mimic the perception from the WGNSSK, which is due to one historic realisation. The issue of fitting operating models to data requires much more attention in the process of developing simulation models. The dynamics in the operating model determine the outcome of the simulations to a large extend and a lack of fit to the historic data reduces the communication value of the evaluation, because clients will want to refer to fixed reference levels.
2. The probability of achieving the plaice B_{pa} target in 2010 is between 98% and 62% depending on the type of stock-recruitment relationships and whether or not additional measures are taken when a stock is below B_{lim}. The probability of SSB being below B_{lim} is less than 2% in all runs.
3. The probability of reaching the sole B_{pa} in 2010 is between 82% and 48% (Table 3). Due to the low recruitment in 2003 and 2004 that has been measured in the surveys, the SSB in all runs is expected to fall below B_{pa} in the first years after the implementation of the management plan (Figure 5). Only when additional effort reductions are applied when perceived SSB is below B_{lim}, there is a high probability (82%) of that SSB will be above Bpa in 2010. This scenario is consistent with overall effort reductions in the order of 40% (Beverton-Holt stock-recruitment curve) or 30% (Ricker curve). See table 4 for details.
4. The recruitment trajectories for future predictions show variances that are equal to the observed variances for both species in the past. The median recruitment in the prediction is higher using the Ricker Stock recruitment curve compared to the Beverton-Holt curve (Figure 6), so that the Ricker curve can be interpreted as a favourable environmental scenario and the Beverton-Holt as an unfavourable scenario.

5. For plaice, the expected landings associated with the management plan remain stable between 65 000 and 75 000 tonnes. For sole, the landings initially decrease in all runs. When a favourable environmental regime is assumed (Ricker curve) the landings are expected to increase again after the initial decline. The 95% confidence intervals of the predicted sole landings vary between 4-28 thousand tonnes with a mean around 9 and 13 thousand tonnes. This is much lower than in the historical period.

5.9.8 The process of evaluation

The process of evaluation of the North Sea RAC management plan has been started in November 2005, when RIVO was requested to carry out such an evaluation by the Dutch Ministry of Agriculture, Nature Conservation and Food Quality (LNV). There were three major actors involved in the evaluation: the ministry LNV, the NSRAC through the chairperson of the NSRAC flatfish group and the research group at RIVO.

The research plan was to develop a simulation model in the FLR[1] framework as this was a way to combine the development of a practical application in FLR with a very directed request from the clients, which could not be addressed with standard software.

It was very clear from the beginning of the process, that the management plan of the NSRAC was not specific enough for a simulation approach. Simulating management plans, requires that all eventualities be covered in the plan and that no ambiguities are left. However, in order to lift those ambiguities, a close connection between the different parties would have been required. Yet, the rush of the December council of ministers where both the ministry and the NSRAC were involved prevented such a connection.

Only in January 2006, it has been possible to establish a discussion on how the contents of the management plan should be interpreted. We noted that it is not obviously clear to the clients what the evaluation software can and cannot do. Sometimes the expectations with regards to details of the plan and the precision of the outcome were much higher than can be warranted from a tool that is mainly designed to explore the overall effect of different strategies.

The lesson learnt from this process, it that there needs to be a frequent dialogue between scientists and clients/stakeholders on how the evaluation should be set up, what kind of results to expect and how to digest the results.

5.9.9 Discussion and conclusions

In the evaluation of the NSRAC management plan, a simulation model has been developed in FLR that consists of an operating model and a management procedure (data sampling, assessment and harvest control rule). The FLR toolbox is still under development but at present it already allows the development of custom made simulation models for specific situations and harvest rules.

The conditioning of the operating model on the observations from WGNSSK 2005 has been proven difficult. The operating model has been “fitted” using a very simple iterative process to estimate catchability, distribution over areas and recruitment levels. The selectivity of the fleet is assumed the result of the distribution of the fleet over the two areas, each with different mesh sizes. Combining the mesh size in each of the areas with the growth curves of the species results in the selectivity. This assumption is different from the assumptions made in XSA to which these data are compared. The final operating model generates approximately

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1 http://flr-project.org/doku.php?id=appl:nsrac

equal stock sizes in both observed and fitted SSB but the predicted landings for sole and plaice appear to be lower than the observed landings. It should be noted that all the results are conditional on the current fit. This study shows that the parameterisation of simulation models to evaluate management plans is an area that requires more methodological development.

The discarding of juvenile sole below the minimum landing size is estimated to be between 10-20%, but has not been included in the WG assessments (WGNSSK2005). Therefore, the stock-recruitment relationship for sole has been derived from a landings-based assessment that underestimates the “true” recruitment. In the simulation model we have implemented the process of fishing as a combination of effort, selectivity and catchability, which does generate discards due to the combination of the distribution of the stock and the fishery. Therefore, the recruitment estimates had to be corrected for the inclusion of discards in the simulation. This could be a generic issue for operating models that are conditioned on stock assessments that are based on landings only.

The management plan as it formulated by the NSRAC is does not always clearly state the objectives and measures. This leaves room for interpretation, and results are dependent on this interpretation. One of the interpretations is that the 15% effort reduction is formulated as a reduction in nominal effort rather than a reduction in capacity. This is especially important in the case of capacity under-utilization, where capacity reduction generally does not lead to effort reduction.

The observed sole SSB has a high probability of falling below B_{lim} in the prediction. This islargely driven by the series of low recruitments at the end of the observed time series. These observed recruitment have been used directly in the operating model. The expected low sole stock implies that management actions to implement the additional effort reduction rule are mainly triggered by sole. If further effort reductions are implemented when a stock is below Blim, this is expected to lead to higher SSB and catches of plaice despite the lower effort.

The success of effort management is dependent on a clear relation between fishing effort and fishing mortality. At present that relationship is poorly known. Figure 2 indicates that the relationship between effort and F in the WGNSSK data is much more noisy that the relationship that is generated from the operating model. This suggests a much more “responsive” effort-F relationship in the simulation model which could give the impression that changing effort will be directly detectable whereas in practice these changes in effort have often not lead to changes in fishing mortality. We also noted that the inclusion of technical efficiency creep was a very important aspect to take into account in the simulation model. In the absence of technical creep and given the observed decreases in nominal effort, any model result would indicate a very strong decrease in fishing mortality and hence a quick increase of the stocks.

The current evaluation of the NSRAC management plan has been restricted to the effects of effort measures. The limitations due to TACs and the 15% limit in annual TAC changes have not (yet) been used in this evaluation.

Table 5.9.1: Model hypothesis used in robustness testing of management plan

Run	Stock recruitment relation	Rule
1	Beverton & Holt	15% effort reduction in 2006
2	Beverton & Holt	15% effort reduction in 2006 Additional 15% effort reduction if stock falls below perceived Blim
3	Ricker	15% effort reduction in 2006
4	Ricker	15% effort reduction in 2006 Additional 15% effort reduction if stock falls below perceived Blim

Table 5.9.2: Summary of model runs for plaice

Run	True SSB < Blim (any year)	Perceived SSB < Blim (any year)	Perceived SSB < Bpa (any year)	True SSB < Blim (2010)	True SSB < Bpa (2010)	Median recruitment simulated period and 95% percentiles	Median true ssb and 95% percentiles (2010)	Median landings and 95% percentiles (2010)
						100,000,000	100,000 tonnes	10,000 tonnes
1	<2%	8%	>98%	< 2%	38%	7.83 (3.60 19.0)	2.48 (1.96 3.85)	6.22 (4.73 9.90)
2	<2%	10%	>98%	< 2%	8%	8.02 (3.11 21.1)	3.27 (2.35 5.50)	6.53 (4.11 10.7)
3	<2%	6%	>98%	< 2%	8%	8.71 (3.72 22.4)	2.88 (2.19 4.37)	7.64 (5.25 11.6)
4	<2%	<2%	>98%	< 2%	<2%	9.29 (4.14 24.3)	3.63 (2.70 6.04)	7.38 (5.56 13.7)

Table 5.9.3: Summary of model runs for sole

Run	True SSB < Blim (any year)	Perceived SSB < Blim (any year)	Perceived SSB < Bpa (any year)	True SSB < Blim (2010)	True SSB < Bpa (2010)	Median recruitment simulated period and 95% percentiles	Median true ssb and 95% percentiles (2010)	Median landings and 95% percentiles (2010)
						10 000 000	10 000 tonnes	1 000 tonnes
1	55%	>98%	>98%	30%	52%	7.48 (1.96 39.1)	3.42 (1.37 7.38)	9.09 (4.08 21.2)
2	42%	>98%	>98%	10%	46%	7.63 (2.37 43.4)	3.96 (2.38 6.34)	7.07 (4.27 18.9)
3	18%	>98%	>98%	6%	30%	11.5 (3.52 39.3)	4.13 (2.61 10.2)	11.4 (7.90 28.2)
4	10%	>98%	>98%	2%	18%	11.8 (2.82 49.0)	5.58 (2.90 9.14)	13.5 (4.58 22.2)

Table 5.9.4: Summary of model runs for fishing effort

RUN	MEDIAN EFFORT AND 95% PERCENTILES (2010)
	10 000 Days at sea
1	2.02*
2	1.24 (1.06 1.72)
3	2.02*
4	1.46 (1.06 1.72)

***percentiles equal to median**

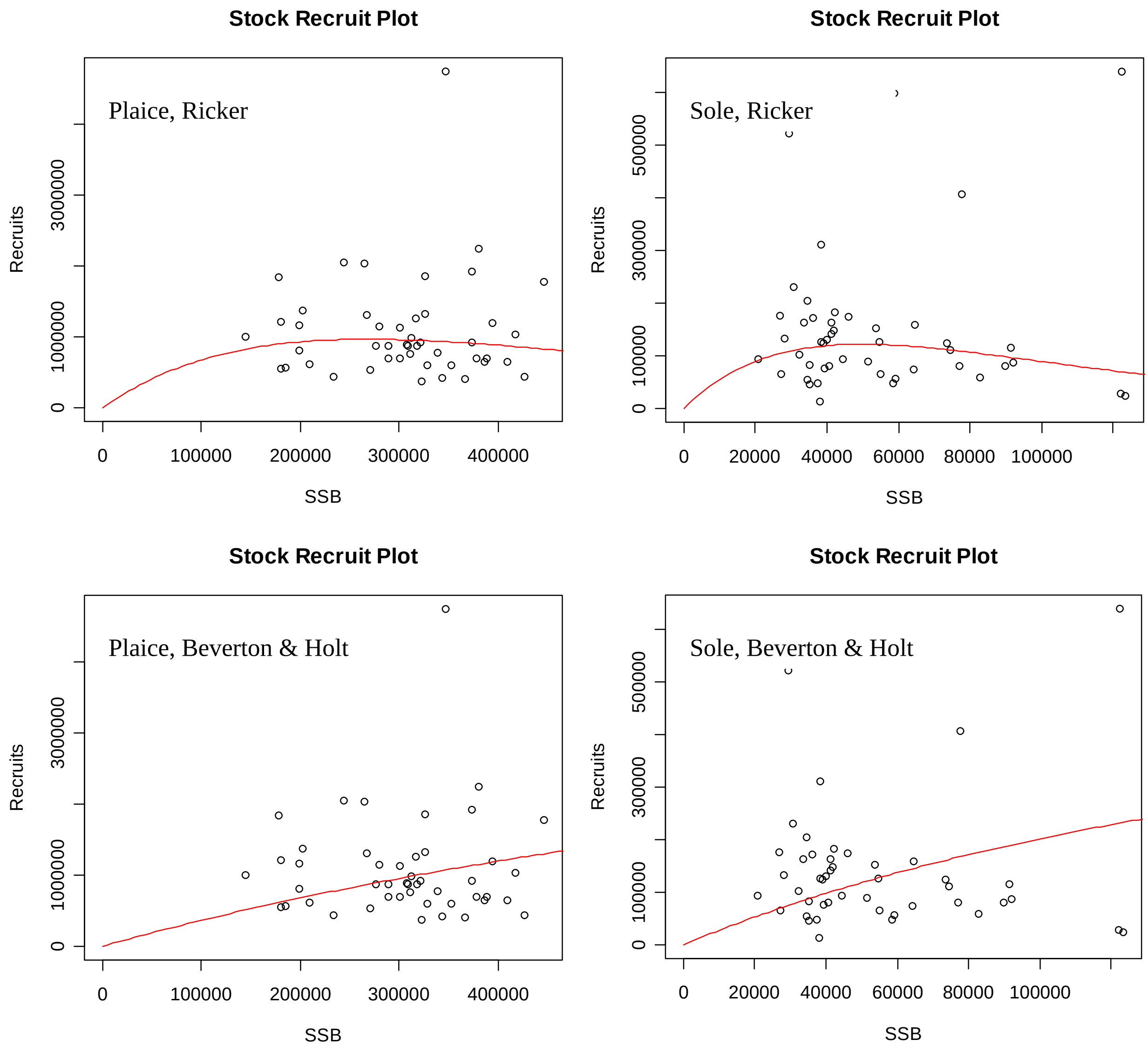

Figure 5.9.1. Stock/recruitment observations (dots) and fitted relations (red lines) of plaice (left) and sole (right), using either a Ricker (top) or Beverton and Holt (bottom) model.

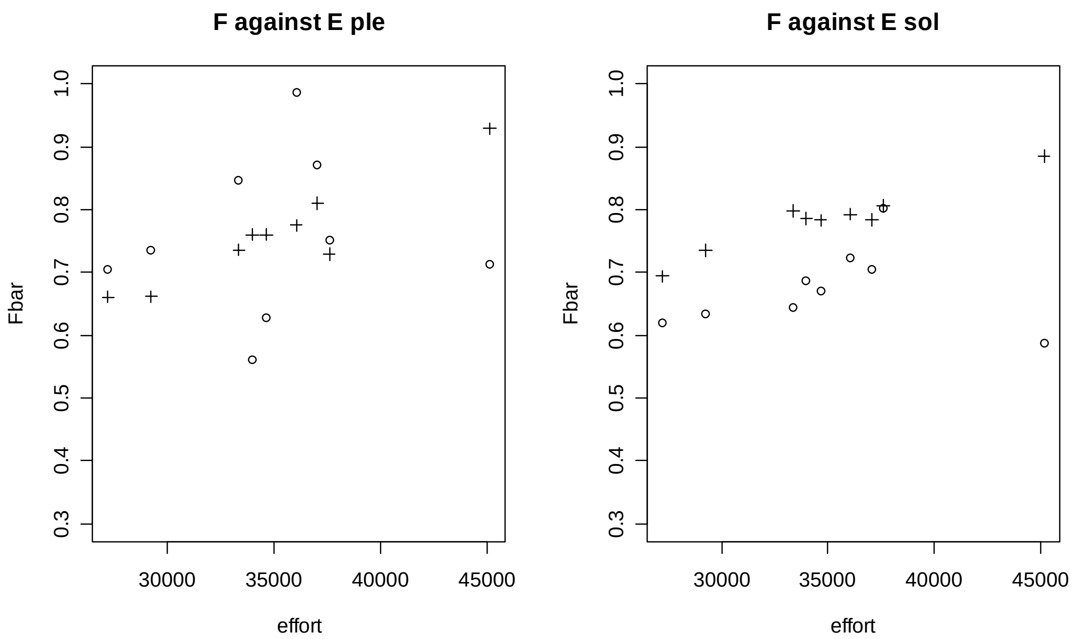

Figure 5.9.2. Effort/ mean F (ages 3:6) relation observed from the model (+) and from the WGNSSK2005 assessment data (○) for plaice (left panel) and sole (right panel)

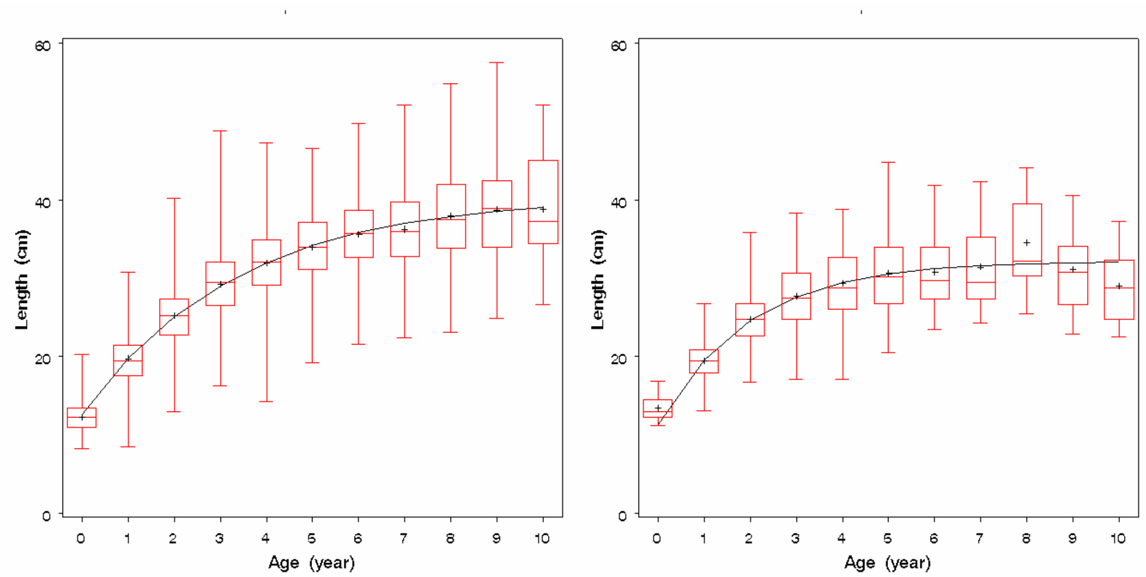

Figure 5.9.3. Age/length observations from BTS curves (boxplots) and fitted relations (black lines) of plaice (left) and sole (right), using a Von Bertalanffy growth equation.

