International Council for the Exploration of the Sea

Theme Session on Management Faced With Multiple Objectives
CM 1996/P: 9

MULTIPLE OBJECTIVES AND FISHERIES MANAGEMENT: AN APPROACH TO DECISION MAKING.

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ABSTRACT

Decision makers need to understand how different management procedures perform in relation to meeting multiple objectives which can seldom be met simultaneously. An aim of fisheries scientists should be to provide decision support material that makes clear how different fisheries management procedures may result in trade-offs between objectives. In order to achieve this, there is a need to understand the objectives of interest and metrics that represent them, and to build models of complex, non-linear, uncertain systems and the management procedures that need to be tested. It is then possible to investigate experimentally, the robustness of management procedures to uncertainty in system models and how different management procedures compare in their ability to meet objectives. The results from such experiments need to be summarised in simple but meaningful ways.

Keywords: Decision making, simulation, uncertainty, objectives, validity, credibility.

INTRODUCTION

Fisheries management comprises three elements - stock assessment, regulation and enforcement (Anon, 1995). In the ICES region, stock assessment primarily consists of determining the perceived state of a single stock by the application of sequential population analysis procedures such as Extended Survivors Analysis, XSA (Darby and Flatman, 1994; Shepherd, 1992). Based on the perception of a stock, simple projections are then made of catches and spawning stock biomass levels that would arise given changes in effort or fishing pattern. Additionally, medium projections are made; a range of biological reference points are calculated and a perception of the sustainability of the fisheries is obtained. The results of these assessments are communicated to managers who take account of other, non-biological factors and make recommendations as to quota levels and other regulations. Politicians hear representations from various interested parties or *stakeholders* (e.g. the fishing industry, fish producers, environmentalists), weigh up arguments and agree quotas and other regulations. All of this happens annually and reactively with little or no clear strategic framework. Enforcement, though of immense importance, especially for over-exploited fisheries, will not be alluded to further in this paper.

The over simplified description above highlights a number of the steps in an unformalised, sequential decision making process involving a large number of individuals with different stakes in the outcome. An important point is that the different stakeholders have different objectives and different values ("utilities" or weights) which they attach to those objectives. In making rational, defensible, decisions, it is necessary to understand how the various objectives are likely to be met (or not) by the application of different regulations, and to form an understanding of the implied, likely trade-offs. Only then can well-informed decisions be made; the basis for making them be communicated, and credibility built. Baird (1989) points out that in the real world, decision makers are vulnerable and that decisions therefore need to be reached in a rational, professional fashion so that they may be conveyed (or "sold") to others who are responsible or affected. The credibility of decision making (and decision makers) becomes as important as the decisions themselves.

A second point to note is that the decisions in the above process are entirely based on perceptions obtained from assumption-rich assessment procedures. The theory, data or knowledge upon which assumptions are made, however, are seldom made. Rather, the assumptions often appear to be simplifications necessitated by lack of knowledge but defended on the basis of pragmatism. The decisions, therefore, are not based on analyses in which uncertainty is confronted, or in which the effects of feedback between the system behaviour, assessment and regulation is accounted for.

Gulland (1986) describes three successive phases of fisheries management: *unthinking optimism*, *naive belief in Science* and *confronting uncertainty*. Gulland talks of uncertainty not just in the sense of unknown structures or parameterisations, but also in the sense of being unable simultaneously to maximise conflicting objectives. The potential for unthinking optimism has long since passed in the greatly over-exploited fisheries of the Northeast Atlantic. Whilst naive belief in science might be more apparent than actual, the most common approach to fisheries management appears still to be based thereon. Uncertainties are seldom confronted, a facade of scientific certitude is often created and the consequences of management actions are often deemed to be predictable.

Even ignoring the well-known phenomenon of deterministic chaos (eg. Gleick, 1987; Grasman and van Straten, 1994; Holden, 1986), complex, non-linear, uncertain systems are unlikely to be predictable (eg. Lighthill, 1986). Uncertainty conspires to prevent predictability on at least three counts - structure of systems, parameterisation of modelled structures and extrapolation. It is a truism that the structures of the complex fisheries systems we seek to manage are poorly understood. Parameterisation can only be achieved through careful analyses of data collected at appropriate scales (which seldom occurs). Many fish stocks are at never-before-experienced levels whilst socio-economic systems and the global environment are entering unknown territory. Also, as Brewer (1984) points out, uncertainty in natural (biological) variations may be less consequential than that posed by other sources.

