CHAPTER 5

THE USE OF SCIENTIFIC INFORMATION IN THE DESIGN OF MANAGEMENT STRATEGIES

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1. INTRODUCTION

A typical marine ecosystem is a dynamic and complicated network of natural populations, sometimes spread over tens of thousands of square kilometres, continually changing and moving, influenced by the variable and usually unpredictable meteorological and marine environments. The fisheries exploiting those natural populations are a part of the ecosystem and are also complex and dynamic, using gear-types, fishing strategies and expert knowledge that differ from fisher to fisher or vessel to vessel and are also likely to change with time. To make it even more difficult, the fish and invertebrate populations are usually widely dispersed, hidden from our view and hence very difficult to monitor. Their growth and mortality rates can and usually do change considerably with age and over time and recruitment of young fish to each stock is highly variable. With all of these complexities and uncertainties put together, the fisheries manager is operating in a complex and confusing environment. However, livelihoods and incomes depend on wise decisions made by the managers, and wise decisions are only possible if the managers have adequate knowledge of the ecosystem and fishery to allow them to understand the causes of the current situation in the fishery and to forecast how the resource and fishery will change in response to management actions. The purpose of this chapter is to examine the issues which need to be considered by the manager in implementing effective management strategies, the information which the manager should attempt to have available to guide those decisions, and how this information should be used in making them.

The fisheries manager is likely to be, and should be, involved in setting the fisheries policy and goals (Steps 1. and 2., Table 1). Policy and goals are a part of the strategic planning of the fishery and are usually put in place and modified infrequently, typically being reviewed only every five years or longer (see also Chapter 9). They set the framework for the fishery during this period and should be established with careful consideration of the best available knowledge of the resources and fishery. On a day to day basis, however, the manager is likely to be more involved with the shorter term, tactical decisions of fisheries management, translating the goals into operational objectives and ensuring that the management strategy being used is the best means of achieving those objectives. These are primary tasks of fisheries management and this chapter focuses on how the manager should ensure that they are done using reliable and appropriate information. The great challenge of fisheries management is to choose and implement the best management strategies to achieve the objectives, despite the fact that there will always be gaps and uncertainties in the knowledge required for fully-informed decisions and actions.

Table 1. The steps normally required in determining an appropriate management strategy to achieve specified operational objectives

Step	Scope	Role of Scientific Information
1. Determine fisheries policy	Applies to whole fisheries sector	Guided by broad information on types of fisheries, nature of resources and ecological context, social and economic characteristics and importance.
2. Set goals	Applies to specific fishery (e.g. as defined by target resources)	▪ Draws on historical performance, including yields, economic performance and social contribution. ▪ Considers existing problems and opportunities. ▪ Constrained by scientifically estimated limits. ▪ May be assisted by formal decision-making techniques.
3. Determine operational objectives and set reference points	Applies to specific fishery. Social and economic objectives may also differ according to sub-sector in fishery (e.g. large-scale commercial, small-scale commercial, subsistence etc.)	▪ Analyses and models used to test, refine and quantify objectives. ▪ Conflicts between different objectives resolved. ▪ Target and/or limit reference points defined. ▪ Requires iterative consultation between decision-makers and scientists. ▪ May be assisted by formal decision-making techniques.
4. Determine management strategy	Composed of management measures, some of which may be sub-sector specific (e.g. gear restrictions, fishing areas) while others (e.g. closed seasons and areas) may apply to fishery as a whole	▪ Uses analyses, models, and expert knowledge of interested parties to test performance of management measures against operational objectives. ▪ Determines suite of management measures best able to achieve operational objectives. ▪ Considers realities of fishing operations in sub-sectors. ▪ Considers compliance and enforcement. ▪ Requires iterative consultation between decision-makers and scientists.