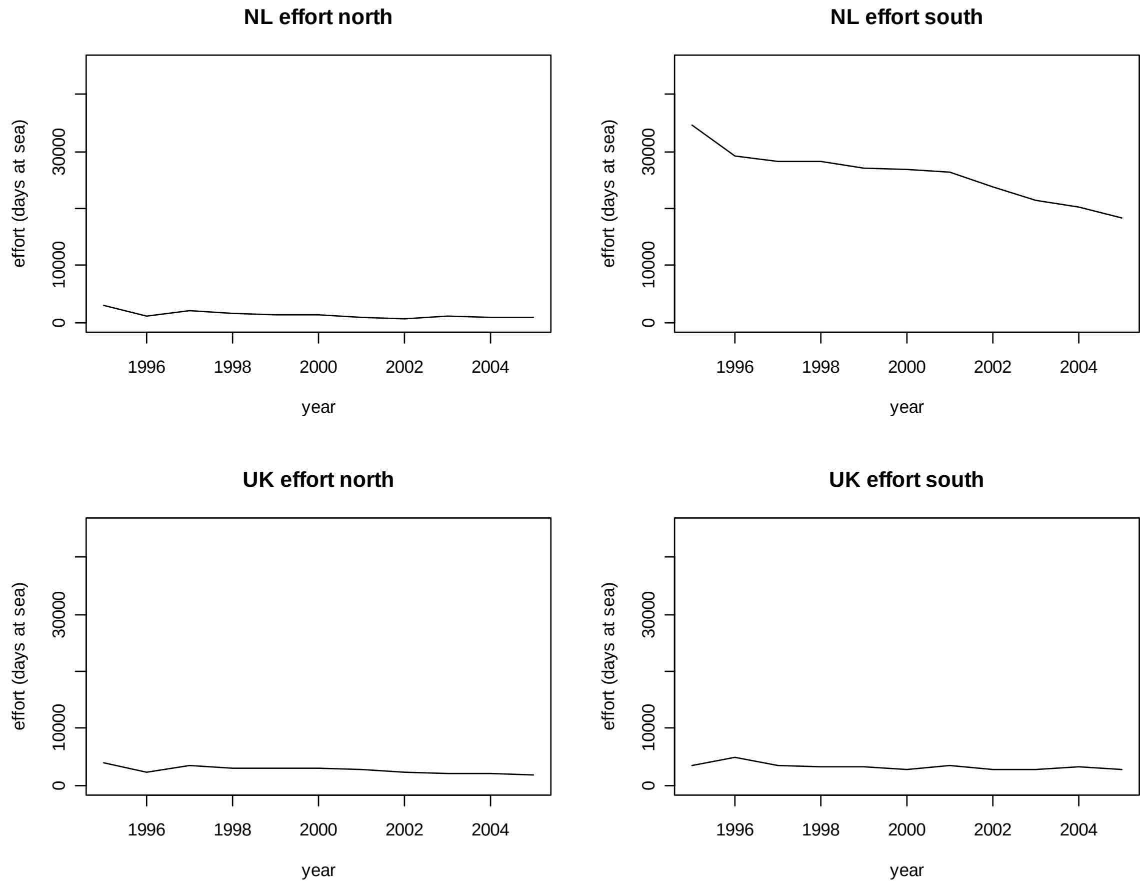

Figure 5.9.4. Estimates of historic fishing effort, expressed in days at sea, for the two fleets in the two areas.

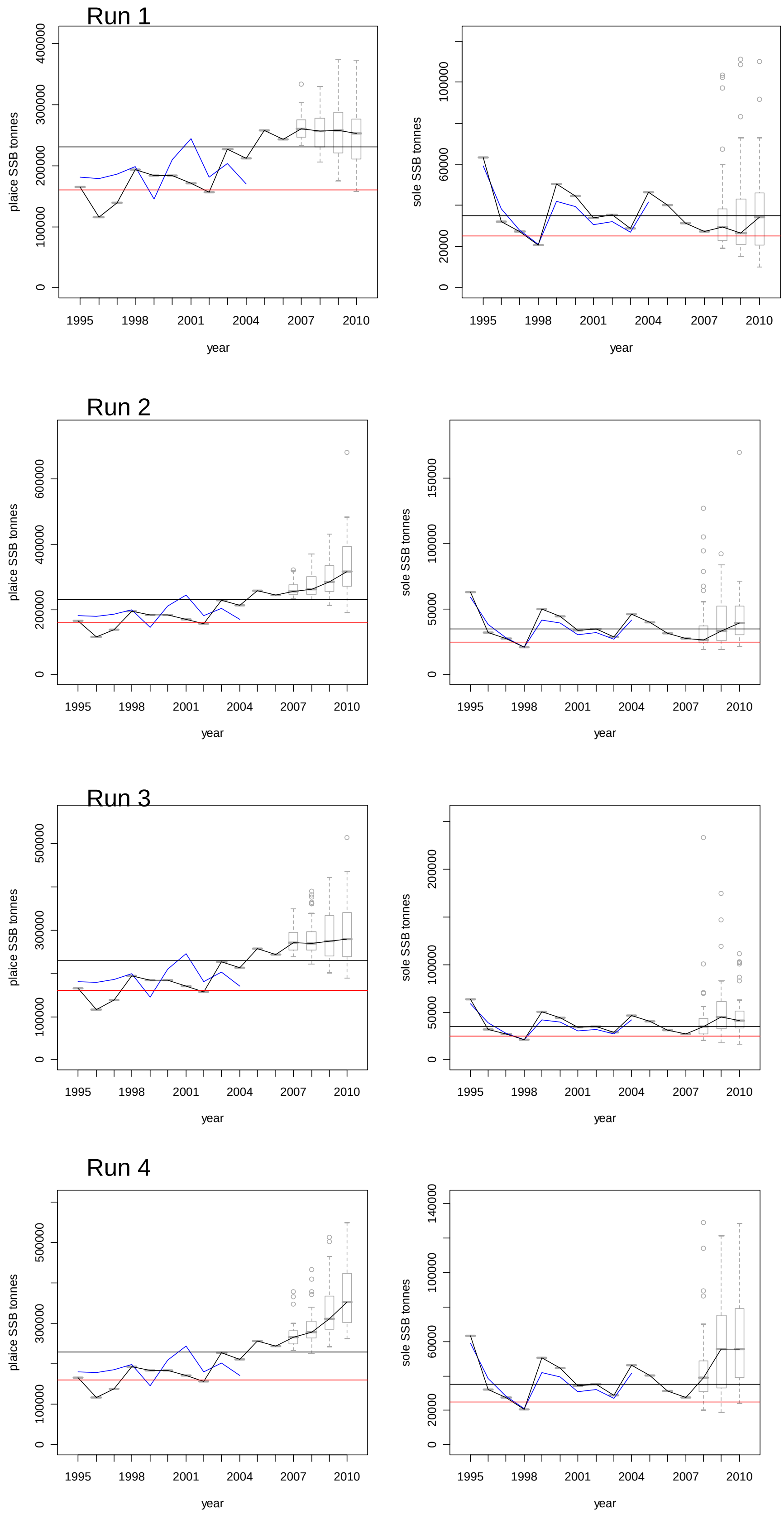

Figure 5.9.5. SSB of plaice (left) and sole (right), for the 4 different runs (see panels, table 1). Boxplots connected through median by black line indicate model fit and prediction. Blue line indicates XSA estimates of SSB from WGNSSK 2005. Horizontal lines indicate Bpa (black) and Blim (red).

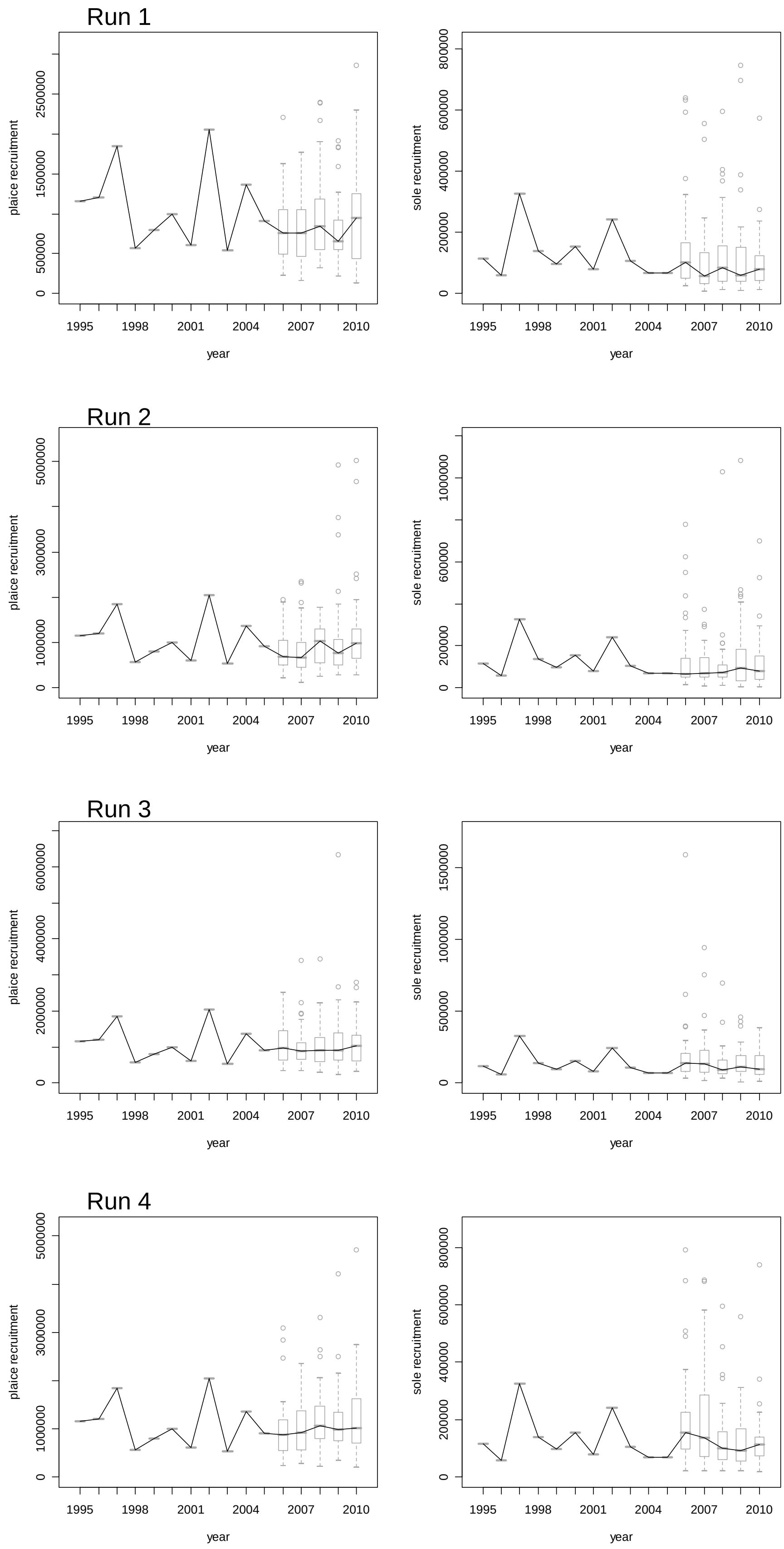

Figure 5.9.6. Recruitment of plaice (left) and sole (right), for the 4 different runs (see panels, table 1). Boxplots connected through median by black line indicate model fit and prediction.

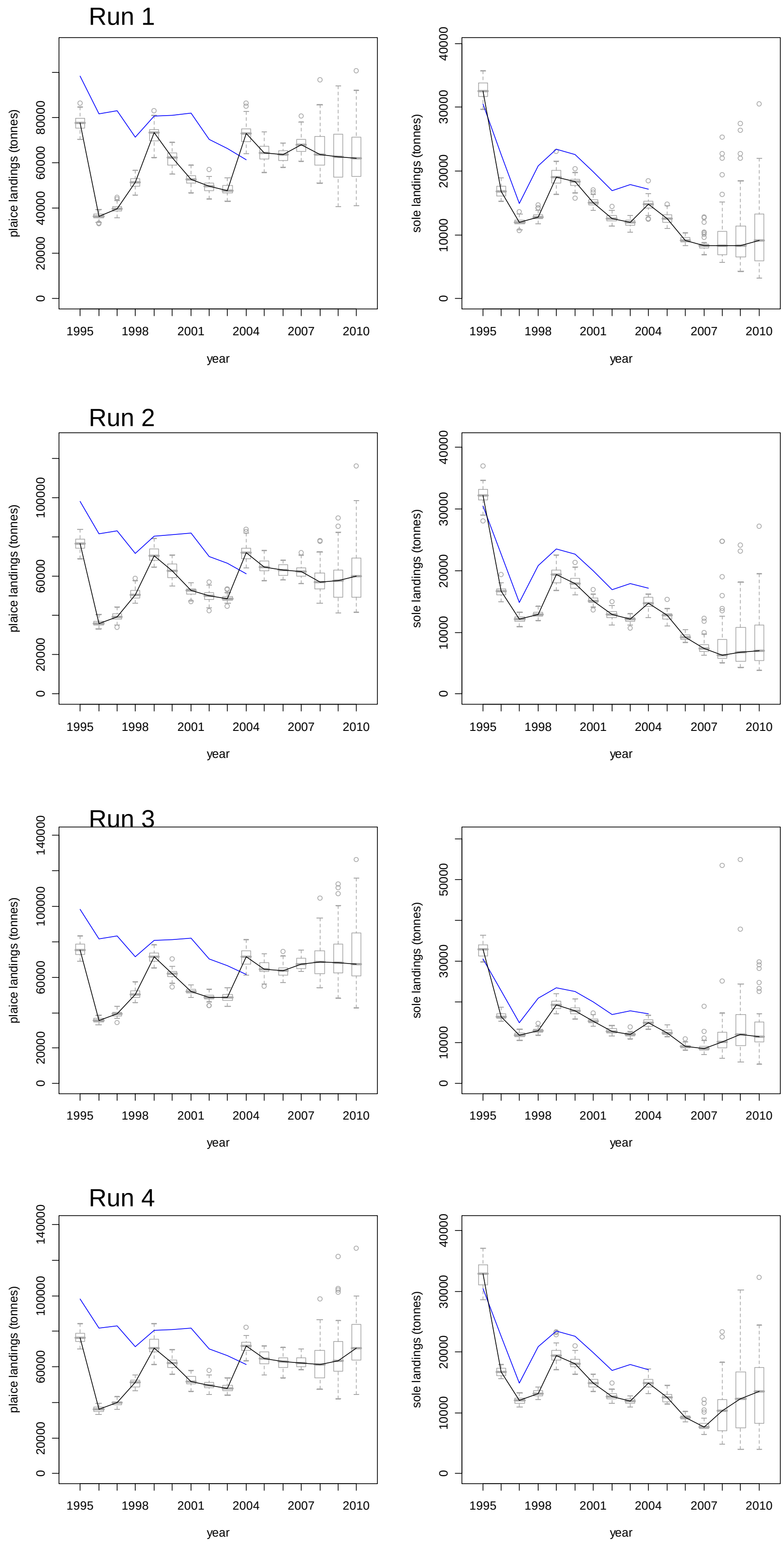

Figure 5.9.7. Landings of plaice (left) and sole (right), for the 4 different runs (see panels, table 1). Boxplots connected through median by black line indicate model fit and prediction. Blue line indicates historic observations.

5.10 Lessons learned from the Irish Sea cod recovery plan

ICES has not yet completed a full evaluation of the Irish Sea cod recovery plan and all its constituent elements. However, a discussion and comparative simulation study is available in a paper by Kelly et al (2006). The main results from the study and discussion from the paper are summarized below.

5.10.1 Context / background

In 1999, ICES advised that the Irish Sea cod stock was in danger of collapse, and recommended that a recovery plan be put in place. In February 2000, the European Commission established measures to aid recovery. These measures initially included two closed areas in the eastern and western Irish Sea to provide the maximum possible protection during the spawning season and to maximize egg production of the existing stock. The closed areas were based on the putative spawning grounds at peak spawning time (14 February-30 April). The closures applied to all fishing activities, excepting derogations for Norway lobster (*Nephrops norvegicus*) trawls and beam trawlers, which were permitted to fish in defined ‘boxes’ within the closed areas. Additional measures were adopted in November 2000, banning various technical specifications of towed nets. The extent of the closed area and derogations for fishing within the area were amended in February 2001, limiting the closure to the eastern Irish Sea and permitting two types of fishing within the reduced closed area through derogation. This was again further amended in July 2001, permitting the use of double twine no greater than 4 mm in the construction of the codend of the trawls. The recovery plan was further specified in 2004, setting a target biomass for the stock of Bpa = 10 000 t and establishing procedures for the setting of the TAC. These procedures were designed to ensure a 30% annual increase in SSB (relative to the most recent assessment estimates of stock size) and to limit annual TAC changes to 15%. During that time there were consultations with fishers, but there were no compensation packages for those disadvantaged by the scheme.

The Irish Sea cod recovery plan relied for its success on the reduction of quotas through a HCR, the closure of spawning grounds, and technical gear regulations. The result of the recovery plan in terms of landings was an initial decrease, followed by increased landings and unreported catches. In terms of SSB, the ‘recovery’ did not yield the expected gain, and some six years on, the stock is still well below Bpa, and is likely also to be below Blim (6000 t).

5.10.2 Management objectives

The initial objective of the Irish Sea cod recovery plan was clearly the recovery of the stock to a ‘safe’ level. In 2004 Bpa was specified as 10 000 t and a HCR introduced to deal with the stock when below Bpa. There was no explicit statement of the timescale over which recovery was expected to be achieved, and the recovery plan did not set out to compensate fishers for their loss of revenue caused by reduced opportunities to fish. It was not an explicit aim of the recovery plan in its initial formulation to reduce effort, and in fact the plan stated that opportunities to fish other species “should not be significantly diminished”. Derogations were introduced to the closed areas so that “fisheries for Norway lobster, shrimps and flatfish, should not be significantly diminished while minimising risk to cod.”

5.10.3 Description and discussion of HCR

The Irish Sea cod recovery plan included measures such as gear regulations and closed areas, as well as some limited form of effort regulation in its later forms, but the only explicit mechanism to control quota (and subsequent stock removals) was the HCR defined by the European Commission in 2004 ((EC) No. 423/2004):

Irish Sea cod HCR: description

For stocks above Blim, the harvest control rule (HCR) requires:

1) setting a TAC that achieves a 30% increase in the SSB from one year to the next,
2) limiting annual changes in TAC to ± 15% (except in the first year of application),
3) a rate of fishing mortality that does not exceed Fpa.

For stocks below Blim the Regulation specifies that:

4) conditions 1-3 will apply when they are expected to result in an increase in SSB above Blim in the year of application,
5) a TAC will be set lower than that calculated under conditions 1-3 when the application of conditions 1-3 is not expected to result in an increase in SSB above Blim in the year of application.

Irish Sea cod HCR: discussion

The 2005 report of ACFM stated: "This plan has not yet been evaluated by ICES…the management plan requires annual predictions of spawning stock size, which is not available given the recent poor catch data…a management plan that does not require such a precision should be considered."