One purpose of this paper is to counter the view which promotes scientific certitude, and to advocate a comprehensive approach to fisheries management in which uncertainty is confronted directly. That is, to consider the effects of management on uncertain fisheries systems and to provide the material necessary for rational decision making when faced with a wide range of objectives which may not be simultaneously achievable.

The role of fisheries scientists would thus be to understand and model fisheries systems and the impacts of management procedures (ie. assessment plus regulations) upon them and to provide decision makers (managers and politicians) with a sound basis for their task. Such a role would require fisheries scientists to take a wide ranging view of the systems of interest and to include factors beyond the traditional biological ones. Most importantly, the whole decision making framework would need to change from an annual, sequential, reactive form to a structured, co-operative form of strategic planning with clear rules for implementing tactics over specified time horizons. The political implications of such a change are fascinating but outside the scope of this paper.

This is quite at odds, for example, with a common interpretation (eg. Fishing News, 1996; Nature, 1996; New scientist, 1996) of a United Kingdom House of Lords Select Committee Report on Fish Stock Conservation and Management (U.K. Government, 1996). The interpretation is that fisheries (assessment) scientists should be willing to make value judgements, stop being "mealy-mouthed" (New scientist, 1996) and give bold advice. The interpretation is predicated upon the assumption that fisheries scientists themselves should make decisions, or bring certain values to the decision making process. An alternative view is that the role of scientists should not be to make decisions but to provide clear decision support material as a basis for rational decision making by managers and politicians.

In brief, current decision making is frequently reactive and tactical in an apparent strategic void. An idealised alternative would be for decision making to be at a strategic level, with scientific input in the form of relevant decision support, and with tactical management being prescribed by specified control laws based on appropriate biological reference points (e.g. ICES, 1994; Mace, 1994; Mace and Sissenwine, 1993; Myers *et al*, 1994; Rosenberg *et al*, 1994) following annual, prescribed stock assessments. Annual management would be automatic, or "clockwork", as described by Hilborn *et al* (1993) and Stephenson and Lane (1995). It would follow well-founded, well-defined management plans.

Without making clear what objectives should be considered, and what weights to assign to different objectives, the United Nations Voluntary Code of Conduct for Responsible Fisheries (United Nations, 1995b) makes explicit that management should involve the production of well-founded management plans (i.e. strategies) with clear management actions to be taken (i.e. prescribed tactics). (See paragraph 7.3.3 - "*Long-term management objectives should be translated into management actions, formulated as a fishery management plan or other management framework.*")

Most fisheries in the world do not have such well-founded management plans. Certainly, most European fisheries do not. One example of a serious attempt to develop management plans is in the United States, where Fishery Management Plans are required by law (Rosenberg *et al*, 1994), and in which definitions of overfishing are being developed for a large number of Fishery Management Plans. Unlike the use of MBAL (Minimum Biological Acceptable Level) used in Europe, the intention is to specify fully control laws in which targets and thresholds are defined and regulations become prescribed, including the response to exceeding thresholds.

Approaches to multi-criteria decision making are well developed and applied in numerous fields of activity. The above prescription, therefore, is not for fisheries management in the ICES region to break new ground. Rather, it is for fisheries management in the region to catch.

up with the techniques of operations research, systems analysis and decision analysis already employed in many other fields (e.g. Grasman and van Straten, 1994 and numerous references therein) and which are already being applied in many regions of the world to the management of living marine resources (references below).

DECISION THEORY AND FISHERIES MANAGEMENT

It is not the intention to give a complete history or summary of Decision Theory. Numerous books are available that cover the field (e.g. Baird, 1989; Clemen, 1990; Keeney and Raiffa, 1976; Winston, 1993) and many authors have considered decision making in the context of living marine resources (see below).

Just as statistics falls into two camps, the classical frequentists versus the Bayesians, so too do approaches to decision analysis. The final outcome of analyses, whether classical or Bayesian , is an inference about nature or some uncertain quantity. Only if action is involved do we move into the field of Decision Theory (Baird, 1989). In Decision Theory, therefore, action is mandatory and must be included in the analysis. In fisheries, assessment equates to inference and regulation to action. Decision Theory is therefore necessarily pertinent to fisheries management but need not be to assessment.