Retrospective year-on-year errors in assessment estimates of SSB are high for this stock, and problems with recent catch data mean that these errors are unlikely to be mitigated in the short term. This means that it is almost impossible to be certain that a 30% increase in SSB has been observed until retrospective errors are removed, so it is hard to see if the plan is working until years later. An easily measurable objective is a key point for the success of any HCR and this appears to be lacking in this case. Further, even with a perfect SSB estimate to calculate the required TAC to produce a 30% increase in SSB, there is still great uncertainty as to whether this will actually happen given both implementation bias and error (exceeding of quotas) and the impact of environmental factors.

The limit in annual TAC changes to 15% is likely to protect the stock if TACs are increasing. However, if highly reactive management action is required and a dramatic cut in TAC is needed (e.g. in the case of successive recruitment failure), then this TAC limit is likely to be too restrictive.

The second part of the HCR, relating to SSB being below Blim, can be rendered ineffective depending on the interpretation. The TAC set in this situation is only required to be less than the TAC resulting from steps 1-3, but there is no explicit description of by how much it should be less (e.g. in practice, 1 tonne less would fit the HCR).

5.10.4 Comparative simulation study

Kelly et al (2006) completed simulations of hindcast projections of the Irish Sea cod stock from 1999-2005 using the F-PRESS software tool, see Section 8.2.5. The projections did not explicitly include the Irish Sea cod HCR in the management model. Instead, a hypothetical HCR based on gradual management of TAC to reach a target fishing mortality was used. Ranges of target fishing mortality values were considered and the effects of error and bias in the observation/assessment model and implementation model were investigated. Further projections were completed to investigate the effect of a 15% annual TAC change limit similar to that specified in the actual Irish Sea cod HCR.

The main results of the simulation study suggest that an effective mechanism to produce stock recovery is to aim for a low value of target fishing mortality. Results suggest that with perfect observation/assessment and implementation, a target fishing mortality close to 0.7 (Fpa =

0.72) produces the optimal yield over the projection. However, when highly conservative levels of error and bias (20%) are introduced, the optimal yield occurs when target fishing mortality is 0.45. This suggests that error and bias can have a large effect on the success in the simulated HCR, and a similar result is predicted for the actual Irish Sea HCR. The effect of introducing an annual TAC change limit of 15% is dramatic: even with perfect observation/assessment and implementation, there is a 40% chance that stock recovery will fail even at the lowest levels of target fishing mortality (F=0.2). When conservative error and bias (20%) is included then this becomes a greater than 70% chance of recovery failure when target F=0.2. This strongly implies that it is not sensible to include a mechanism to limit downward changes in TAC if a stock is in a recovery state and vulnerable to recruitment failure or environmental fluctuations. In this situation it is critical that managers retain the ability to react quickly to the state of the system and take drastic action if necessary.

5.10.5 Conclusions and management issues related to the study

Kelly et al (2006) argue that the Irish Sea cod recovery plan in its current form fails to adequately deal with the underlying system uncertainty and lacks clear and measurable objectives. They further argue that this is likely to be the reason why stock recovery has not occurred as originally expected. They suggest that a better approach to the development of a recovery plan for Irish Sea cod would include the following:

i) Clear objectives that effectively communicate that the instrument of recovery is the reduction in exploitation, and how this is to be achieved.

ii) Clear understanding that this will require a reduction in fishing opportunities, and a consideration of the fleet-specific reduction in revenue of such reduced exploitation.

iii) Clear mechanisms to ensure this reduction will be adhered to.

iv) Clear, measurable performance targets, underpinned by sufficient data collection to assess performance of recovery, and an understanding of the inherent uncertainty involved.

v) A multispecies harvest plan to manage the stock when (or if) recovery is achieved.

Even so, there is no guarantee that these measures if rigidly applied will lead to recovery of the stock, and this possibility should be discussed openly. However, such suggestions should allow for clear evaluation of the state of the stock in relation to both management actions and objectives.

5.11 Bay of Biscay sole (ICES Div. VIIIa,b)

In September 2006, the Subgroup on Management of Stocks (further called SGMOS under this section) of the Scientific, Technical and Economic Committee for Fisheries (STECF) met to develop long-term management strategies for Bay of Biscay sole, Celtic Sea cod and anglerfish VIIIc-IXa. The following section is an extraction the topics of the SGMOS report related to Bay of Biscay sole.

The TORs for the SGMOS group were:

1) STECF is requested to evaluate a range of harvest rules for Bay of Biscay sole, Celtic Sea cod and Anglerfish VIIIc-IXa with respect to medium and long term yield, stability of yield and effort and stock status with respect to safe biological limits. Evaluations shall in the first instance be made on a single species basis but the experts shall, to the extent possible, quantify mutual compatibility of the rules for the target species with the conservation needs of other species caught in the same fisheries.

2) STECF is requested to advise whether effort management is necessary to achieve the effective implementation of the harvest rule and the attainment of conservation targets.

3) The rules shall be evaluated through simulations that take into account the variability and uncertainties considered appropriate by the scientists following the guidance provided in the ICES SGMAS study group report.

4) The performance of the rules shall be evaluated both with respect to the perceived state of the stock and to the state of the underlying operating model population.

5) Evaluations shall show the robustness of the harvest rules in assuring stock recovery and maintaining stocks inside safe biological limits, considering a plausible range of scenarios.

The SGMOS group did not address mixed fisheries issues due to lack of time and data. SGMOS was also not able to consider implementation options due to lack of information and time. They also thought that implementation issues would probably be better addressed in a wider audience including the administration and stake holders.

A. Management Objectives

A.a Broad objectives

There are currently no specific management objectives for this stock. However, this stock is currently managed by TAC, which is (or should be) set conform the principles of the precautionary approach (i.e. to maintain the stock within the precautionary limits Bpa and Fpa).

A.b Operational Objectives

The long term target conservation reference point that was considered for Bay of Biscay sole was Fmax.

The choice for this target reference point is explained in the SGMOS report. *'… During the World Summit on Sustainable Development on Johannesburg (2nd to 4th September 2002) an international commitment was achieved to drive stocks to this level. Fishing mortality that keeps stocks at Bmsy level, Fmsy, can be estimated by Fmax (the fishing mortality rate that would produce the highest yield per recruit if adequate recruitment is maintained) or by F0.1 (a fishing mortality close to Fmax but at which the risks of depleting the stock are lower). At this fishing mortality levels yield will be stable, fishing costs will be lower and the risks of bringing the stock to levels were its dynamics are unknown will be lower'.*

B. Conformity of a HCR to the management strategy

Bay of Biscay sole is currently managed by TAC. The stock is caught in a fixed net sole fishery, by mixed demersal otter trawlers and mixed demersal beam trawlers. A TAC is not the most appropriate management tool in this case, especially to control the mixed demersal trawlers. The HCR simulations carried out were focused on F-based scenarios (if the biomass is lower than a trigger level, reduce F by X%, otherwise by Y%, until Fmax is reached). Fishing mortality should be reduced by effort measures rather than by TACs. The SGMOS group considered that '*an effort control system should be used to effectively reduce fishing mortality, which can be implemented through several actions including: direct control of fishing effort (e.g. reduce fishing activity by x days per month), decommissioning, technical measures like closed areas and/or periods, changes in gear selectivity, etc*.' However, the link between fishing mortality and effort is not clear and cannot be quantified at the moment. Consequently the group was not able to simulate the effect of possible effort measures on the fishing mortality. In this context, there is not enough knowledge to actually implement an effort based HCR.

C. HCR simulation parameterization

The simulation parameterization was summarized in Table 3.4 of the SGMOS report, and is given over below.

Simulations assumptions

Model	Parameter	model	bias	uncertainty	error dist	Source	Comments
Biological	mo					Sampling	
	wbars					Sampling	
	m					Assumption	
	R	Ockham		0.3		historical S-R	
Fishery	wbarc					Sampling	
	selectivity						Not considered
	spatial structure						Not considered
Observation	C					Sampling	
	discards						Low impact
	abundance						Not available
Assessment	N	XSA	+25%	0.15	lognormal	WGSSDS 05	
	F	XSA	-20%			WGSSDS 05	bias estimated from retrospective analysis
Implementation error	F multiplier					Assumption	

D Management measures

Management of Bay of Biscay sole is by TAC and technical measures. The minimum landing size is 24 cm and the minimum mesh size is 70 mm for trawls and 100 mm for fixed nets, when directed to sole. Since 2002, the minimum mesh size was increased to 100 mm for trawlers operating in those areas of the Bay of Biscay that fall under the hake recovery plan.

A TAC is not the most appropriate management tool for Bay of Biscay sole, especially to control the mixed demersal trawlers.

E The Robustness of the management strategy

The ICES Working Group on the Assessment of Southern Shelf Demersal Stocks (WGSSDS) caries out the assessment of Bay of Biscay sole and currently uses XSA to assess the stock. The catch at age matrix is mainly composed of the French fixed net fleet, and the assessment is tuned with three commercial trawler fleets and two surveys. The surveys were discontinued in 2002. The lack of survey data is a deficiency in the assessment, especially for estimating incoming recruitment. Retrospective analysis shows that F is underestimated in the terminal year (on average 20%) and therefore SSB is overestimated.

F Results

A summary of the scenarios tested by SGMOS is given in the text table below.

Summary table for the different scenario settings

Scenario	S/R	Constraint TAC change	F 2006	F 2007 onwards	Target	Error	Type
1	Ockham	/	F_{sq}	F_{sq}	F_{sq}	/	HCR
2	Ockham	/	TAC_{05}	TAC_{05}	Constant TAC	/	HCR
3	Ockham	/	$0.9F_{sq}$	F -10% every year	F_{max}	/	HCR
4	Ockham	/	$0.9F_{sq}$	F -10% every 3 years	F_{max}	/	HCR
5	Ockham	/	$0.9F_{sq}$	If SSB < B_{pa}: F -10% every year else if SSB > B_{pa}: F -3% every year	F_{max}	/	HCR
6	Ockham	/	$0.9F_{sq}$	If SSB < B_{pa}: F -10% every year else if SSB > B_{pa}: F -10% every 3 years	F_{max}	/	HCR
7	Ockham	/	$0.9F_{sq}$	If SSB < B_{pa}: F -10% every year else if SSB > B_{pa}: F -3% every year	F_{max}	25% bias in N	Sensitivity
8	Ockham	/	$0.9F_{sq}$	F -10% every year	F_{max}	5% implementation error	Robustness
9	Ockham	/	$0.9F_{sq}$	If SSB < B_{pa}: F -10% every year else if SSB > B_{pa}: F -3% every year	F_{max}	5% implementation error	Robustness

The inputs and the output figures for scenarios 3 are presented in this section, those for the other scenarios can be found in the Annex

Fishing at status quo fishing mortality (Scenario 1) would bring SSB further down into unknown population dynamics. Scenario 2 suggests that the stock can sustain landings at a level that is similar to the 2005 TAC. As catch rates increase over time, effort should decrease accordingly in order to keep the landings at the same level. Scenarios 3-6 simulate different HCR with Fmax as long term target. Scenario 5 might be the best option that finds a balance between biological and socioeconomic priorities under the condition that the F reductions corresponding to the HCR are actually realized. If a yearly reduction of 10% in F is realized, the stock will be above Bpa within 2-3 years from now. From then onwards less severe yearly reductions bring F to the target in ~20 years. Equilibrium SSB is around 30000 t. Note that the highest SSB values observed so far are around 20000 t. Although this scenario results in short term losses in yield compared to fishing at status quo, estimated yields would remain above the TAC05 of 4140 t. Long term yields are estimated to be around 5000 t. If an implementation error of 5% is assumed (Scenario 9), then there is a low probability that F will reach the Fmax target, and that the stock will increase into known population dynamics. With a yearly 10% reduction, F reaches Fmax by 2015 (Scenario 3). This scenario is in agreement with the commitments made on the World Summit of Johannesburg. Applying an implementation error of 5% (Scenario 8) fishing mortality is unlikely to reach the Fmax target. The sensitivity of the HCR to a bias in the population numbers is simulated in Scenario 7. A bias in population numbers of 25% corresponding to an underestimation in F of on average 20% results in a delay in achieving the targets of ~10 years.

H Conclusions

SGMOS concluded that although the current status of Bay of Biscay sole is not in such a way that the stock is at a high risk of collapsing, current SSB is estimated to be at a lower level and current fishing mortality is too high. Therefore measures to reduce fishing mortality and increase biomass in the short term are required. These should be complemented with long term management goals. Such a long term target point for this stock is Fmax. To get to Fmax different HCRs can be developed, hence the different scenarios to get to Fmax that are presented here are not exclusive. It is clear that the more severe the reductions in F are, the quicker Fmax is reached and vice versa. For Bay of Biscay sole stringent measures need to be taken in the short term to bring the stock back as quickly as possible into known population dynamics while in the longer term gradual but less severe F reductions towards Fmax might be more acceptable. Scenario 5 (10% F reduction if SSB < Bpa, 3% F reduction if SSB > Bpa, target Fmax) might be a possible HCR that fits to these conditions. It is obvious that scenario 5 considers that the F reductions are actually realized. Simulating an implementation error of 5% on this scenario shows that the Fmax target may not be reached. A re-evaluation of the HCR is therefore necessary within 3 years. If the presupposed goals are not met, new HCRs should be developed including stronger reductions in F. Beside implementation errors, the HCR is also sensitive to the bias in population number estimates. A bias in population numbers of 25% results in a delay in achieving the targets of ~10 years. The scenarios consider that fishing mortality can be reduced with according effort reductions. In the case of Bay of Biscay sole, the fixed net fleet is the major fishery. Conversely to the trawler fleets, regulating fishing mortality by direct effort limitations (e.g. by limiting the number of fishing days), is not as straightforward for the fixed net fleet. Other possibilities to regulate effort are regulating the number of vessels, adjusting mesh sizes, temporal and/or spatial closures, etc.

Finally, SGMOS proposed following management plan for Bay of Biscay sole.

For the HCR:

1) The fishing mortality is decrease until it reaches Fmax by:

10 % if SSB is below Bpa,

3 % if SSB is over Bpa

2) Assuming fishing mortality is proportional to fishing effort, the change in fishing effort must be defined according to the previous rule.

3) In addition, the TAC is set in accordance.

For the technical measures:

The implementation of the proposed HCR for sole in Bay of Biscay should imply that the present agreed technical measures should be maintained (minimum mesh and landing size) and likely strengthened.

H Additional information

The success of a management plan for Bay of Biscay sole was, according to SGMOS, conditional to:

Bias in N is estimated to be 25%: this bias must be consider for fishing mortality reduction conditional on an SSB level. Recruitment was simulated using an Ockham model. Parameters are based on a reduced time series geometric mean because an apparent change in recruitment regime since 1993 (CV set at .3) and the lowest observed SSB. If new observations invalidate these choices, the consequences in the management plan must be investigated.

The environmental conditions (swell periods) may cause a large increase in gillnets catchability (as observed in 2002 winter, see ICES, 2005) and generate a temporal difficulty for the implementation of the HCR.

Given bias, uncertainties in input parameters, possible implementation error in a predicted scenario for this stock, a 3 years control of its realisation is considered to be necessary. The HCR should be re-evaluated taking into account all these sources of uncertainty.

5.11.1 Testing harvest control rules for Western Horse Mackerel

Work is under development in response to the joint EU-Norway request concerning western horse mackerel:

“Advise on appropriate management systems including management strategies, objectives and ecosystem considerations for western horse mackerel.”

A management strategy for Western horse mackerel should include decisions on objectives such as sustainable utilisation and compatibility with the precautionary approach. Other much more specific objectives need to be agreed between scientists and managers taking into account relevant features pertaining to the Stock and Fishery.

Issues to be taken into account when considering a management strategy for western horse mackerel are the following:

- Horse mackerel is a spasmodic recruiter.
- At present, the strength of a year class cannot be confirmed before it is 5 years old, when it is fully recruited to the fishery.
- The only fishery-independent information available is an estimate of egg abundance made every third year.
- Fecundity is unknown.
- The fishery has expanded in recent years to take a large proportion of juvenile fish.
- There is a mismatch between the area of distribution of the stock and the TAC area.
- The western horse mackerel stock has declined since the early 1990s and the status of the North Sea stock is unknown, although the fishery in the latter area has expanded in recent years.
- The distribution of both stocks is contiguous (see Figure 1).

Given that horse mackerel is a spasmodic recruiter, a harvesting strategy could be designed to take advantage of large year classes if maximising yields was an objective in this fishery. However, if commercial catches are the only means of establishing the presence of a large year class, there is an intractable problem of distinguishing a large recruitment event from a targeting change by the fishery. The only way to establish the magnitude of recruitment at present is to develop a fishery-independent recruit index. Moreover, exploration of the IBTS data for North Sea horse mackerel has demonstrated catchability or other technical problems associated with estimating its abundance through bottom trawling by research vessels.

The only fishery-independent information is available from the triennial egg survey based on the Annual Egg Production Method. In the past, this application resulted in an estimate of SSB given an estimate of total fecundity that was also obtained during the survey. In recent years, horse mackerel have almost certainly been reclassified as indeterminate spawners, so total fecundity is unknown. Recent analytical assessments have used the triennial estimates of egg abundance as indices of SSB.

The WGMHSA (WG Rep 2004) stated that if a TAC control were to be used (covering all fishery areas), application of a TAC to the fishery should be mindful of the circumstances of the fisheries. In the first instance, managers would need to agree an appropriate trade-off between exploiting adults and juveniles, and also be mindful that the tolerance of a juvenile fishery will necessarily lower the overall yield. In the second instance, managers would need to ensure that catches are not misreported between adjoining areas in which the distribution of the juveniles of both the North Sea and western stocks is contiguous. Although we recognize this last point as a potential problem, investigation of the impact of the western horse mackerel fishery on the North Sea stock is considered to be beyond the scope of this study.

Harmonizing stock distribution areas with the TAC appears to be highly relevant if the stock is to be managed rationally. However, implementing such changes could be a long process, and the stock needs to be managed in the meantime. Therefore, the *Ad hoc* Study Group on long term advice (SGLTA) has recommended that a simple approach based on information on stock trends be used to deduce a TAC for the reduced area. Also, SGMAS suggested that for stocks where an assessment was not available, a low TAC could be adjusted slowly, based on changes in trend indicators. If a constant (unknown) fecundity of horse mackerel could be accepted scientifically, such a trend indicator could be based on egg abundance from the triennial egg survey.

5.11.2 Proposed approach

Management strategies appropriate for what is known about the dynamics of Western horse mackerel stock and fishery need to be tested by simulation. The simulation framework will take into account the main sources of uncertainty such as the ones related to observation and process error (see Appendix), estimation error and implementation uncertainty. Given time constraints we propose to undertake the simulation study in two phases. In the first phase, the following will be developed:

- Simulation framework coded in FORTRAN, detail presented in the Appendix. The assessment will be mimicked by introducing appropriate levels of uncertainty and bias.

Our first phase approach may pose problems at the time of assessing the merits of a particular strategy against management objectives expressed in absolute terms, i.e. attaining certain catch level over a period of time. However, the approach proposed was found appropriate to assess and to compare the performance of selected management strategies against each other in the case of the Thames herring (Roel et al.2004).

Kell et al. (2005, in press) point to a need to incorporate full assessment feedback in the framework. Therefore, in the second phase of this study we propose:

- Simulation framework as in previous point but performing an assessment in the predictions when required.
- Use of FLR (Fisheries Library in R) which would imply performing the assessment as above and, for the purpose of comparison, possibly other assessment models available in the framework.

5.11.3 Simulation testing

Operating model

This will be based on the parameters estimated in the last assessment. There is a scaling problem in the estimated numbers-at-age by the current assessment. The problem is likely to be solved if fecundity could be estimated, for example by introducing a Bayes-like approach to estimate fecundity incorporating a prior for fecundity based on existing information for other horse mackerel stocks and/or stocks with similar dynamics. The weight at age in the stock and the catch, the age-at-maturity and natural mortality were all based on historic data.

Fishery model

Both fisheries, the one that catches primarily juveniles and the one that catches adults, need to be regulated. Therefore, the behaviour of both fleets will be taken into account in the operating model.

Stock assessment

Estimates of egg abundance and SSB will be based on the numbers-at-age generated by the operating model and on estimates of fecundity.

Harvest control rule

Given the recent development of a fishery on juveniles (consisting of fish 1–3 years old) and the impact that fishing mortality on such ages is likely to have on the sustainability of the stock, separate harvest rules applying to the juvenile area and to the adult area need to be considered. In the absence of a recruitment index, the juvenile fishery can only be regulated by a fixed catch or by limiting effort. Effort control on a shoaling species such as horse mackerel would be difficult to implement successfully, so it may need to be combined with area closures. However, testing area closure approaches will require developing an operating model that takes spatial distribution into account or modelling availability, both beyond the scope of this study. Therefore, we only propose harvest rules that result in a TAC as a form of managing the fishery.

The WGMHSA (ICES 2003) examined the selectivity patterns in the juvenile and adult area fleets (Fig. 2) showing that the proportion of juveniles caught in the juvenile area is much larger compared to the adult area. Given this reality the TAC will be computed for two components: one applied in the juvenile area (referred to as $TAC_{j)}$ and the other to the adult area (TAC_{ad}).

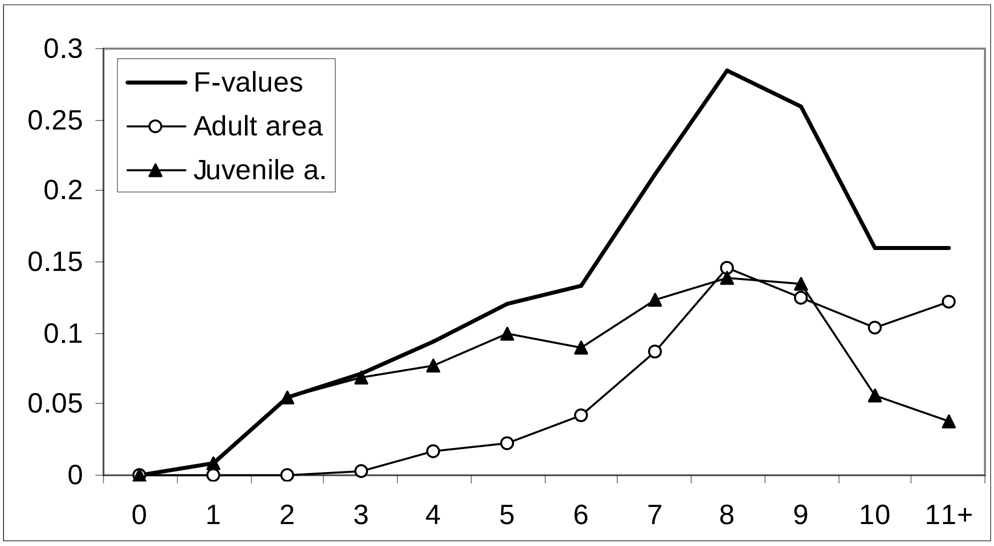

Figure 2. Fishing mortality patterns in the juvenile and adult areas.

Another question is whether an annual or rather a multi-annual TAC is more appropriate in this case. At present, the TAC is adjusted every year on the basis of the results from an analytical assessment performed with the SAD model. Conversely, an assessment could be provided every third year when the egg survey results become available, in which case a multi-annual three-year TAC could be considered. Some arguments in favour of multi-annual TACs for northeast Atlantic mackerel also apply to western horse mackerel:

- the assessment data, apart from catches in numbers at age, are restricted to one point estimate of the SSB every third year;
- the SSB data are noisy, the noise carrying over to the assessment of recent years' stock abundance;
- if variability in recruitment is not particularly great (extraordinary year classes are not taken into account) and there are no clear changes in weight and maturity over time, then those could also be arguments in favour of multi-annual TACs.

Implementation error model

We propose to model the mismatch between TAC area and the area where the stock's catch is taken as implementation error. Examination of trends in TAC overshoot suggests that, when a strong year class was present in the fishery, the EU TAC was largely exceeded as it was limiting the fishery. In recent years, as the strong 1982 year class has virtually disappeared from the fishery, total catches have been close to or slightly below the EU TAC, likely related to stock availability. For the purpose of this simulation testing exercise, the overshoot will be a function of the EU TAC, with random variation added (Figure 3).

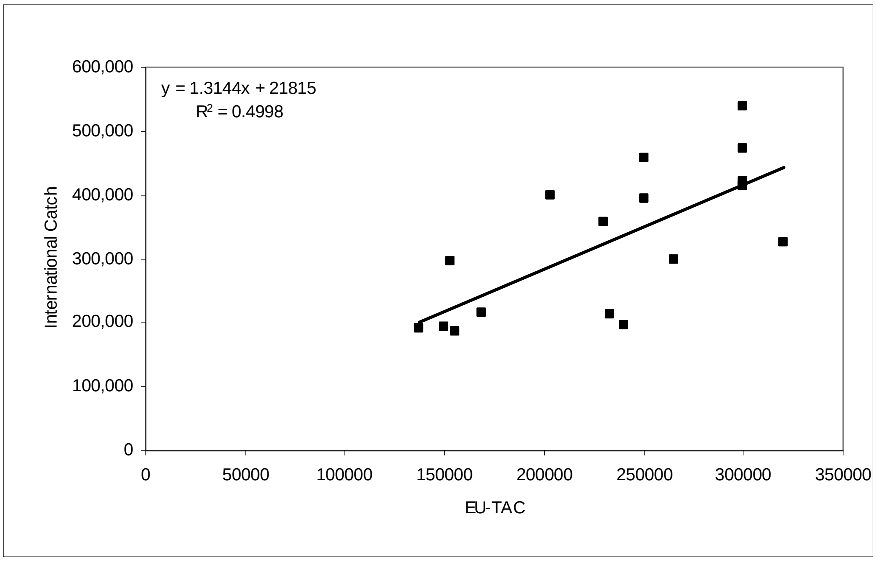

Figure 3: International catch against EU TAC (tons) for the period 1987 – 2003 and linear regression used to model the overshoot.

Performance statistics

The following performance statistics to be computed to provide managers and stakeholders with the tools to make an informed decision between the strategies presented:

Risk SSB<$B_{threshold}$: probability of the SSB falling at least once within the simulation period below one of the biomass reference points. $B_{threshold}$, equated to the biomass that produced the extraordinary 1982 year-class, should be kept consistent with the assessment results.

Mean catch: median value over 1000 simulations of the average of 20 years of annual catch.

End SSB: median values over 1000 simulations of the biomass at the end of the 20-year projection period.

Median interannual catch variability: median value over 1000 simulations of the average 20-year interannual catch variability (*ICV*):

$$ICV = \{\sum_{y=a}^{z} \text{abs}[(C_{y-1}-C_y)/C_{y-1}]\}/(z-a),$$

where *abs* denotes the absolute value, and *a* and z the first and last years in the projections, respectively.

Choice of simulation period

Given the spasmodic nature of recruitment, the simulation period needs to be sufficiently long on average for at least two major episodic events to be included. Managers may wish to consider how they want to make best use of an outstanding year class, so the simulation period should ideally see such a year class through until it has disappeared from the fishery. In practice, the simulation period should be fixed, and given that the assessment models 10 true ages, the simulation period was fixed to 20 years.

5.11.4 TAC Strategies Tested

Results from 500 simulations are presented for two types of three-year TAC strategies:

1) Only one TAC is set but in this case the TAC is computed as the sum of a fraction (β) of the juvenile biomass and a fraction (α) of the estimated SSB.

$$TAC,y = \beta\ Juvy + \alpha\ \ SSBy$$

Results are presented for two cases: a) the juveniles are estimated based on geometric mean recruitment for 1983 – 2002 (base case) and b) the juvenile component is computed as a proportion of an index of juvenile abundance with a CV assumed = 0.25.

2) The TAC is adjusted according to the trend in the last 3 egg surveys data:

$$TAC_y = TAC_{y-1}(f(slope))$$

The function of the slope (f(slope)) which, takes values between 0 and 1.4, is illustrated in Figure 4.

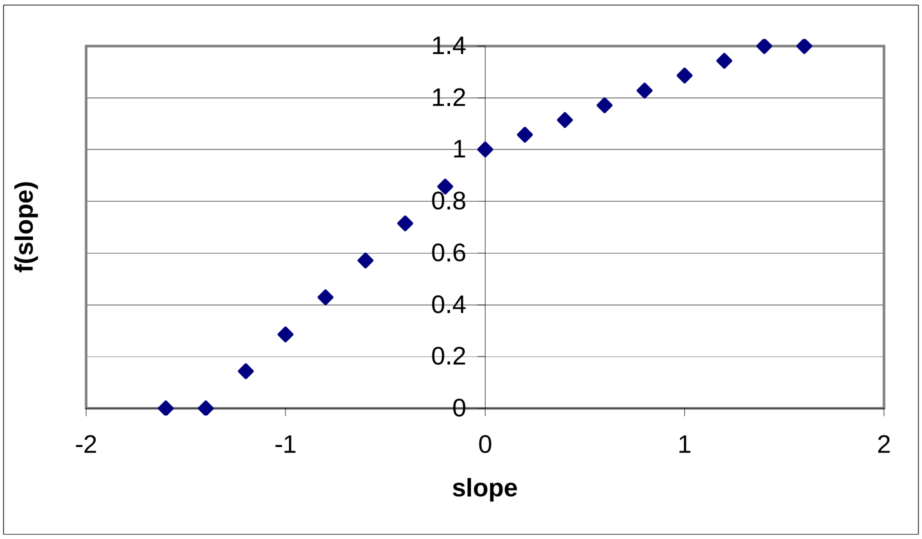

Figure4 Slope of the last 3 years egg data used to estimate the TAC_y.

This strategy caps the TAC upwards so that it cannot increase from one TAC year to the next by more than 40% but it can be decreased to zero. Results from this strategy are presented for a range of TACs in 2007.

It is important to test sensitivity of the HCRs proposed to the increasing fishing mortality taking place in the juvenile area. In the base case the TAC is split between the juvenile and adult areas on the basis of recent data. As a sensitivity test, results are also presented for a range of fractions (γ) of the TAC taken by the juvenile area fleet (0.3, 0.5 and 0.7).

The effects of overshooting the TAC were tested by modelling the historic overshoot.

5.11.5 Results and discussion

Preliminary results suggest that taking a larger component of the TAC in the juvenile area increases the risk for the stock. Also, if a juvenile index was available the risk associated with a higher TAC will increase at a slower rate compared to using the geometric mean to predict juvenile abundance. However, if the fishing mortality was relatively high in the juvenile area, then it would result in no advantage. The slope strategy is also sensitive to the fraction of the TAC taken by the juvenile area fleet.

Comparison between the constant proportion and the slope strategies suggests that the slope strategy is more conservative and results in less inter-annual catch variability than the constant proportion strategy. In the case of the constant proportion strategies there seems to be a trade-off between juvenile fraction in the TAC and inter-annual catch variability. This is because the scenarios compared have similar risks and similar median catch but the TACs are computed using different α values. Inter-annual catch variability increases when α increases.

Under the assumptions made in this study, overshoot of the TAC at levels similar to the ones seen in the recent past results in substantial increase in associated risk for a similar outcome in terms of catches. However, results in absolute terms are dependent on the biomass level which is uncertain.

What next?

Steps need to be taken towards completing the simulation testing and to incorporate stake holders in the review and consultation process. In brief, that would entail:

- Take into account the uncertainty in fecundity in the observation model;
- Incorporate the assessment process/uncertainty in the simulation framework;
- Broaden scientists’ participation in the study
- The work needs to be peer-reviewed, is the assessment WG the right forum for that?
- Results need to be presented to managers for feedback and to start another round of the process.

5.12 Sandeel in the North Sea

5.12.1 Background

Management of North Sea sandeels is particularly problematic due to the fishery being principally on the 1-group whilst there is no reliable assessment estimate of this year class at the time of the December council to assist TAC setting.

The total landings of sandeels from the North Sea were at a historic low level in 2003. Due to the scarcity of the 2002 year-class the strength of the 2003 year-class was particularly important to the state of the stock in 2004. For this reason the EU adopted the following ad hoc harvest control rule for the 2004 fishery for sandeel in the North Sea at the Council meeting in December 2003:

a) where STECF estimates the size of the 2003 year class of North Sea sandeel to be at or above 500 000 million individuals at age 0, no restrictions in kilowatt-days shall apply;
b) where STECF estimates the size of the 2003 year class of North Sea sandeel to be between 300 000 and 500 000 million individuals at age 0, the number of kilowatt-days shall not exceed the level in 2003 as calculated in total kilowatt-days;
c) where STECF estimates the size of the 2003 year class of North Sea sandeel to be below 300 000 million individuals at age 0, fishing with demersal trawl, seine or similar towed gears with a mesh size of less than 16mm shall be prohibited for the remaining of 2004.

The Council decided the year-class size thresholds. The limit of 300 000 million has only been reported three times in the period 1983-2002, indicating a very poor recruitment (ICES 2003). Year-class strengths of between 300 and 500 billion at age 0 have been reported in 5 of these same years. The average year-class strength for the 1983-2002 period was 712 000 million age 0.

In order to facilitate the estimation of the 2003 year-class an *ad hoc* WG (STECF, 2004) under STECF was established with the specific purpose to assessing the strength of the 2003 year class. The sandeel fishery in the North Sea is mainly Danish, and the necessary data for assessing year class strength is based on Danish data obtained from the commercial fishery. The basic assessment methodology was a regression of recruitment indices against XSA estimated figures for the corresponding 1-groups, which are the youngest fish caught in the beginning of the fishery season. From the CPUE of 1-group, the historical relation between CPUE and stock size of 1-groups, and an assumption of mortality of 0-groups the observed 1-group CPUE index was translated into the recruitment strength of 0. The ad hoc WG concluded that a reasonable precision of the recruitment could be obtained from the fishery using data for the period including April (10-30% of the annual catches).

The ad hoc WG provided a final estimate of the size of the 2003 year class as well as an appendix summarising the 2004 sampling regime in May 2004. The available CPUE data up to week 17 gave an estimate of more than 600 billion individuals at age 0 of the 2003 year class and concluded that, according to the HCR set up by the Commission, there should be no restrictions on effort for the 2004 fishery. This was then the advice given by the WG to STECF. This recommendation was then evaluated by STECF and the group concluded that when year-classes are from average to weak, the ability of the method used to classify year-class strength is highly unreliable. STECF recommended that in keeping with the precautionary approach, fishing effort for North Sea sandeel in 2004 be restricted to a maximum level no greater than that deployed in the fishery for North Sea sandeel in 2003 (level b in the HCR).

As a response to the critique from STCF the precision of the method was improved during a new ad hoc WG in Feb 2005 (STECF, 2005a). This improvement was obtained simply by excluding very strong year-classes from the stock-number - CPUE regression.

The fishery in 2005 had an extremely low CPUE in the beginning of the season and both the *ad hoc* WG and STCEF concluded that the fishery should be closed for the rest of 2005 (level c in the HCR).

5.12.2 Evaluation of the 2004-2005 management setup.

It is not possible yet to fully evaluate whether the methodology has estimated the recruitment level appropriately. The latest estimate of recruitment (ICES 2005) suggests 0-group numbers for 2003 and 2004 at respectively 345 and 324 billions. These numbers relate to recruitment estimates from the real time monitoring at 660 and 150 billions.

The very poor mach for the estimates of the 2003 year-class strength is partly due to the use of the old and now changed relation between CPUE and stock size which gave a too optimistic estimate of the year-class strength. In addition, a new configuration of the VPA used in 2005 downscaled the strength of the 2003 year-class. As the regression used for estimating the year-class strength is based on the stock numbers estimated by the 2004 assessment, the numbers from the assessment and real-time monitoring are not fully comparable.

The CPUE in 2005 of 1-groups doubled after the monitoring period was over which indicates that sandeel became available to the fishery much later in 2005 compared to previous years. The CPUE for the whole first half-year of 2005 was later used in tuning of the VPA, which resulted in a 1-group estimate twice as big as the real-time estimate.

In both the 2004 and 2005 data sampling and compilation, and the advising from STECF were finalized mid May, which was in accordance with the agreed procedure. The implementation of the regulation was however delayed considerable as the formulation and agreement of the law text among the EU-member states took additional 4-6 weeks after the advice was given. As effect, the regulation came in force after the main fishing season was over.

5.12.3 Stochastic simulation of management strategies

An *ad hoc* STECF study group (STECF 2005b) met November 2005 to evaluate a range of potential HCRs through stochastic simulation. A summary of the methodology and results are presented below.

The SMS model (see software Section 8.2.8 for details) was used as simulation tool. The projection framework follows the STPR3 approach applied by several simulation studies within ICES, however the approach has been extended to handle the simulation of real time monitoring, escapement strategies (leaving a minimum SSB to spawn after the fishery has taken place) and trigger values based on stock numbers (as used in the current sandeel HCR). The HCR simulation makes use of half-annual time steps, which is applied for the sandeel assessment due to the highly seasonal fishery. Essentially the HCR is applied to “observed” or “perceived” stock numbers and translated into a TAC, which is subsequently taken from the true population. Uncertainty enters the system as observation noise, recruitment variation and implementation error. Specific uncertainties were attached to stock numbers estimated from ICES assessment and to stock numbers estimated from real time monitoring.