Ignoring the distinction between Bayes and pseudo-Bayes approaches, the difference between classical and Bayesian approaches to Decision Theory lies in the willingness to use prior information, or belief, to assign probabilities to states of nature. The distinction is important in that if prior information is not admitted, and uncertainty exists as to assumptions, decision analyses cannot reveal an optimal solution. If, therefore, a decision is based upon an analysis in which prior probabilities, or subjective information, are inadmissable, it cannot be objectively defended. On the other hand, if prior belief is used as a basis for decision making, the decision may be defended - but only if the subjective prior belief can be justified.

To a statistical non-purist, the arguments between classical and Bayesian devotees often seem somewhat over-emphasised. For practical purposes, and notwithstanding philosophical debate concerning statistical details in particular applications (eg. Givens and Bravington, 1995; Schweder and Hjort, 1995), the application of careful data analysis and experimental design, together with a modicum of common sense, may permit the artful use of either classical or Bayesian approaches to achieve the same ends.

In fisheries, classical approaches to Decision Analysis have been extensively developed and applied in recent years (eg. BEP, 1991; Cooke, 1995; de la Mare, 1985, 1986; Donovan, 1989; Francis, 1992; Horwood, 1994; IWC, 1993; Kell and Stokes, 1995; Powers and Restrepo, 1993; Punt, 1991,1995; Restrepo *et al*, 1992; Restrepo and Rosenberg, 1994; Sakuramoto and Tanaka, 1986; UNEP, 1992). Bayesian approaches have been advocated (Hilborn, 1992) for both assessment and decision making. They have been used for assessment (inference) purposes by, for example, Givens *et al* (1993) and Raftery and Zeh (1993). Despite the hope of Hilborn, however, Bayesian approaches have not been so extensively used for actual decision analyses, except in limited cases, eg. McAllister *et al* (1994). This may be due to computational limitations more than to philosophical ones; perhaps the next decade will see a change in emphasis. Whatever, current state-of-the-art is dominated by Monte Carlo simulation approaches (eg. Heuberger and Janssen, 1994) and careful experimental designs (e.g. Box *et al*, 1978) to provide the material needed by decision makers (Grasman and van Straten, 1994).

A PRAGMATIC APPROACH TO DECISION MAKING IN FISHERIES

Keeney and Raiffa (1976) provide a simple, now "classic", paradigm for decision analysis which has five steps: *Preanalysis*, *Structural analysis*, *Uncertainty analysis*, *Utility or value analysis*, *Optimization analysis*.

Preanalysis refers to the identification of the problem and the various alternative actions that might be taken. If, in fact, no problem is identifiable, and viable alternatives do not exist, decision making is either inappropriate or unnecessary. *Structural analysis* refers to the decision maker's structuring of the problem. That is, identification of information gathering potential, experiments that might be performed, choices that can be made (and when) and so on. These questions and possibilities would generally be describable in the form of a decision tree (e.g. Clemen, 1990; Keeney and Raiffa, 1976). *Uncertainty analysis* refers to the assignation of probabilities to branches in a decision tree. *Utility* (or *value*) *analysis* refers to the assignation of value (utility) that the decision maker assigns to branches in a decision tree. *Optimization analysis* refers to the calculation of a strategy that optimizes utility.

In fisheries, these steps can be applied, but usually in a rather less formal manner than that envisaged by Keeney and Raiffa or other decision theory practitioners:

Preanalysis is a prerequisite. Problems and viable alternative management actions to evaluate need to be clearly identified. It may not be necessary to identify, *a priori*, all possible alternative states of nature or management actions, but a clear set must be available to start analysis. The important point is to identify plausible states of nature and viable management actions.

Structural analysis may be highly complicated in a multivariate fisheries problem. This is a natural and inevitable consequence of dealing with complex, non-linear, uncertain systems about which we have little information.

Formal *uncertainty analysis* may sometimes be impossible in fisheries decision making. There is a problem of how to assign probabilities to states of nature or, perhaps most importantly, human responses to management, with no prior experience or insight. Informal uncertainty analysis, however, has and can be undertaken. The most common approach is the use of experimentally designed Monte Carlo simulation work.

Experience suggests that these first three, scientific phases involve considerable iteration.