Within the HCR evaluation model it was assumed that the fishery in the part year before a management decision is reached operates with a fixed F of 0.1. Historical performance of the in-year estimation of the 1-group indicates a CV of 35%, whilst the observation uncertainty from the assessment of other age groups is assumed to be 25%. Recruitment was generated from a hockey-stick stock-recruit relationship parameterized from historical assessments and a fixed inflexion point of 430kt (Blim).

A range of HCRs were evaluated, including the Commission’s current HCR as well as use of a fixed TAC or F and HCRs based escapement strategies.

The use of a fixed TAC as a management tool would do away with the need for the in-year estimation of the 1-group. The simulation results show that in the long term a TAC of around 200-300kt would ensure that SSB would be below Blim with a <5% probability. The exact long term TAC depends on the assumption on the maximum F (Fcap) the fleet capacity can inflict. With an Fcap=0.5 the TAC could be set at 300kt, with Fcap the TAC should be reduced to 200kt.

Even though a fixed F strategy is impossible to implement I real life, the simulation results showed that a fixed F=0.4 would ensure that SSB would be below Blim with a <5% probability and a median catch at 400kt.

The in-year estimation of the 1-group permits the fishery to take, around 500kt (long term average) whilst complying with the SSB<Blim<5% condition. The HCR currently employed by the Commission implies frequent closure of the fishery immediately after the in-year estimation. Another HCR, using Bpa (600kt) as a target SSB for the following year (escapement strategy) results in a lower probability of closure of the fishery whilst still complying with the SSB<Blim< 5% condition.

HCR performance is highly dependent upon the recruitment scenario assumed. A long-term shift to a lower productivity regime would prevent the achievement of the current B_{lim} criterion, although in that situation a revision of the biological reference points may be desirable.

All the results depend very much on the assumption of the existence of Fcap and thereby an assumption of a clear relation between capacity, effort and F. Analysis of historical fisheries data showed that this is probably not the case for the sandeel fishery.

5.13 Anchovy in the Bay of Biscay

5.14 Introduction

Anchovy is a short lived species with catches and population mostly composed of one year old individuals (Figure 5.14.1). Two fleets operate on anchovy in the Bay of Biscay: the Spanish purse seine fleet (mainly in spring) and the French fleet composed of purse seiners and pelagic trawlers (basically operating during the second half of the year and winter). These fleets produce catches all year long with a peak in spring and summer-autumn. Anchovy is a very valuable resource for the economy of these fleets, with annual catches of about 29,000 t since 1990 and high prices per kilogramme (ICES 2006). The catches vary according to fluctuation in recruitment.

5.14.1 Monitoring.

The major weakness of the scientific advice has always been the impossibility of forecasting the population for the year of the advice due to the absence of a valid recruitment index. Direct monitoring of the population (Figure 5.14.2) has consisted on evaluation of the spawning biomass by acoustic and DEPM surveys in the interim year, but the contribution of those adults to the spawning of the next year (survivors) is very low compared to the contribution expected to arise from the recruits to adult population in the next year (1 year old anchovies). The lack of knowledge of the recruitment population for the year of the advice has been tried to be covered by a) understanding the influence of environmental oceanographic conditions on recruitment success (Borja et al. 1988, Allain et al. 2001) and b) setting up recruitment surveys in September-October to estimate the recruitment (0 group) (JUVENA surveys, Boyra et al 2005) and to study its ecology (JUVAGA surveys, Petitgas et al. 2005). However, the available environmental recruitment indices have a poor predictive power to improve advice (ICES 2006, De oliveira et al 2005). Moreover, the recruitment surveys are still under development with a too short series of estimations as to become operative (ICES 2006).

5.14.2 Advice to managers.

ICES advice a Blim at 21 000 t and a Bpa at 33,000 t.

In the absence of any valid recruitment index, since 2003 STECF and ICES recommend to the EC a management regime consisting of an initial low (precautionary) annual TAC, which should be revised in the middle of the year, after the survey estimate of spawning biomass becomes available.

An *ad hoc* STECF meeting took place in Brussels from 11th to 14th July 2005 to assess the stock of anchovy according to new available information (mainly spring surveys) and to give advice on management measures to be considered in the near future. Besides recommending the closure of the fishery until reliable estimates of the 2006 SSB become available (based on the results from the spring 2006 surveys), the STECF suggested that alternative management measures were required to maintain the longer term viability of the stock, which would need to be scientifically evaluated prior to adoption.

In autumn 2005, ICES recommended a revision of the current management regime to take into account the fluctuations in recruitment. This may be achieved by developing a decision rule, which directly uses the information from the May surveys or, possibly in the future, bases decision on an assessment taking into consideration the results of the September-October juvenile surveys. Additional measures like area restrictions may also be considered. Such a revision should be undertaken through dialogue between ICES and managers. In recent years, there has been considerable development of tools for evaluating management strategies and accordingly, consideration of the management regime is timely.

5.14.3 Management

The anchovy stock has been managed by annual TACs which has been set at a fixed level independently of the advice (from 1979 to 2005) at about 30,000-33,000 t.

In 2005, the evidence from surveys that the stock reached its historical minimum - well below Blim - led managers to close the fishery for the second half of the year.

Despite the recommendations of ICES and STECF of keeping the fishery closed until evaluation of the SSB in 2006, in December 2005 managers decided to reopen the fishery from March 2006 and to set a low TAC of 5000 t.

For June 2006 the STECF has anticipated and ad hoc sub-group meeting to obtain the opinion of ICES advice by correspondence and it mentioned a possible meeting for HCR reflection.

The current situation demands the adoption of a management strategy by managers which clarifies the objectives of the management and the HCR which should be followed to comply with it. However, despite the advances in the understanding of the dynamics of the stock and the capacity in evaluating by simulation the results of different HCR, so far a dialogue between scientists, managers and stakeholders leading to the adoption of a management strategy is not foreseen.

5.14.4 Recent advances in evaluation of management strategies:

During the last year a couple of simulation exercises for testing HCR for the Bay of Biscay anchovy stock have been presented in the ICES Working Group on the Assessment of Mackerel, Horse mackerel, Sardine and Anchovy (WGAMHSA - ICES 2006). The first one is based on Leslie’s matrices (Petitgas 2005) and the second one is an extension of the work started in 2003 based on the biomass-based dynamic model (Ibaibarriaga 2005). Both approaches consider new management measures such as the closure of a certain area or the temporal closure along different periods in addition to TAC.

A. Management Objectives

There are no explicit management objectives for this stock.

The present closure of the fishery aims at protecting the remaining stock until a strong year class recruits to the stock. The implicit objective is to bring the stock above Blim as soon as possible.

> ICES in 2005 mentions that "in the context of the precautionary approach, there will be a need to ensure that the recruitment is not impaired by management actions. In practice, this means that a Blim will be necessary."

The reopening of the fishery implies the sustainability of an operative fishery where situations of closure are avoided as much as possible. This should imply a management strategy preventing as much as possible declining below Blim, and trying to avoid the closure of the fishery.

B. Conformity of a HCR to the management strategy

No HCR has been adopted for the management of this anchovy stock.

Among the harvest control rules considered for revision in these years we list the following ones:

- Fixed TAC of 33 000 tones without any closure or change in time.
- Fixed level TAC (unchanged across years) or annually changing TACs
- Annual TAC kept constant the whole year or Revised TAC once estimates from the spring surveys are available: - Revise the TAC at mid-year according to the definition of the HCR and the most recent biomass estimates from the surveys in May.
- Close an area for a certain period of the year in order to protect a certain fraction of the population. Only the part of the population outside the box would be exploitable at each period. This requires assuming which fractions of each age class of the population are within the area during each period. In some cases the efficiency of closing the fishery only during the spawning season was considered, in others closing the same area over the whole year can be considered, etc.
- Close the fishery when the biomass estimate from the spring survey is below B_{lim}. Note that this follows naturally from the definition of the TAC when the TAC is revised at mid-year.
- Cap the TAC at certain value: This is a ceiling value for the TAC which satisfies the needs of captures for the current fleets and therefore TACs above that value are not set.

The ICES working group where the HCR has been preliminary tested (ICES 2006) considers that it is not the role of the WG to propose a concrete HCR. The WG recommends that further discussion and work between managers, stake holders and scientists is promoted to develop appropriate management strategies for the Bay of Biscay anchovy stock. ACFM supported that view indicating that a revision of the HCR should be done through a dialogue between ICES and managers.

C. HCR simulation parameterization

From here onwards only the parameterization performed by Ibaibarraiga et al. (WD 2005) is presented, given its consistency with the assessment model of this population.

C.a Biological operating model

The population dynamics was based on the biomass based model used in the WGMHSA (2004).

The model considers three periods: the first one from the 1st January to the 15th May, when the peak of the spawning and both DEPM (Daily Egg Production Method) and acoustic surveys take place. The second periods goes from the 15th May to mid-year, when the implementation of a revised management strategy based on the results from the surveys could start. The last period is from the 1st of July to the end of the year.

In addition, population is structured in two age classes: age1 and age2+. The basic equation describing the dynamics of each age group in each period from time t_0 to time t_1 is given by:

$$B_{t_1} = B_{t_0} e^{-g(t_1 - t_0)} \quad (1)$$

where B_t denotes biomass at time t and g is a constant parameter accounting for growth G, and natural mortality M, annual rates ($g = M - G = 0.68$). Catch is assumed to be taken instantaneously in the middle of each of the periods.

Initial states (recruitment and biomass at age 2+ at the beginning of the first year of simulations) of the anchovy population were taken from the recruitment and biomass at the beginning of year 2005 resulting from the biomass model in STECF 2005. The initial TAC was taken as 1200 tones, the total catches taken this year until the fishery was closed.

C.a.a Selection of Stock / Recruitment relationship.

Data on the state of stock is available from 1987 to 2004,

The recruitment at age 1 entering the population every year was randomly sampled from the Ricker stock-recruitment model

$$\mathrm{R}_{\mathrm{y+1}} \sim \mathrm{N}\,(\mathrm{mean} = \hat{\beta}_0\ \mathrm{SSB_y}\ e^{-\hat{\beta}_1 \mathrm{SSB_y}}, \mathrm{var} = \hat{\sigma}^2) \quad (2)$$

where $\hat{\beta}_0$, $\hat{\beta}_0$ are the fitted coefficients and $\hat{\sigma}^2$ is the residual variance from fitting the model to 1987-2005 recruitment at age 1 and total biomass resulting from the biomass model in STECF 2005. See Figure 5.14.3.

C.a.b Natural mortality and growth

Natural mortality and growth are merged into a single parameter G ($g = M - G = 0.68$) equal for all ages.

C.a.c Maturity;

Maturity is fully achieved when they are 1 years old.

C.a.d Other issues;

The closure area considered enclosed the French coast and the river plume of the Garonne. The proportions for each age group considered to be within the area for each period are given in the following table:

	1 January - 30 June	1 July – 31 December
Age 1	75 %	20 %
Age 2+	15 %	5 %

These are guessed values according to results of surveys but they are not actual estimates and therefore are partly subjective formulating a static picture of a dynamic process. For a more defensible evaluation of their effects actual estimates of the fractions occurring in that area should be considered. This is probably feasible for the second quarter of the year when surveys have taken place for many years.

C.b The fishery

The fishery is just modelled as total harvest (catch in tonnes) without any selectivity modelling. Catches are taken from the available population to the fishery regardless their age. No age 0 is available according to the negligible catches on this age.

All the TAC is taken unless the population does not support, in which case a maximum proportion of the available population is taken. The maximum exploitable fraction of the population allowed to be taken was 0.8 (assumed value).

The fraction of the TAC taken in each period is assumed to be the average fraction according to the historical series.

C.c Representation of the knowledge and decision process in the simulation

C.c.a Observation error on biological parameters

Observation error on growth and maturity (***g*** parameter) is not included so far.

C.c.b Assessment error

The survey biomass estimates are assumed to be log-normally distributed with mean the true biomass and certain given coefficient of variation. In the analysis, the coefficient of variation of the spring survey which gives an index of spawning biomass was assumed to be 25%. Although this a parameter the simulation can play with. When two surveys would become available (as it is the case for this anchovy) a combination of both surveys (by some predefined procedure) would be required in order to obtain the revised TAC at the middle of the year and provide the survivors for next year. This definition is not explored so far, although work is in progress elsewhere (FISBOAT project).

For the definition of recruitment: Similar observation errors are assumed for any recruitment index in case of being included in the simulation (coming either from surveys or from environmental indices). When no recruitment survey is expected then average recruitment is assumed (this is also a value with which we can play with).

C.c.c Advice and decision making.

- Update the TAC every year as a proportion γ' of the spawning stock biomass estimate $S\hat{S}B$ for that year as illustrated in Figure 2:

$$TAC = \gamma' \, S\hat{S}B = \begin{cases} 0 & \text{if } S\hat{S}B \le B_{\lim} \\ \gamma \dfrac{S\hat{S}B - B_{\lim}}{B_{pa} - B_{\lim}} S\hat{S}B & \text{if } B_{pa} \le S\hat{S}B \le B_{\lim} \\ \gamma \, S\hat{S}B & \text{if } S\hat{S}B \ge B_{pa} \end{cases}$$

(A)

$S\hat{S}B$ is the sum of the recruitment entering the population and the projection forward from the previous year biomass estimate taking into account growth and mortality. In case a survey on recruitment is conducted the recruitment estimate at the beginning of the year is sampled from the error distribution of the survey assumed to be log-normally distributed with mean given by true population recruitment and certain given coefficient of variation. Otherwise, a certain recruitment scenario has to be assumed.

Each advise correspond to Bpa frame of advise, with a harvest γ' or a fixed TAC and a monitoring frame of the population of SSB and recruitment indices, for which an advice in terms of the corresponding TAC (capped or not to a ceiling value), the possibility for its revision (if any) within the year, the conditions for closing the fishery (if any), and the closure or not of an area for a given period of the year.

D Management measures and implementation

Management measures correspond with the advice given and the implementation is considered to be efficient and timely made.

E The robustness of the management evaluation

No sensitivity to the assumptions on the operative modelling (stock recruitment, fixed g parameter), observation error model (different CV of surveys) or to deficiencies in the implementation error have been so far assessed.

F Results

A full combination of the different features defining each possible HCR have not been fully analysed so far, however as an example we present table 5.9.1 where the performance of different HCR for a common harvest rate γ' of 0.5 is presented. There, it is evident that the inclusion of a recruitment survey with a CV of 25% halves the probabilities of falling below Blim in 20 years ahead to about 0.05-0.06.

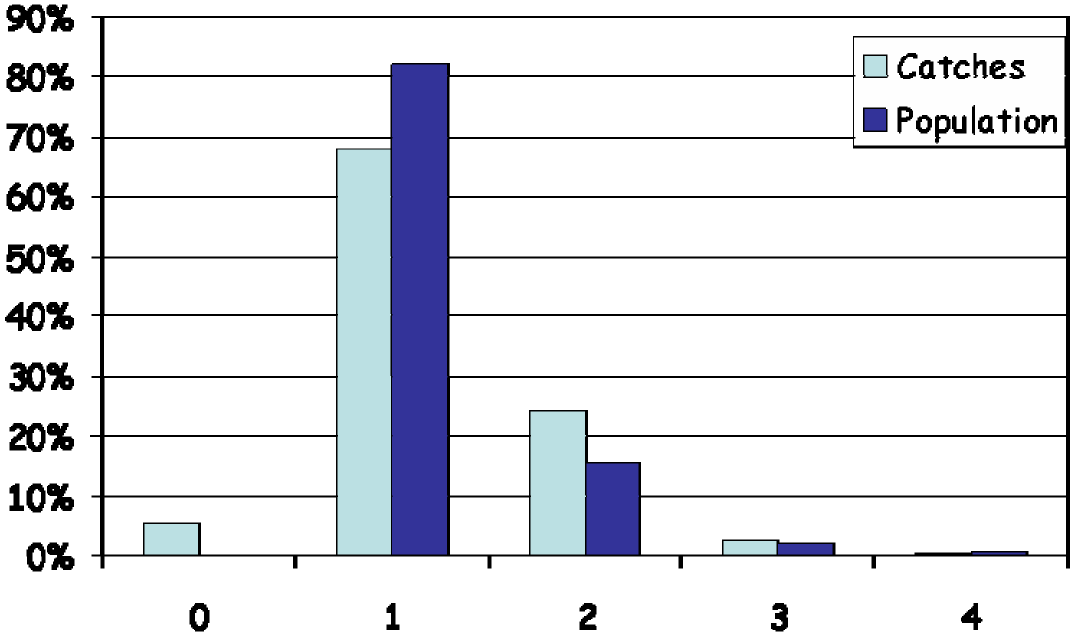

Figure 5.14.1 Average Age composition the annual catches of anchovy and of the population at the spawning time.

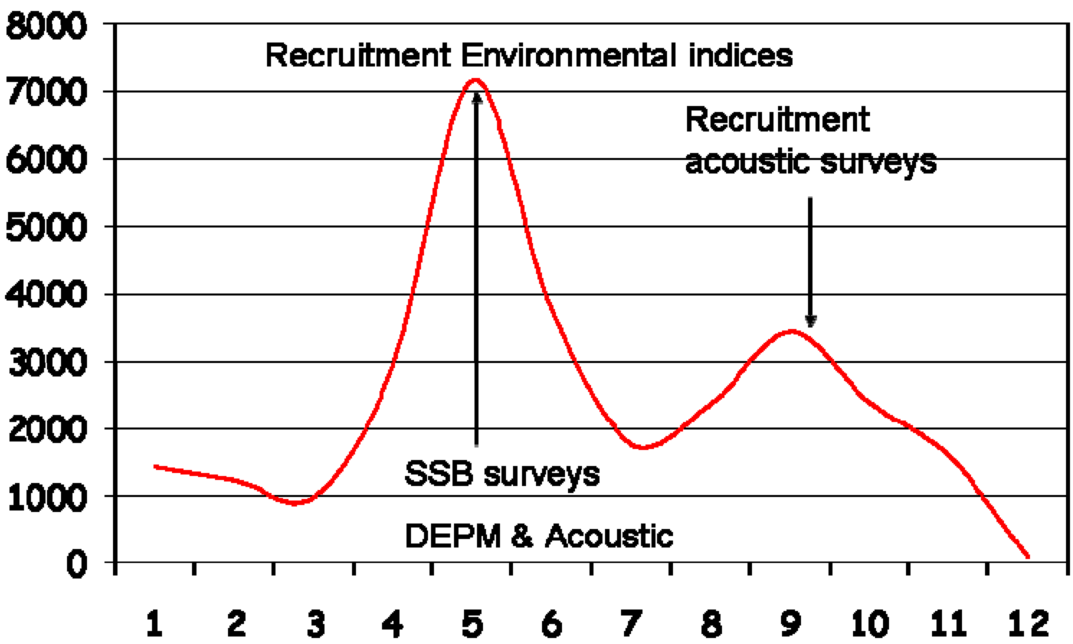

Figure 5.14.2 Average monthly landings of anchovy and direct monitoring of the population (and of the environment which may affect recruitment).

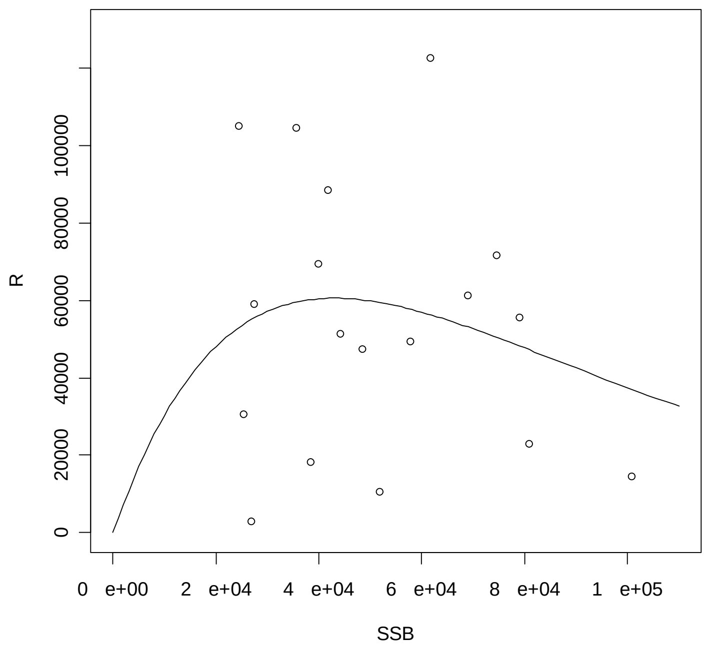

Figure 5.14.3: Ricker model fitted to the stock-recruitment series of anchovy from 1987 to 2005

Table 5.14.1: Performing statistics for different harvest control rules for anchovy with $\gamma = 0.5$ and a TAC no capped.

HCR	Management measures						SSB			Catch			TAC new			TAC rev			P(B<Blim)	P(B<Bpa)	P(C=0)
	fixed TAC	survey rec	box	revised	TACcap	closure	low	median	up	low	median	up	low	median	up	low	median	up			
1	yes	no	no	no	no	no	1682	44476	100592	8931	33000	33000	33000	33000	33000	33000	33000	33000	0.192	0.339	0.000
2	yes	no	no	no	no	yes	1666	44578	100027	8849	33000	33000	33000	33000	33000	33000	33000	33000	0.195	0.342	0.000
3	no	no	no	no	no	yes	6066	51600	106552	7795	23926	40621	18975	24538	41454	18975	24538	41454	0.116	0.243	0.000
4	no	no	1st sem	no	no	yes	7849	51410	106186	6977	23888	40421	19247	24481	41166	19247	24481	41166	0.111	0.240	0.000
5	no	no	2nd sem	no	no	yes	6459	51944	107193	7919	23802	40119	19112	24555	41152	19112	24555	41152	0.112	0.239	0.000
6	no	no	all year	no	no	yes	7615	52012	105967	7256	23829	40271	19414	24584	41307	19414	24584	41307	0.113	0.241	0.000
7	no	yes	no	no	no	yes	15648	51297	98570	0	25754	56990	0	25779	57176	0	25779	57176	0.058	0.195	0.061
8	no	yes	1st sem	no	no	yes	15932	51960	98096	0	26211	56870	0	26246	57009	0	26246	57009	0.056	0.196	0.060
9	no	yes	2nd sem	no	no	yes	16223	51722	98861	0	25961	56917	0	26028	57782	0	26028	57782	0.054	0.193	0.058
10	no	yes	all year	no	no	yes	15956	51801	99123	0	26153	56692	0	26205	57656	0	26205	57656	0.055	0.193	0.057
11	no	no	no	yes	no	yes	7203	49702	103495	8077	24294	58943	19816	24872	31104	0	24296	61539	0.123	0.259	0.000
12	no	no	1st sem	yes	no	yes	8213	50115	104316	7792	24447	59750	20032	24890	31437	0	24454	62013	0.122	0.257	0.000
13	no	no	2nd sem	yes	no	yes	7612	50324	104281	8091	24348	55563	19893	24893	32509	0	24370	60672	0.118	0.257	0.000
14	no	no	all year	yes	no	yes	8134	49543	103798	7733	24356	54847	20019	24912	32712	0	24407	60127	0.120	0.259	0.000
15	no	yes	no	yes	no	yes	14456	51657	98974	0	25219	57611	0	26029	56869	0	25263	59113	0.062	0.196	0.037
16	no	yes	1st sem	yes	no	yes	15317	51731	99776	0	25370	58529	0	25920	56936	0	25417	59640	0.062	0.198	0.034
17	no	yes	2nd sem	yes	no	yes	15479	52127	99747	0	25454	56260	0	26042	57308	0	25603	59423	0.059	0.194	0.034
18	no	yes	all year	yes	no	yes	14976	51828	99863	0	25206	56472	0	26094	57718	0	25401	59207	0.061	0.197	0.035

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

Some of the specific issues that refer to management measures are discussed below. The different aspects are addressed at varying levels of detail and additional issues may 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 in most cases apply to landings and not to total removals. They are output measures intended to control fishing mortality. Quotas are widely used for the management of stocks and their popularity lies in the fact that they are easy to implement for managers and can be negotiated between stakeholders. Nevertheless they are experienced as more appropriate for single-species fisheries, than they are for mixed fisheries.

A major drawback of quota regulations is that they control the landings but not the catches. This may result in discarding, high-grading, misreporting and unreported landings. These are undesired practices and are difficult to quantify. This is especially true for mixed fisheries where these practices often occur to postpone quota-exhaustion, or when the quotas for some of the species are fished out.

6.2 Effort regulations

Effort regulations are input measures to the fishery with the primary purpose to control fishing mortality. However, there are only few examples of stocks, assessed by ICES, where a clear relationship between effort and fishing mortality can be demonstrated. Since fishing mortality is not only determined by the effort exerted but also by the catchability of the fish, effort regulations are only expected to work when there is also sufficient control over catchability. If this is not the case effort regulations are less relevant, e.g. for shoaling pelagic species.

A number of factors can affect the catchability such as the behavior of the species (example in longline fishery for cod in Faeroes waters), the behavior of the fleet (change in fishing grounds, change in directivity to other stocks) and creep (improving efficiency of the gear, navigation and knowledge).

So in order to make effort restrictions work well, additional measures may be required to control fishing mortality. A few examples are: the use of effort measures in combination with species quota in order to avoid a change effort direction to other species; the allocation of effort distribution over periods of the year and/or spatial allocation preventing redirection of effort to specific aggregations (spawning areas). In addition it is necessary to specify carefully the technical features of the gears which affect efficiency and selectivity of the gear.

Additional quota type measures may also be needed for other purposes such as to maintain historical or agreed distribution of the resource between different stakeholders.

It should also be noted that the effect of effort measures alone are difficult to predict if it not known in advance which fisheries will be affected by the measure. This makes it more obvious to accompany effort measures with additional measures with the intention to restrict the directivity of the effort.

Management through effort control creates different (additional) needs with regard to monitoring and enforcement of the fishery. A clear definition is required of the units in which effective effort is expressed. The parameters which affect fishing efficiency, such as engine power, vessel tonnage, soaking time and length of net in passive gears and others, need to be taken into account in defining these units. Also it should be taken into account that efficiency will vary between different fleets (gears) participating in the fishery and conversion factors for catch and effort between different types of fleets may be required.

It is be noted that different ways of implementing effort regulations (days at sea or vessel licenses) may have different economic implications.

6.3 Vessel licensing

Restrictions of the number of vessels, size and category by licence, makes a defined upper limit to the maximum effort that can be exerted worldwide, licensing has been a major tool of fisheries management, in many countries. A special form of restriction of the capacity is decommissioning, where vessels will be taken out of the fishery. An example of capacity regulation is the MAGPs (Multi-Annual Guidance Programmes) of EU, with the stated aim of bringing fishing capacity more into line with available resources.

Measures to reduce capacity are often counterbalanced by technical innovation improving the efficiency of the vessels. For example a number of decommission programs have been introduced in the ICES area to limit capacity, but the effect has in some cases been reduced due to reinvestment of the financial compensation in more efficient vessels. However, nominal effort has been reduced in many countries due to decommission programmes.

6.4 Gear regulations

The purposes of gear regulations 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.

Gear regulations 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.

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.

Knowledge requirements. Evaluating gear regulations 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.

Effectiveness of implementation. It is important to consider the degree of compliance that will be or has been achieved during the evaluation period, in order to more accurately attribute effects to their causes. Lack of compliance may be driven by competing or conflicting objectives (e.g.: socio-economic or 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.

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

6.5 Seasonal and area closures

Management actions applying seasonal and area closures to fishery activities may be of a temporary nature or may be permanent. In either case, their application can be spatial or temporal, or in combination. While gaining increasing attention as an additional management measure in terms of both marine fish populations and, in the case of area closures, marine ecosystems, knowledge regarding the degree to which these approaches are effected in reducing fishing mortality or increasing population size is still accumulating.

Seasonal and area closures may be applied for a variety of purposes; including to protect components of a stock, such as juveniles, or prime reproductive individuals; to protect key biological features such as spawning or fish aggregations; or to protect habitat that is considered important. In this context, the size of the closed area or the duration of the closed period relative to the behaviour of the stock is an important consideration. We know from existing studies that closed areas need to be large to have a positive impact on commercial fish stocks. It also has to be taken into account that changes in biology (age composition, migration patterns etc.) can have a significant effect on the success of area and season closures.

A number of issues related to evaluating these types of management actions should be noted. The following list should be augmented as necessary 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. In addition to effects on commercial species, there may be ecological effects of closed areas that can in turn influence growth and survival of fish populations.

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.

Evaluation in management strategies. The evaluation of closed area or season controls in management strategies through simulation may require more detailed modelling of spatial and seasonal aspects of the biology of fish stocks than would normally required in the evaluation of harvest control rules.

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 or area / seasonal restrictions 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.

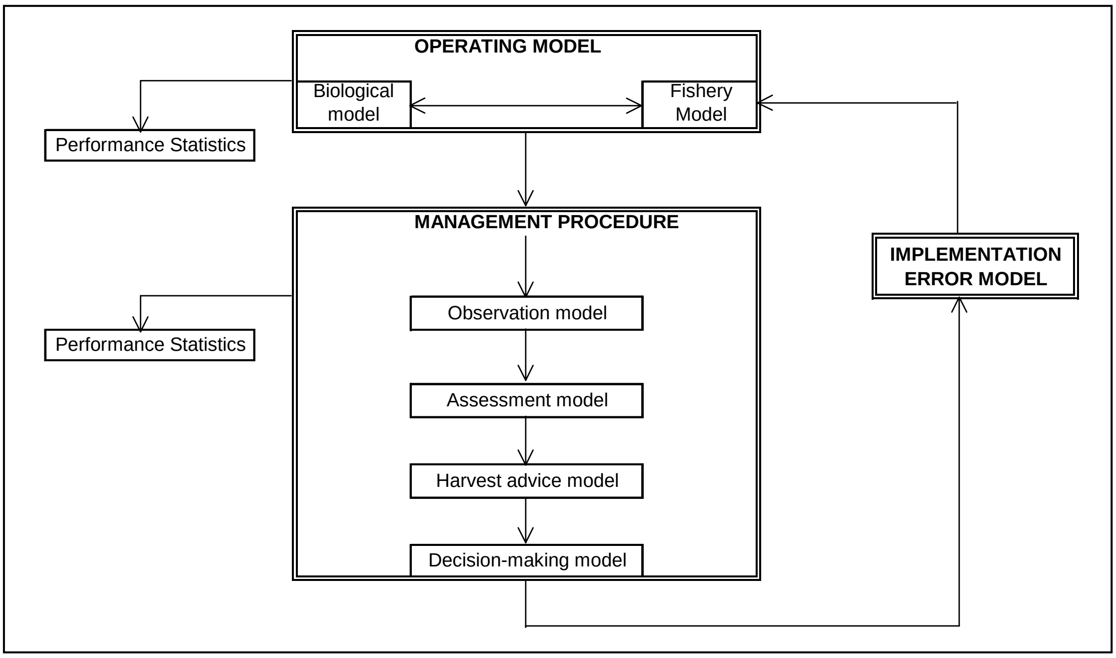

Figure 7.1. Conceptual framework for the evaluation of management procedures, recovery plans and harvest control rules.

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 (i.e. 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 be 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:

1) 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 mechanism that produce errors and biases.

2) 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 realized 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.

The problem of validation of algorithms, as opposed to management procedures and HCRs, was discussed. One possibility is to have an algorithm section of the ICES Journal to which algorithms could be submitted and peer reviewed, this idea will be discussed with the editorial board.

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.

7.7 The use of fisher interview data

The use of fisher interview (field survey) data has been extensively discussed in Section 2.3 of the report of EU project TECTAC (2005). This report contains a large number of references on this and related topics. The TECTAC applies interview data in connection with the modelling of fisher's behaviour; by the RUM model (Random Utility Model). The basic input data for estimation of parameters in the RUM, come from log books. The logbook data can be combined with interview data, either as independent variables or as independent data to test the RUM model.

So-called "anecdotal data" are thus considered an attribute of a choice, which is a factor that determines which choice a fisher makes depending on the fisher's expected catch with the given choice. How the RUM can be incorporated in a fisheries simulation model is also discussed in the TECTAC project. TEMAS is an example of a fisheries management evaluation frame incorporating the RUM (see Section 3.1 in the TECTAC report)

The present group does not possess experience in the use of interview data in conjunction with the RUM (or any other model). A selection of references related to fisheries applications of the RUM and other behaviour models is given in Section 12.2 below. For more information on RUM and the use of interview data, see the TECTAC report.

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	DIFRES,	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,	2006
FPRESS 1.0	Medium term HCR	N	Y	In progress	Y	Y	R	FSS (Ireland)	Aug.2005
TEMAS	Medium term HCR/Tecn. Interact.						EXCEL/ Visual Basic	DIFRES	
Fishlab	Toolbox	Y	Y	Y	Indirect	N	C++, Visual Basic, Excel	CEFAS	1999
FLR	toolbox	In Develop-ment	In Develop-ment	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
SMS	Multi-species multi-fleet VPA & Forecast incl. HCR evaluation	Y	In progress	In progress	Y	N	ADMB (C++), R	DIFRES	2006
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 generally 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, or drawn from historical data.
- Recruitment: fixed, Beverton-Holt, Ricker, Ockham, Ockham with cyclic term, Beverton-Holt 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 F-PRESS

F-PRESS (formerly known as FSSSPS) is a stochastic simulation tool based on a simple algorithm designed to fit in with the ICES conceptual framework for software development (F-PRESS = Fisheries PRojection and Evaluation by Stochastic Simulation). F-PRESS can be used to develop probabilistic assessment advice or to evaluate management strategies or harvest control rules (HCRs). F-PRESS is written and runs in R and is designed to be easy to edit by end users to suit their requirements. A package with version 1.0 of the basic program and user documentation is available.

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 continues to be validated using feedback from end users.

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’). End user can add new recruitment function as required. Historical recruitment can be replicated.
- 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). Bias can be included.

Management model

- Basic assessment model on relevant parameters (e.g. current virtual F or SSB levels) where random ‘error’ and bias can be specified and controlled. No ‘assessment feedback’ model.
- Management through fixed F or TAC or specified harvest control rule. HCRs based on current virtual F or SSB levels work as modular functions and easy to edit/change/add. Historical catch levels can be replicated.
- User considerations
- Easy to implement program by novice user.
- Straightforward to add simple recruitment or HCR functions or basic code (assuming basic knowledge of R). Different assessment models or complex HCR functions can be added but would require significant editing of the underlying code (requires good / expert R knowledge).
- Output files in ASCII format.

- Program produces graphical output.
- Descriptive paper 'in press', user manual available now, technical manual to be available soon.

Conclusions/Recommendations:

Program will offer flexibility and transparency and basic version is available for immediate use. Easy for end user to run simple projections and run and evaluate 'simple' defined HCRs. Significant additions or changes to the program (e.g. a new assessment model) would require good working knowledge of R. User documentation (including basic tutorial) available but full technical manual yet to be completed.

8.2.6 FishLab/FLR libraries

8.2.6.1 FishLab

FishLab is a set of dynamic link libraries (dll) containing core routines callable from Excel and Visual Basic conceived and developed specifically for the evaluation of management strategies for use in the ICES WG on Longterm Management Strategies (ICES, 1999). 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 can be 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.

They have been used for a number of EU studies (MATACS, MATES) and papers (Kell *et al*., 1999, 2005a, 2005b and 2006) 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 libraries are still available but are no longer supported.

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 criticized as requiring high user expertise

- Selection of commonly used assessment available (i.e. XSA, Adapt, Stock Production, ASPM).
- 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. With appropriate expertise can be successfully applied to carry out evaluations of management strategies.

FLR

This platform, already applied in various research projects, consists of a set of libraries for the R statistical environment (an S engine, see R Development Core Team (2005), Venables & Ripley (2003), http://r-project.org). This has the important advantage of providing a powerful supporting system for data manipulation and a tested set of routines for statistical analysis and modelling capability, making use of the S language and several database interfaces. The code is open source and licenced under the GPL2 Free Software Licenses. It has been fully designed to deal with uncertainty estimates and variability in data and models, and allows for complete replicability of the analyses carried out for later inspection or audit in mind.

The library is design in a modular system implemented as a set of R packages, building up from a central package, called FLCore, that provides a common interface on which secondary packages can be built through the use of standard classes and methods for storage and manipulation of input and output of fisheries models. This package is in a mature state since release 1.1 and it was submitted to CRAN (http://cran.r-project.org) and accepted as an official R package. Development of secondary packages is greatly simplified by this emphasis on Object Oriented Programming (OOP). Currently 17 packages are available for a range of more specific purposes, and other numerous packages are under development. These cover tasks ranging from: stock assessment, construction of Harvest Control rules, the construction of operating models, the evaluation of HCRs using simulation and the graphical exploration of inputs and outputs.