Formal *utility* (*value*) *analysis* is difficult. Indeed, without explicit utilities being available, it is impossible. Informal utility analysis involves collaboration with actual decision makers (and possibly a variety of stakeholders) and a willingness on their part to make explicit the values that they attach to different objectives. This may require iteration back to the scientific work.

Optimization analysis is probably an academic nicety in terms of fisheries management due to the large number of conflicting objectives and uncertainty as to states of nature.

Given the near impossibility of conducting fully-fledged, formal decision analyses, one recourse is to the provision of decision support material that will allow decision makers to attach utilities to the outputs from uncertainty analyses. Scientific input would therefore be concentrated on Keeney and Raiffa's first three phases. The fourth phase (utility analysis) would be undertaken subjectively ("human integration") by decision makers, aided by scientists, using the decision support material provided (Punt; 1993). The fifth phase (optimization analysis) is probably seldom of relevance in practice. Certainly, it cannot be carried out following human integration; only after a formal utility analysis.

In the context of fisheries management, therefore, the role of scientists would be to evaluate management options in terms of objectives, or representative metrics, of interest to a wide variety of stakeholders. In this way, scientists could contribute to the decision making process at a strategic level and then implement the agreed tactical elements of strategies as appropriate. Actual decision making would almost always be by human integration by various decision makers using subjective judgements of results from analyses concentrating on phases 1 to 3 of Keeney and Raiffa's paradigm.

This prescription is far from new. Many scientists around the world have similar views with only minor departures (e.g. Butterworth *et al*, 1992; Stephenson and Lane, 1995). The view is certainly very close to that espoused by Stephenson and Lane (1995), but does not go so far as to say that scientists can make decisions or bring their own values. It is in line with the view of Caddy (1995), that scientists can and should provide the necessary material for rational decisions to be made by relevant stakeholders, or decision makers. Whether or not scientists should be involved in the decision making process *per se* is a moot point and will depend on the prevailing organisational and political structures.

In summary (see figure 1), classical decision making involves five steps. In fisheries, only the first three can be undertaken at the scientific level. Careful consideration of objectives and viable management actions is required, as is the building of valid (and hence credible) system models to permit uncertainty analyses to be undertaken. This scientific part of the process needs to be followed by careful communication of results to decision makers who should then be able to determine courses of action, and provide a clear rationale for their decisions. Importantly, credibility can then be built in the overall decision making process (Baird, 1992). Optimization is seldom possible in practice.

OBJECTIVES

The ideal starting point for any decision making process, is the clear definition of objectives. These may, for example, be biological, social, economic, environmental, recreational, administrative or political in nature. Biological objectives are usually concerned with resource conservation (e.g. avoiding recruitment overfishing) or maximising biological production (yield). Generally, biological objectives are relatively simple compared to those in other categories. They thus limit the potential for fisheries biologists and assessment scientists to participate in the decision making process (ICES, 1993). Useful discussions on management objectives can be found in Hilborn and Walters (1992), Anon (1992) or Laevestu, Alverson and Marasco (1996).

At the international level, emphasis has been placed on a "Precautionary Approach" to management (United Nations, 1995a,c) and the use of reference points based on biological and other factors (Caddy, 1995). The Precautionary Approach embodies biological caution but also care for other factors. Fundamentally, it is a risk averse strategy that seeks to avoid undesirable or unacceptable outcomes. Given, however, the emphasis on avoiding undesirable biological outcomes, it effectively constrains the "decision space" that may be available in any management problem. Certainly, it motivates the postulation of generalised objectives which relate to conservation and sustainability, and the development of robust strategies.

Pope (1983) postulated the idea of "Minimum Sustainable Whinge". In effect, this is a risk averse approach to management which seeks to maximise outcomes on a decision-space, bounded by the minimally acceptable outcomes for all objectives. The point of the minimum sustainable whinge is that even if decision makers can not, or will not, provide values to be used in analysis, they may often be willing to provide boundaries or "Musts" (Baird, 1993). These boundaries are useful in that they constrain the viable management actions that need to be investigated.

The Precautionary Approach and Minimum Sustainable Whinge, together provide a useful starting point for determining objectives and viable actions that might to be analysed.