A wide variety of standard stock assessment methods are being implemented in FLR as well as some more novel methods, including Bayesian estimators.

Validation mechanisms follow standard R language procedures, and include not only the software behaviour, but also the existence of documentation. In addition, validation of model results will be conducted following a standard procedure. Finally, all source code is open for inspection and testing.

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

Operating model

- Currently various operating models are being developed on a case specific basis, for both mixed and single fisheries: stochastic implementation where required;
- Most applications single species, age structured annual time step, but design allows for development of multi-species, multi-fleet, alternative time scales;

- A variety of observation error models are being developed, and a variety of forms of uncertainty can be modelled including process errors that can be modelled using a parametric or non-parametric facility to include correlation

Management model

- Management model explicitly modelled: sampling errors, assessment methods, decisions and implementation errors may be all explicitly modelled

User considerations

- Ease of implementation depends on complexity required, but has been criticized as requiring a steep learning curve. However, full documentation, tutorials and course notes are available. In addition courses are available on request.
- Good selection of commonly used assessment is being made available (e.g. FLBRP, FLSTF, FLXSA for the calculation of biological reference points, performing short-term forecasts and performing VPA). Common data formats through classes simplify testing of various assessment models on a single dataset without extra work.
- Interface allows flexible implementation of HCRs
- Developed using Concurrent Versions System (CVS) to insure integrated development. All development and discussion carried out openly through website http://flr-project.org/
- Documentation is available and can be updated, corrected or added to by users via the web-site. A mailing list is also available for users and developers.

Conclusions/Recommendations:

Highly flexible, with appropriate expertise it will be suitable to carry out full evaluations of management strategies. The routines have been used to perform stock assessments in ICES and has been used to set up a management strategy evaluation scheme for Antarctic and Patagonian toothfish in CAMMLR as well as simple OM explorations in ICCAT.

8.2.7 TEMAS

Developed by DIFRES under various Danish national projects and subsequently under the TECTAC, EFIMAS and PROTECT projects. The name refers to the first version dealing with analysis of Technical Management Measures, but the software has developed into a general evaluation frame for fisheries management during the EU projects. The evaluation frame compares two or more alternative management regimes. The most recent description of TEMAS can be found in the report of TECTAC.

Program.

The current version is implemented in EXCEL/Visual Basic. A new version in R/C++ is under development. The R-version makes use of the FLR whenever that is possible, and is planned to extend the EXCEL version. The EXCEL version will not be further developed, but may be maintained at is present state for presentation of results. Both versions are under development.

Operating model

The TEMAS operational consists in four sub models: Biological model, Technical model, Bio-economic model and Behaviour model. It operates with an optional time step (month, quarter or year).

The basic control (input) variable of TEMAS is effort by fleet and gear.

Biological model: Multi-species (but not species interaction), Multi-fleet (country, fleet and gear), Multi-area (optional migration model).

Technical model: Converts effort by fleet and gear into fishing mortality, and models gear selectivity, and discarding.

Economic model: Costs and earnings by country, fleet and gear and stake-holder. It models dynamics of fleet capacity by investments, dis-investment, and decommission.

Behaviour model: Trip behaviour and structural behaviour is modelled by the Random Utility Model. Trip behaviour includes choice of fishing/not fishing, choice of gear-rigging, choice of discard practice and choice of fishing grounds. Structural model allows for simulation of investments, disinvestment, attrition and decommission program.

Optional deterministic and stochastic simulation.

Management model

Sampling and stock assessment simulated. Simulation of management procedures (HCR) and implementation of management. The reaction of the industry to management measures is modelled.

Comparison of two alternative management regimes, e.g. TAC management vs effort-based management. Comparisons made for an optional suite of stake-holders, e.g. (1) Industry (2) Government (3) Society.

User considerations:

The program contains many features, most of which are optional, and in its simplest form, TEMAS equals the traditional ICES forecast program/HCR for a single stock exploited by “one fleet”.

The running of the EXCEL version is user friendly, requiring knowledge of EXCEL only. Presentation of input and output are facilitated by the EXCEL graphical user interface.

The source code in Visual Basic is comprehensively commented, and emphasis has been made to make the code understandable for non-experts in Visual Basic. The same qualities are aimed at with the R/C++ version by combining R with the tcl (tool command language) for graphical user interface.

Considerations/Recommendations

Flexible with respect of most existing management strategies and strategies which may be implemented in the future, notably effort/capacity-based strategies. The software can be run on many levels of complexity. The prediction power of the model is unknown but probably low, and therefore it is not expected to be used for quantitative predictions. The objective of the model is rather to make structure in ideas of how mechanisms of the fisheries system operate. Perhaps some qualitative conclusions can be made.

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 criticized 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 SMS

SMS (**S**tochastic **M**ulti **S**pecies model; Lewy and Vinther, 2004) is an age-structured multi-species assessment model that includes biological interactions. However, the model can be used with one species only. In "single species mode" the model can be as a traditional assessment model and is fitted to observations of catch-at-age, survey CPUE at age, and SSB and recruitment. When SMS is used as a forecast program for evaluation of HCRs, the stock is projected forward in time using the maximum likelihood estimate of the assessment model parameters and the population in the terminal year as initial stock size.

The SMS approach for evaluation of HCR is quite similar to the approach used by CS5/STPR3 (see Section 8), however with some additional features to handle in-year management (e.g. sandeel), escapement strategies (e.g leaving a minimum SSB to spawn after the fishery has taken place) and trigger values based on stock numbers (e.g. to handle the current HCR for sandeel in the North Sea). The main difference between the STPR3 and the SMS implementation is however, that SMS can handle several species simultaneously, with or without taking biological interaction (predation) into account. SMS HCR evaluations requires a HCR assessment as starting values. This close link makes it possible to bring the uncertainties of the assessment model parameters into the HCR evaluation by using get the posterior distributions of the parameters as estimated by Markov Chain Monte Carlo simulations.

Program

- Compiled C++ code (from Ad-model builder **(**Otter Research Ltd.)) and R-scripts for presentation of results and "batch-runs"

Operating model

- Single or multispecies, with and without biological interaction, single fleet, age structured, optional time step.
- 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 and exploitation pattern can be drawn from derived from point estimates or from the posterior distributions as estimated by Markov Chain Monte Carlo simulations.
- Deviation of actual catch from recommended catch can be modelled (implementation error) using stochastic multiplier.

Management model

- HCR can be catch-constraints, F-constraints or combination of both.
- TAC for year calculated on projected SSB or stock numbers using HCR.
- No assessment model included. Perceived stock numbers (or SSB) are taken from a probability distribution dependent on true stock numbers. Two probability functions can be used simulations for stock numbers; one representing the assessment uncertainties and one representing e.g. real-time monitoring.
- TAC decision based on this ‘faulty’ stock numbers or SSB data.

User considerations

- Easy to configure and run compiled program for a single species configuration. Multispecies configurations require some skill to use.
- Non-standard formatted ASCII files for input and run options (however a FLR implementation is planned).
- Output in ASCII files to be used in spreadsheets or similar. R-script available for configuration of complex simulations and presentation of results.
- Rather poor documented.

Conclusions/Recommendations:

SMS has mainly been developed to handle biological interaction. The present implementation of HCR simulation has been used for the evaluation the current HCR for sandeel in the North Sea (STECF 2005b). This was done in “single species” mode. The implementation of biological interaction is not fully tested.

8.3.4 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.

SMS includes multispecies interactions, but including such interactions require some skill. 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. SMS 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 Management Strategies: Work in other areas

It is not intended to provide here a comprehensive review of existing management strategies, rather to identify a number of instances in which they have been implemented in other areas. The cases considered include that of The International Whaling Commission; The International Commission for the Conservation of Atlantic Tunas; The South African Operational Management Procedure; The Australian Management Strategy Evaluation; The Chatham Rise Orange Roughy Fishery in New Zealand and the approach of the Northwest

Atlantic Fisheries Organisation. Specific objectives of the various management strategies are contrasted and any major difficulties and issues encountered during the implementation of the measures are noted.

9.1 Introduction

Management strategies have been formalized as management procedures in a variety of regions to meet a range of social objectives and legislative requirements, see Kell et al (submitted) for a review. The approach was pioneered by the Scientific Committee of International Whaling Commission (IWC; Hammond and Donovan, in press; Kirkwood, 1997), and is also being used in fisheries management, particularly in South Africa (Butterworth and Bergh, 1993; Butterworth *et al*., 1997; Cochrane *et al*., 1998; Geromont *et al*., 1999; De Oliveira and Butterworth, 2004; Johnston and Butterworth, 2005) and Australia (Punt and Smith, 1999; Campbell and Dowling, 2005; Tuck *et al*., 2003; Punt *et al*., 2005; Dichmont *et al*., 2005).

The management procedure (MP) approach allows for a lack of information to be explicitly taken into account, consistent with the principles of the precautionary approach (FAO, 1996). MPs are generally tuned so that when information is low and uncertainty over stock size is great TACs are set at a low level.

Use of the precautionary approach is developing rapidly in a few countries (e.g. USA, Canada, Australia, and South Africa). In all these cases, the precautionary approach has been largely confined to its biological elements and a more balanced application needs to address social and economic risks as well (FAO – Fisheries Atlas)

9.2 International Whaling Commission

The International Whaling Commission (IWC) has developed management procedures (MPs) for two different classes of whaling (commercial and aboriginal subsistence). These two classes differ in their management objectives, their political acceptability, as well as the nature of the whaling operations concerned. A single OMP (the Revised Management Procedure, RMP; IWC, 1999) has been developed for commercial whaling of baleen whales, while a more flexible scheme involving case-specific MPs has been developed for aboriginal subsistence whaling (the Aboriginal Subsistence Whaling Management Procedure, AWMP). These MPs have been tested extensively using the MPEF (Management Procedure Evaluation Framework). Considerable effort has been expended to quantify the management objectives and assign priorities to them, and to clearly define realistic data and analysis requirements.

9.3 International Commission for the Conservation of Atlantic Tunas

Management of Atlantic bluefin tuna is the responsibility of the International Commission for the Conservation of Atlantic Tunas (ICCAT), whose Convention states that “The Commission may, on the basis of scientific evidence, make recommendations designed to maintain the populations of tuna and tuna-like fishes that may be taken in the Convention area at levels which will permit the maximum sustainable catch” (ICCAT, 2003a). Maximum sustainable catch is generally assumed to be synonymous with maximum sustainable yield (MSY). Management of tunas must also be consistent with the Agreement for the Implementation of the Provisions of the United Nations Convention of the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (Doulman, 1995) and with the precautionary approach (FAO, 1996). A variety of regulations have been implemented on a stock specific basis to try and stabilize stocks at or rebuild to B_{MSY}, e.g. TACs, capacity limitations, size limits and restrictions on floating aggregation devices (ICCAT, 2005), but no formal management procedure or HCR exist.

9.4 The case of the South Africa OMP (Operational management procedure)

Management objectives

In South Africa, the Marine Living Resources Act (1998) clearly defines fisheries management objectives aimed at achieving the best utilization of living marine resources. These OMPs are based on scientific principles, recognizing the inherent variability of resources and the interdependence of the components of marine ecosystems. The management plans are being developed through a cooperative process involving all interested parties and include monitoring and control programmes, as well as enforcement. They require taking into account the socio-economic implications of management decisions, for example, the impact of a reduction of the TAC on employment.

Types of fisheries in South Africa under OMP

- Pelagic fisheries (such as the anchovy that supplies the reduction industry and the sardine fishery supplying the canning industry)
- North West rock lobster fishery
- Cape hake fishery.

Implementation issues of the S. African OMP

OMPs are being developed for the most important marine resources in South Africa, and long-term management plans have been explicitly developed for them. The implementation process has been reported by Cochrane et al. (1998) and Butterworth and Punt (1999). It has meant a big institutional change in terms of stakeholder inclusion in the process. One of the main problems encountered during the application has been the diverse and often conflicting positions of the parties involved, due to the interested parties often have different aims. During the introduction of the pelagic OMP, conflict arose within the industry due to clashing interests between the anchovy based reduction industry and the sardine based canning industry (Cochrane et al. 1998).

For managers and stakeholders, some key technical concepts as Bayesian statistics are difficult to understand. This problem was also reported during the implementation of the OMP in South Africa (Cochrane *et al.* 1998). One of the problems encountered during management procedure (MP) implementations, is the wide gap in the communication between the diverse parties involved. To overcome that, scientists developed computer simulation games to familiarize industry and decision-makers with the range of possible outcomes under different MP (Butterworth and Punt, 1999).

Since the implementation demands that managers, scientists and industry agree on clearly defined rules prior to its implementation, the introduction of such a system has demanded active participation, which in turn has brought about positive outcomes. Stakeholder’s involvement in the process has allowed scientists to get in touch with the problems of the industry and to be aware of their needs. Stakeholder inclusion in the process produces transparency that brings about legitimacy and therefore compliance.

9.5 The case of the Australian MSE (Management strategy evaluation)

Management objectives

In Australia, the Fisheries Management Act No. 162 (1991) states the management objectives which are:

- implementing efficient and cost effective management;

- exploitation of fisheries resources in accord with the principles of ecologically sustainable development;
- maximising economic efficiency in the exploitation of fisheries resources;
- accountability of fisheries management
- meeting cost recovery targets set by government.

Types of fisheries under Australian MSE

School and gummy shark, Brown and grooved tiger prawns, East coast tuna, Eastern stock of gemfish and Patagonian toothfish.

Implementation issues of the MSE

Implementation of the MSE has had to face diverse constrains such as resistance from decision makers to shift to such an innovative change. It has meant a big institutional change. In the beginning, managers were reluctant to accept a system that requires explicit and measurable performance indicators because they were understood as s ort of auditable mechanism for their activities (Smith et al. 1999). Moreover, stakeholders were also reluctant to accept a system that resulted cryptic because of being highly technical. One of the main challenges to introduce this system in Australia was the difficulty of including users' knowledge into scientific assessment. According to the philosophy of these systems, participation of stakeholders and stakeholder's knowledge inclusion are important components because they bring a stream of expertise and understanding of the interaction between men, resources, technological factors and what enhances or weakens compliance. This knowledge helps to develop the simulation-based models, which attempt to mimic reality Australians report technical difficulty of integrating fishers' knowledge into the process (Baelde, 2003). The well established co-management approach, being carried out by the Australian Fisheries Management Authority (AFMA) has offered a fertile field of development for this system.

Being a highly participatory system, not only inclusion of different factions as industry, conservationists and government is essential, but also the inclusion of scientist coming from a variety of disciplines such as sociology and economics. They are needed are to estimate the cost effectiveness of the approach and finding the means to enhance legitimacy and, therefore, compliance (Smith *et al.,* 1999). This system incorporates a scientist funded by the industry who acts as a catalyser for effective communication, backs up industry views with science, revisits the work of the other scientists and communicates their findings to the stakeholders in an understandable way. He has helped to establish and run the industry's monitoring and sampling programme.

After the lessons learnt in the St Helen's Hill orange roughy fishery, a much more precautionary approach has been taken in Australia with the Cascade Plateau orange roughy fishery. In the peak of winter, spawning fish aggregate on the Cascade Plateau making them vulnerable to capture. In response, AFMA and industry have closed this area during spawning to protect the stock. An extensive scientific monitoring program has been in place since 2001 to collect valuable data to assist the management of this species, including the setting of precautionary TAC in this area.

9.6 New Zealand: Orange Roughy

In New Zealand the objectives from the New Fisheries Management Act are:

- Healthy aquatic ecosystems in which the use of the fisheries resource contributes to the social and economic well being of all New Zealanders, without limiting options for future generations.
- Maori and Crown working together to give recognition of and protection for traditional Maori fishing rights.

- People with rights to harvest fisheries being given increasing responsibility to manage them, within the environmental limits set by the Government.
- Fisheries stakeholders recognising and respecting each other's rights and interests and constructively resolving issues among themselves

The management strategy identified in the Management Act and applied within the quota management system (QMS) is to maintain the stocks at or above the levels required to produce the MSY. The prime management tool is the TACC (Total Allowable Commercial Catch), which is subdivided into individual transferable quotas (ITQs). Other technical measures include gear restrictions and area restrictions. Stakeholders have an active participation in management. However, the government, through the Ministry of Fisheries, decides the TACC and the individual quota allocation and other management measures. This management is characterized by participatory governance, which involves government, quota owners and other stakeholders. Industry carries out exploratory fishing under provisional catch limits.

Due to the QMS revolution in New Zealand fisheries and the resulting extensive ITQ use in New Zealand, fisheries management and research is almost entirely funded by the industry. This is done by independent assessment funded by the industry as well as assessments funded by the government through taxes collected annually on quota holders. The Ministry of Fisheries contracts out private research facilities to conduct its funded research.

In most other countries around the world, the government provides fish stock assessment that, in turn, acts as a sort of subsidy towards its fishery. It is not rare that the total investment of the stock assessment is more than the actual worth of the fishery. Due to the emphasis of ownership in the ITQ system, the industry has an invested interest in conducting own independent stock assessments of the most important commercial stocks.

For example, in 1998 the Orange Roughy Management Company Ltd (ORMC), made up of 12 industry shareholders funded an independent acoustic survey and assessment of the North-East Chatham Rise orange roughy fishery to compare with the government-based survey of the same stock. With these two independent assessments, all parties were satisfied of the results of the stock assessment.

9.7 Northwest Atlantic Fisheries Organization

Prior to the collapse of a number of groundfish stocks in the late 1980s and early 1990s, NAFO Scientific Council relied primarily on F0.1 for providing annual TAC advice. NAFO has recently adopted the Precautionary Approach in principle, but it has yet to decide to implement it. Although a number of once important groundfish stocks are now under moratoria with respect to directed fishing, 2J3KLMNO Greenland halibut (turbot) and 3LNO yellowtail flounder support significant directed fisheries. Greenland halibut is currently under a NAFO Fisheries Commission developed multi-year rebuilding plan involving prescribed TAC reduction steps. It is not clear whether or not this plan is PA-compliant or whether it is likely to have the desired effect of rebuilding the stock. The most recent Scientific Council XSA assessment shows that the biomass is still declining and F is still increasing. 3LNO yellowtail flounder is assessed by Scientific Council using a dynamic production model (ASPIC) and scientific advice is provided under a PA framework in which Blim=30% Bmsy and Flim=Fmsy. The recent assessments for this stock have found that B> Blim and F<Flim. TAC advice has been provided by Scientific Council on the basis of Ftarget=2/3Fmsy. This advice has been accepted and used by Fisheries Commission. Further development and evaluation of HCRs under NAFO is planned.

9.8 Conclusion

It is beyond the scope of this report to provide a critical analysis of the success of the management strategies detailed above and in some cases it is still considered to be too early to tell whether the strategies have been successful in delivering the management objectives, particularly in the case of long lived species. It is apparent, however, that the cases considered above involve an increased level of stakeholder participation in the management process in comparison to the approach currently implemented in the ICES area.

In summary, the OMPs-MSEs frameworks for fisheries management are structured approaches to take account of scientific uncertainties, in the spirit of the precautionary approach, when choosing a harvest control law that will reasonably contain the risk to the resource. (Butterworth and Punt, 2001). The inclusion of reference points as part of the HCR and the use of evaluations to simulate the performance of alternative strategies in terms of meeting the objectives of management is an important component and in line with the precautionary approach to fisheries management.

10 SGMAS links with other ICES groups

10.1 Linkage between SGMAS and the Working Group on Ecosystem Effects on Fishing Activities (WGECO)

WGECO has devoted a full chapter in the 2005 report on the development and evaluation of management strategies. The chapter contains many interesting ideas and closer linkages between the two groups would be beneficial to the progress on this topic within ICES.

We see two main pieces of work in the WGECO with respect to management strategies:

- Issues related to the role of ecosystem aspects in management strategies (e.g. how ecosystems affects fish stocks, how fisheries affect ecosystems, intrinsic value of ecosystem components).
- Issues related to the process of setting up management strategies (e.g. stakeholder involvement, adaptive management)

At present, much of the practical work that is ongoing within SGMAS is directed towards methods for simulating the effects of harvest control rules. Ecosystem factors are presently incorporated into simulations by robustness testing: e.g. if different ecosystem conditions would affect the expected recruitment, how would that affect the outcome of a management strategy. Ecosystem factors could also be added directly to simulations of harvest control rules if a hypothesis of the relationships is available. In the absence of such a hypothesis, ecosystem aspects could still be incorporated as unpredictable switch factors that suddenly change the relationships between some of the model components.

A first step of including biological interaction in the evaluation of HCRs are taken by the ICES multi-species assessment study groups for the Baltic (SGMAB) and the North Sea (SGMSNS). These groups are dealing with estimation of fish predation and do as such just cover a small part the ecosystem. The multi-species groups have shown that the performance of the single species HCRs is often very different when evaluated in a single species or multispecies model (4M-HCR, see Section 8.2.1 of SGMAS report, 2005).

However, it would be very useful to expand both the ecosystem knowledge and the ecosystem implications in simulations of harvest control rules. An example of such an expansion could be in the evaluation of sandeel in the North Sea where the reservation of sandeel for breeding birds is an important aspect that could have been taken into account more explicitly. At present this reservation is implicitly used in the model through natural mortality. It would be possible to include these reservations for other species more explicitly.

The guidelines for evaluations (Section 4.4) include a much wider perspective on the fishery system and the role of management strategies. There is some resemblance between the SGMAS guidelines for evaluation and the Strategic Environmental Assessment (SEA) of fisheries that is described by WGECO. There is scope for integrating these two approaches to make sure that all the relevant aspects are covered at an operational level to give an overall evaluation framework; one important area for joint development is how to allocate / interpret the different components of such a scoring process to arrive at meaningful and reliable advice in the event that there are conflicting signals.

WGECO has also commented on the process of arriving at different management strategies and the involvement of different parties in that process. These are valuable comments. In Section 9 of this report, we refer to the development of management strategies in other parts of the world. The involvement of different parties in the definition of management strategies and tactical decision making is a very common feature. This is now also captured in our description of the management strategy where the questions of who is participating and how are they participating are prominent features. SGMAS is not aware of evaluations of such arrangements. However, this is important food for thought.

WGECO suggested that the WGECO and SGMAS meetings should be organized at the same time and place to enhance communication between the two groups. Although is likely that this is the last meeting of the SGMAS in the present form, we think that instead of such an arrangement, it would be better to actively incorporate the expertise of WGECO in a groups that are focussed on carrying out evaluations of actual management strategies or harvest control rules. Such an approach would provide a strong incentive to integrate ecosystem aspects in management strategy evaluations in a concrete way.

SGMAS was encouraged by the work presented by WGECO. Some aspects of this work are already in our guidelines, and we have tried to clarify other aspects in this year's revised report. Input from WGECO on parameterization of any effects / influences for use in predictions into the future would be of great assistance. Such aspects relating more explicitly to parameterizing ecosystem aspects/services would be especially beneficial. The aim of evaluating harvest control rules is that ICES can provide feedback on a tactical component of the fishery system. These evaluations should take the environmental conditions into account under which they operate.

10.2 Links to the Working Group on Fisheries Systems (WGFS)

The Working Group on Fishery Systems (WGFS) provided very valuable insights into the nature of fishery systems. WGFS was present in the SGMAS meeting to present the contents of the WGFS work. We have adopted the process oriented description of the decision making system (who gets to participate, how do they get to participate) and have modified elements of the report accordingly.

10.3 Links to the Adhoc Group on Long Term Advice (AGLTA)

Time constrains have limited the explicit evaluation of the report by AGLTA (Ad Hoc Group on Long Term Advice). Ideally it should have been presented in SGMAS as an application of an evaluation. Such an evaluation could have informed SGMAS explicitly how the evaluation criteria operate in a real application, however, the close links in participation between SGMAS and AGLTA have ensured that communication between the groups has not been unreasonable.

10.4 Links to the Working Group on Fish Ecology (WGFE)

The Working Group on Fish Ecology (WGFE) is presently undertaking work to relate fishing activities to some fish community indicators in a simulation environment for their sensitivity to fishing. These results may suggest how a community indicator reacts to fishing and suggest some certain kinds of fish community reference points (ECOQOs) that is some manner relate to fish community "health". For this reason, groups undertaking evaluations of management strategies may find work being done in WGFE useful for addressing objectives related to ecosystem and community properties.

11 Future

The SGMAS was established with the specific task to

"define a framework based on long-term considerations for management strategy evaluations in a Precautionary Approach context "

and to

"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".

The process was started in 2005, and the meeting in 2006 was to complete the work in areas that could not be covered at the first meeting.

The SGMAS considers the present report as the requested document, and proposes that the SGMAS in its present form is dissolved. However, there is definitely a need for a continued work on management strategies in ICES. The SGMAS has some suggestions for further work and how it might be done.

- Methods to evaluate various aspects of management strategies is a rapidly developing field. These developments, both in methods and applications, to a large extent take place outside ICES. A dedicated group to keep track of this development and provide input to the rest of the ICES community should be considered.
- The SGMAS emphasizes that the various aspects of management strategies must be developed in a dialogue process with all interested parties. Science can contribute at all stages of the development. Evaluation of an agreed management arrangement is only one (and often the last) step in the process. The dialogue should be both on a formal level and in an informal dynamic environment. ICES needs to consider both channels for communication and instruments for contributing scientific insight.
- ICES is requested to evaluate numerous management plans, notably harvest control rules. As noted in Section 1.1 in the 2005 report, SGMAS considers that the existing assessment Working Groups should have a role in controlling and communicating such evaluations. However, it is clear that WGs cannot do the actual work themselves on top of their other tasks. There is a wide range of ways to get the work done, either by individual institutions or by ad hoc study groups inside or outside ICES.
- It is suggested that ICES arranges courses in evaluation work, along similar lines as the WKAFAT. Such courses should cover theory and practical applications. Simulation games should be considered, both for training of scientists and as a tool to improve understanding of how management strategies may work to a wider audience.
- Full evaluation of management strategies requires wider expertise, including economic and social sciences, and will need separate fora.

- As noted in Section 10.1, SGMAS suggests, in order to facilitate the inclusion of ecosystem aspects in management strategies, to actively incorporate the expertise of WGECO in a groups that are focussed on carrying out evaluations of actual management strategies or harvest control rules.

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STUDY GROUP ON MANAGEMENT STRATEGIES

23 - 27 January 2006

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Annex 2: Terms of reference

The **Study Group on Management Strategies [SGMAS]** will meet 31 January to 4 February 2005 at ICES HQ, Copenhagen (Co-Chairs: Dankert Skagen, Norway and John Simmonds, Scotland, UK) to:

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;

The **Study Group on Management Strategies [SGMAS]** will meet 23-27 January 2006 at ICES HQ, Copenhagen (Co-Chairs: Dankert Skagen, Norway and John Simmonds, Scotland, UK) to:

a) Continue development of the framework and operational guidelines, started in SGMAS 2005, for the evaluation of fisheries management strategies;

b) provide in particular a operational framework for fisheries management strategies for types of stocks that are not amenable to the ‘mainstream’ HCRs, such as:

   i) short-lived species;

   ii) stocks where there is poor knowledge base or deteriorating data;

   iii) long lived species;

c) identify one or more examples of management strategy evaluation (possibly such as stocks evaluated by AGLTA) that have been carried out within guidelines similar to those provided by SGMAS and include these worked up examples as annexes to the guidelines;

d) address ecosystem aspects of fisheries management, in particular the comments and requests from WGECO;

e) explore methods for incorporating the influence of socio-economic factors into fisheries management strategies;

f) explore approaches to development of management strategies for mixed fisheries incorporating developments from the workshop on simple mixed fisheries management models [WKMIXMAN]

g) Outline the kind of relevant information that will be required from other ICES WGs for management strategies as a first step to obtaining a coherent approach across the ICES WG structure.

Annex 3: 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
Data poor	Reference to stocks for which there is insufficient information for standard analytical assessments	
Decision-making system	Part of the management procedure that results in harvest decisions that are largely determined by the harvest advice model.	WGMG2004
Empirical indicator	An indicator that is calculated directly from raw data.	SGMAS 2006
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
Estimated indicator	A synonym for a model estimate of a variable such as SSB	
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
Eyeballing	The process of looking for patterns or signals in the data by eye alone	SGMAS 2006
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

Term	Definition	Source
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
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
Indicator	Quantifiable information that relates in some predictable way to a property of the real fishery system.	
Initial conditions	The set of conditions (assumptions and events) that result in the historical data that are needed to start the simulations.	WGMG2004
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

Term	Definition	Source
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
Metier	A unit of a fishery that has a specific group of vessels operating with a single gear type in one season and one area.	
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
Operating Model	A virtual world that is a simplified representation of reality. It's main components are fish and fisheries (adaptation).	WGMG2004
Operating model*	A virtual world that is a simplified representation of reality. It's main components are fish, fisheries, assessment and management.	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
Raw indicator	A synonym for empirical indicator	SGMAS 2006
Rebuilding plan	Same as recovery plan	SGMAS2005

Term	Definition	Source
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 choices	The process of choosing between different options at the tactical level.	SGMAS 2005
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.

APPENDIX I (from De Oliveira *et al.*)

Spawning stock biomass*:*

The spawning stock biomass in the underlying model, referred to as the "true" spawning stock biomass, is calculated as follows:

$$SSB_y^{true} = \sum_{a=1}^{11+} N_{y,a} Q_a w_a^{stock} e^{-p_F s_a F_y - p_M M_a} \qquad y = 2002,...,2021 \qquad \text{A1}$$

where

$N_{y,a}$	*is the number of fish aged a in year y;*
Q_a	*is the proportion of mature fish aged a;*
w_a^{stock}	*is the mean weight of fish aged a in the stock;*
s_a	*is the selectivity at age a;*
F_y	*is the fishing mortality in year y;*
M_a	*is the natural mortality at age a;*
p_F	*is the proportion of fishing mortality that occurs before spawning;*

and

p_M	*is the proportion of natural mortality that occurs before spawning.*

Recruitment

Recruitment is generated using a combination of the Ricker stock-recruit function with parameters a and b estimated from a fit to stock-recruit estimates derived from the SAD model (ICES, 2004), and a process that allows the influx of very large recruitment with a frequency of roughly one in 20 years (equation A2). The recruitment variation and serial correlation parameters, σ_R and ρ_{ser} (equations A2 and A3), are derived from this fit.

$$N_{y,0} = \begin{cases} a\, SSB_y^{true}\ e^{-b\, SSB_y^{true}}\ e^{\sigma_R \zeta_y - \frac{1}{2}\sigma_R^2} & \text{for } \psi \geq 0.05 \\ 45 \text{ billion fish} & \text{for } \psi < 0.05 \end{cases} \qquad \text{A2}$$

where y = 2002,...,2021, ψ is independently drawn form a U[0; 1] distribution, and

$$\zeta_y = \rho_{ser}\ \zeta_{y-1} + \sqrt{1-\rho_{ser}^2}\ \xi_y$$
$$\xi_y \sim N[0;1] \qquad \text{A3}$$

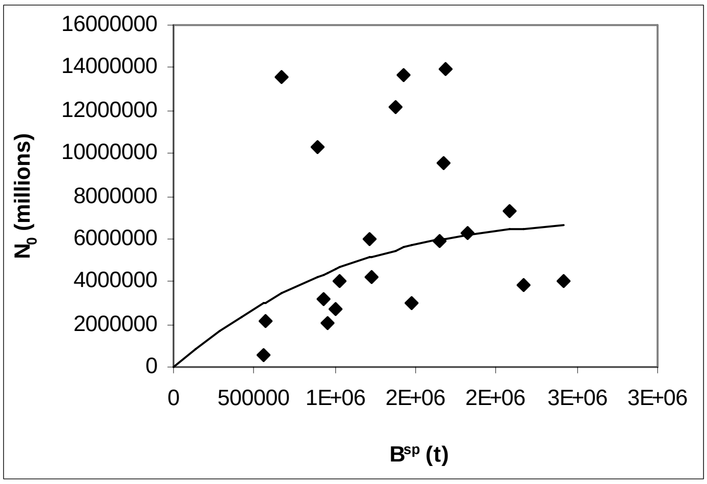

Fig A1.1 Ricker fit to 1983 – 2002 stock and recruitment data (2004 assessment results).

A cumulative probability distribution of the recruitment values used in the simulations and of the historic time-series (excluding 1982 year-class) is shown in FigureA1.2. Simulated values of recruitment, based on the Ricker curve, larger the 95th percentile of the distribution were omitted in the simulations.

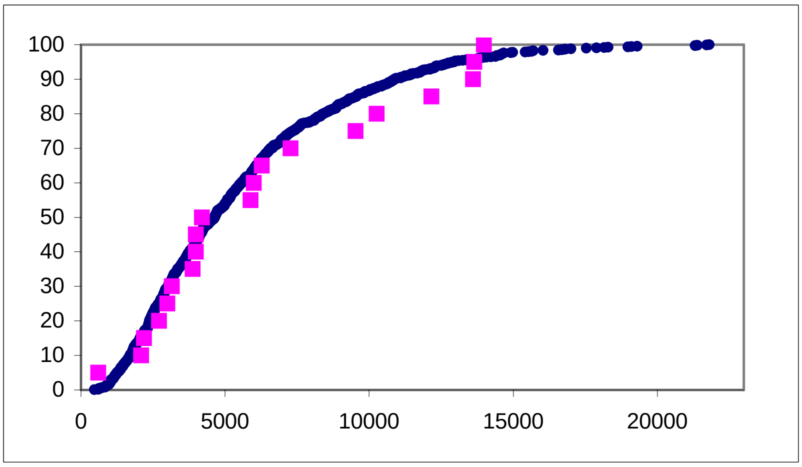

Fig A1.2. Cumulative distribution of simulated recruitment and of the historic data.

Numbers-at-age

An age-structured deterministic underlying model is used, and is based on a separable assumption with regard to fishing mortality and selectivity, and assumes a plus group at age 11. Uncertainty in the starting numbers at age will be taken into account.

$$\left.\begin{aligned} N_{y+1,a+1} &= N_{y,a}\ e^{-s_a F_y - M_a} && a = 0,\ldots,9 \\ N_{y+1,11+} &= N_{y,10}\ e^{-s_{10} F_y - M_{10}} + N_{y,11+}\ e^{-s_{11+} F_y - M_{11+}} \end{aligned}\right\} \quad y = 2002,\ldots,2021 \qquad \text{A4}$$

Calculating the fishing mortality and catch

The fishing mortality that results from applying C_y is calculated by solving for F_y from the following:

$$C_y = \sum_{a=0}^{11+} N_{y,a} \; w_a^{catch} \; \frac{s_a F_y}{s_a F_y + M_a} (1 - e^{-s_a F_y - M_a}) \qquad \text{A5}$$

An upper limit is placed on catching efficiency. To achieve this, F_y is restricted to be ≤ 20, which results in $\frac{s_a F_y}{s_a F_y + M_a} (1 - e^{-s_a F_y - M_a}) \le 0.98$ for any age group, given the values used for s_a and M_a. If no implementation error is considered (i.e. no mismatch between TAC and catch is modelled), then as long as $F_y < 20$, it follows that $C_y = TAC_y$. However, when F_y is restricted to a value of 20, this is no longer the case and C_y is calculated by solving equation A5 (with $F_y = 20$) after replacing TAC_y with C_y. If implementation error is considered, then generally $C_y \neq TAC_y$, even when $F_y < 20$.

Generating egg abundance observations

In order to generate egg abundance observations, the “true” egg abundance needs to be obtained from the “true” spawning stock biomass (equation A1). It is modelled on the basis of the relationship between egg abundance and spawning stock biomass estimated from the SAD model (ICES, 2003). To incorporate different components of variance into this relationship, the total variance can be apportioned into a "process" error component (λ_{egg}) linking true egg abundance to true spawning stock biomass (where fecundity plays a role), and an "observation" error component (cv_{egg}) linking observed egg abundance to true egg abundance through the sampling CV of egg abundance estimates.

EGG^{true} is derived from SSB^{true} with process error, as follows:

$$EGG_y^{true} = \frac{1}{q} SSB_y^{true} \; e^{\lambda_{egg} \eta_y} \qquad \text{A6}$$

where $\eta_y \sim N[0; 1]$. In equation A6, 1/q is the constant of proportionality linking egg abundance to spawning stock biomass, and λ_{egg}^2 represents the process error component of the total variance of the egg abundance versus spawning stock biomass relationship (in log-terms), which could in part be due to variability in fecundity. The observed egg abundance is generated from EGG^{true}, with observation error as follows:

$$EGG_y^{obs} = EGG_y^{true} \; e^{cv_{egg} \, \omega_y} \qquad A7$$

where $\omega_y \sim N[0; 1]$, and cv_{egg} represents the sampling CV related to observed egg abundance estimates.