The recently agreed voluntary Code of Conduct for Responsible Fisheries (United Nations, 1995b) includes the following text:

7.2.1 Recognizing that long-term sustainable use of fisheries resources is the overriding objective of conservation and management, States and subregional or regional fisheries management organizations and arrangements should, inter alia, adopt appropriate measures, based on the best scientific evidence available, which are designed to maintain or restore stocks at levels capable of producing maximum sustainable yield, as qualified by relevant environmental and economic factors, including the special requirements of developing countries.

This catch-all paragraph clearly emphasises sustainability (ie. conservation and biology) but with the strong rejoinder that other factors need to be included in decision making. Importantly, no explicit, relative valuation is made of the various categories of objective. As with all international treaties, or voluntary codes of conduct, interpretation is intentionally (and necessarily) open and adherence is customary rather than requisite.

In fact, explicit valuation is difficult in the fisheries context with such a variety of objectives for which there is no common currency (or "numeraire" in the language of economics). How should spawning potential be valued relative to short term employment? An analogy to the difficulty is that of using national accounting systems (GNP/GDP) which include costs (eg. environmental clean up) as product, and hide national performance on a variety of conflicting objectives. Using an idealised Sustainable National Income (SNI) measure (van Dieren, 1995) is an option, but the problems in assigning valuation and merit to competing objectives are fraught with difficulty. Subjectivity must be brought to bear. Whilst a consistent subjectivity may be agreed upon for national accounting purposes, it is likely to remain variable from state to state and stakeholder to stakeholder in fisheries management problems. Thus, no universal method of dealing with conflicting objectives is likely to be found for fisheries management and decision making, and scientific support thereof will need to adapt on a case by case basis.

Whatever objectives are regarded as important, it is necessary to find metrics that adequately represent them to decision makers. In some cases this might be trivial. For instance, an objective for maximising yield can be examined by looking at total yield (over a specified time horizon) under different management scenarios. An objective for stability within the industry, on the other hand, is not so easy to represent in a simple metric. One that has been used in the International Whaling Commission and elsewhere is the annual average variation in catch, AAV. This, however, is just one choice which may be represented in a variety of ways. Finding metrics that represent social or economic objectives becomes even more difficult, but it is imperative in most cases. These difficulties do not make decision making impossible, but they do illustrate the requirement to involve a wide range of stakeholders in the decision making process, and scientific disciplines in the production of decision support materials. As stated in the introduction, decision making needs to be credible. To achieve that, objectives and metrics need to be discussed, developed and agreed with those involved.

Even if decision makers are not forthcoming with objectives and values, fisheries scientists can still postulate certain generalised objectives. Obvious candidates are, for example, total or continuing yield (biological productivity), AAV (biological and perhaps industrial stability), SSB above required levels (based on idealised reference points and representing biological conservation/sustainability) and socio-economic indicators such as NPV or total employment. As a starting point for an iterative decision making task, these may be sufficient. On a case by case basis, biological, economic or social objectives may be more or less emphasised. Additionally, given a history of decision making, it might be possible to infer objectives and values of decision makers (Hilborn and Walters, 1992). This is a potentially fertile field of endeavour into which more effort might be usefully directed.

SYSTEM MODELLING AND UNCERTAINTY ANALYSIS FOR FISHERIES SYSTEMS

In order to evaluate and compare the performance of management procedures as a basis for decision making, it is necessary to simulate complex fisheries systems, stock assessments, consequent management actions and feedback to the underlying systems. This needs to be done for a number of years (depending on the desired duration of strategic management plans), many times (to reflect parameter uncertainty) and in a number of ways (to capture the plausible states of nature that may be encountered in reality). From all simulations, it is necessary to collect statistics, from which metrics representing decision makers' objectives can be calculated.

This task, essentially the second and third phases of Keeney and Raiffa's paradigm, is far from trivial. Fisheries are complex in space and time and have multi-faceted attributes: biological, economic, social, anthropological, to name but a few. Which elements need to be included in any simulation modelling will depend partly on the objectives of decision makers, but also on the inter-dependencies. For instance, even if decision makers do not require information on economic or social objectives, the behaviour of fishermen in response to management actions may be influenced by economic, social and other factors (Allen and McGlade, 1987; ICES 1993).

The difficulties of complex systems analysis are not exclusive to fisheries. In fisheries, however, the inter-dependencies and uncertainties are considerable. It may not be sufficient to rely on over-simplified models of the systems of interest, but care is needed to produce models which, whilst realistic, are not unnecessarily complicated. The key is accuracy, not complexity (Blythe and Stokes, 1993; Castanza and Sklar, 1985). No theory or model fits data precisely and what scientists need to know is exactly how well models perform over a broad range of conditions and criteria (Castanza, 1989). In the context of evaluating and comparing management procedures, the models in question are not just the biological system models, but the whole complex of system models, assessments and management actions plus feedback. An understanding is required of how well management actions perform over a broad range of uncertain conditions and criteria.

The requirement is to produce models which are valid. Just as decision makers need to build credibility, so too do scientists in the analyses that underpin decision making. When a simulation model is accepted as being valid, and is used as an aid in decision making, credibility is built both in the under-pinning science, but also in the decision making process.

The term "valid" in used here in a precise sense. The terms verification, validation and credibility are reserved and distinct in the field of systems analysis. Briefly, verification is the process whereby a program is determined to perform as intended (ie. debugging, cross checking etc.). Validation is concerned with determining whether the conceptual model (as opposed to the computer program) is an accurate representation of the system under study (Law and Kelton, 1991).

Hodges (1991) points out that many models used in systems analysis or policy analysis cannot be adequately validated and, as such, they are "bad models". Nevertheless, they can be utilised. The "six (or so) things" that Hodges suggests "bad" models can be used for, include aiding decision making and "selling" ideas. This philosophy is similar to that of Fagerström (1987) who suggests that an imortant role of models is to provide "constructive lies". Current assessment procedures, with no feedback to simulated, plausible states of nature, implicitly assume one, constant, simple state. It can be argued that these approaches, if used as the sole means of evaluating management actions, are bad - not only in the sense of Hodges or Fagerström, but literally.

Building valid models can follow many paths. In fisheries, large amounts of data are often available as an aid to the process. Care is needed, however, as fisheries data tend to be collected for assessment purposes. They are often "coarse-grained". The information content of data that can be retrieved is determined by the scale and accuracy of their collection, together with the power of the analytic techniques available for their interpretation. In addition to data we have recourse to scientific experience and theory and potentially, to the extensive knowledge of fishermen (McGoodwin, 1990). The task is to use these bases to construct the range of plausible simulation models required to evaluate the potential performance of viable management actions for any particular fisheries system. The simulation models constructed need to be accurate and conditioned on data. If they are not, credibility is hard to build.

The approach of creating plausible system models and using Monte Carlo simulation techniques is now well developed in fisheries. The application of such techniques, together with experimental designs, provides a powerful means of supplying decision makers with a valid and credible basis for dealing with multi-criteria problems.

COMMUNICATING UNCERTAINTY ANALYSES TO DECISION MAKERS

One criticism often levelled at the complex systems analysis/decision making approach outlined above, is that it is too complicated to communicate to decision makers. In fact, these techniques have been used with success in Australia, New Zealand, South Africa, the International Whaling Commission and the United States, at least (references above). The experiences of scientists and decision makers in the process has received no formal attention in the literature. It is difficult, therefore, to judge whether or not certain methods of communication are better or worse than others. This is an area in which research is needed.

The longest and most complete decision making process has undoubtedly been in the somewhat unusual circumstances of the International Whaling Commission. In that body, which had to decide upon a Revised Management Procedure for baleen whales, the political agendas were indisputably more important than the scientific facts. A personal view (TKS) of the IWC experience is that the decision making process nevertheless followed closely the prescription in this paper. That is, The Commission asked its Scientific Committee to develop a management procedure. The Scientific Committee asked the Commission for objectives to aid in this development but received only three suggestions, with no agreement on relative weightings. The three suggested objectives were conflicting, were imprecise and could not be defined operationally. The Scientific Committee therefore interpreted for itself, what metrics (performance measures) might be appropriate. Following this, the Scientific Committee slowly, and iteratively, developed plausible system models and management procedures to test. Initial screening of procedures on simple system models was used to remove management procedures that did not meet minimally acceptable performance levels on the performance measures. Only procedures that were adequate were tested on the full range of plausible system models. The results from this work were obtained over many years and amounted to thousands of pages of output. The communication of results to the Commission, however, involved a considerably reduced set of outputs which related directly to the objectives first suggested, and sufficient for the Commission to reach a decision. In reaching that decision, scientists had to use subjective interpretation and choose outputs, and the Commission had to use subjective judgement, weighing up scientific results but also multinational political objectives. In reaching the decision, objectives were traded-off or neglected dependent on negotiation and/or voting strength.

How to involve the many relevant, interested parties in decision making is beyond the scope of this paper. What is clear, is that decision analyses require careful specification of objectives, viable management actions and, ideally, values. This is best achieved by involving interested parties in the whole process. The task of scientists is to develop techniques to communicate the outputs from complex uncertainty analyses in a clear and understandable fashion that relates directly to management objectives.

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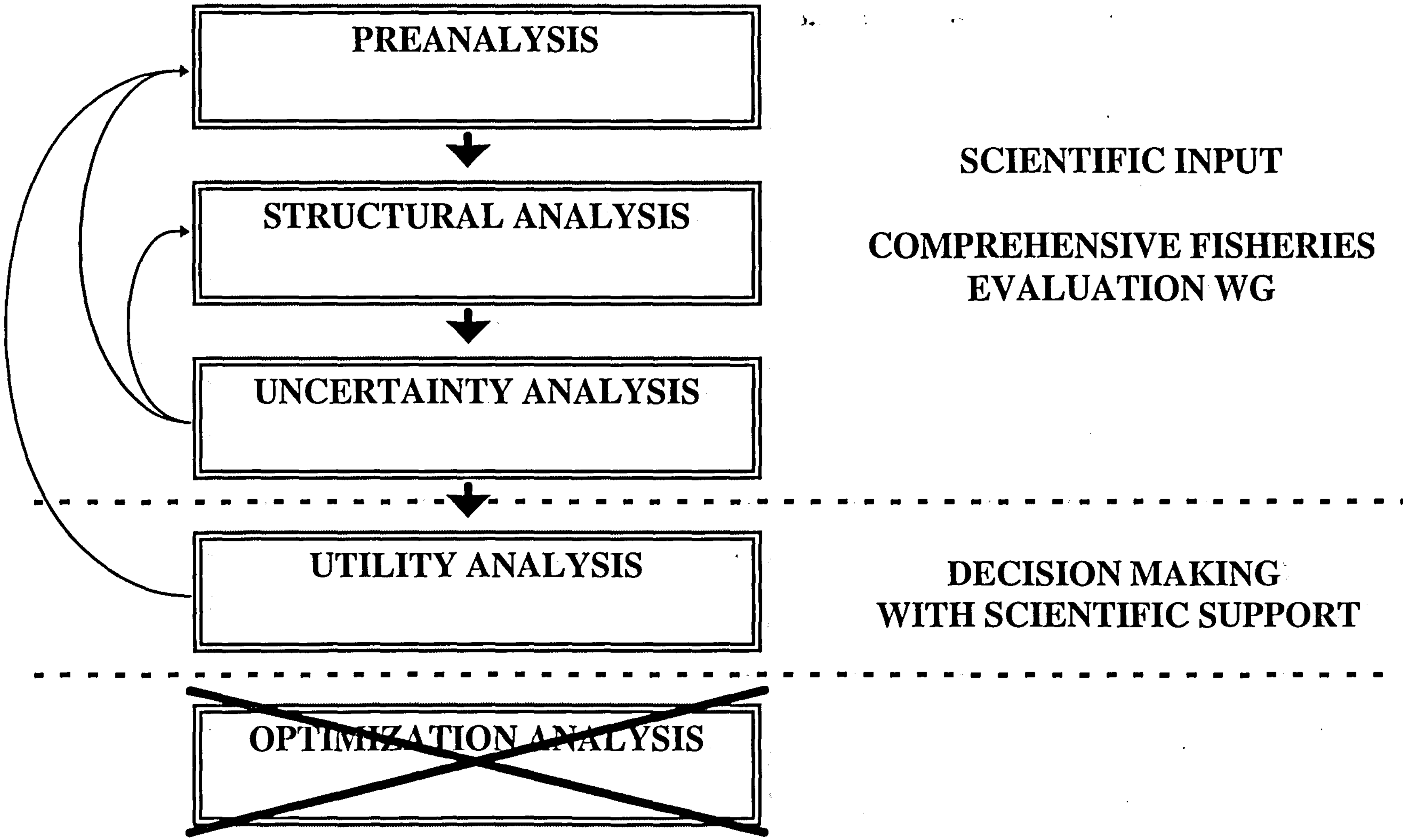

Figure 1. A schematic for decision making in fisheries