2. WHAT DATA AND INFORMATION DO I NEED?

2.1 What information is needed to help make a decision?

In many fisheries agencies, insufficient attention is given to the collection of data and information, and the attempts by these agencies to manage their fisheries are therefore flawed from the outset. Some other agencies go to considerable trouble and expense to collect information on their fisheries, but then do not process and store the information correctly and do not analyse it properly, or at all. Collection of fisheries data is not an end in itself, data stored in log books or on data collection sheets and collecting dust in a cupboard represents a wasted resource. For responsible fisheries management to occur, the required data must be collected and used to obtain information to assist in managing the fishery effectively and hence improving the long-term benefits derived from it. Table 2 summarises the data that are typically required for management. These requirements are determined by the issues and operational objectives the manager needs to consider. They fall into the categories used in Table 2: biological, ecological, economic, social and institutional and can be summarised by the following simple questions that should be continually in the mind of the manager.

– Are current catches in the fishery sustainable and making good use of the resource?

– Are current fishing practices avoiding any damaging and irreversible impact on non-target species in the ecosystem?

– Are the current fishing activities having minimum practical impact on the physical habitat?

- Are other non-fishing activities in the fishing grounds and in the supporting ecosystem being adequately managed to avoid damage and irreversible impact on the ecosystem, including the critical habitats?
- Is the fishery being conducted in an economically responsible and efficient manner consistent with the economic goals and priorities of the country or local area?
- Are those dependent on the fishery for income and livelihoods receiving appropriate, beneficial returns from their fishery-related activities?

If the answer to any of these questions is "No", then the manager needs to consider how the management strategy can be adjusted, through changing management measures, to correct the situation without unacceptable negative impacts on the answers to the other questions. If the manager is unable to answer any of these questions then he or she is inadequately informed to be able to fulfil the mandate of the job properly.

Table 2. Some basic data requirements for providing information to fisheries managers and decision-makers to assist them in selecting suitable management strategies. Additional information on these can be found in the Technical Guidelines (FAO, 1997)

Objective(s)	Data Requirements
Biological	Total landings by major species per fleet per year Total effort by fleet per year Length and/or age composition of landings for major species Discards of major species per fleet per year Length and/or age composition of discards per species per fleet per year Areas fished by each fleet
Ecological	Total catches of bycatch species (including discarded species), or selected indicator species, per fleet per year Length and/or age composition of catches of bycatch species or selected indicator species Impact of fishing gear and activities on the physical habitat Changes in critical habitats brought about by non-fishing activities
Economic	Average income per fishing unit per year for all fleets Costs per fishing unit per year Profitability of each fleet (in the absence of detailed economic data this could be based on interviews or similar information) Destination of landings from each fleet, and a measure of the dependence on the fishery of other sectors of the community (e.g. processors, wholesalers etc)
Social	Total number of fishers employed within each fleet Total number of people employed in fishing or shore-based activities per fleet, by gender and age group where appropriate Dependence of fishers and shore-based workers for their livelihoods for each fleet

It is not enough in modern fisheries to attempt to answer these questions with "gut feel" or the unsubstantiated opinions of others. It should be possible for the manager to answer all of these questions making use of good, accurate and recent information, including verifiable information from the interested parties, that will enable him or her to justify the answer and demonstrate the rationale for the answer. The data collected from the fishery will usually be the major source of the information available to the manager. However, these data need to be properly collated and analysed in order to extract meaningful and relevant information for the manager. In most agencies, the scientific division or unit of the agency would be responsible for processing and analysing the basic scientific data.

2.2 Where do I get the information and how can I use it?

Recognising both the importance and difficulties of using good knowledge, the Code of Conduct (Paragraph 6.4) requires that "Conservation and management decisions for fisheries should be based on the best scientific evidence available, also taking into account traditional knowledge of the resources and their habitat, as well as relevant environmental, economic and social factors". This requirement involves three steps:

- the collection of suitable data and information on the fisheries, including on the resources and on the environmental, economic and social factors;
- appropriate analysis of these data and information so that they may be used to address the decisions that need to be made by the fisheries managers, and
- the consideration and use of the analysed data and information in actually making the decisions.

The first of these topics, data collection and monitoring, is a vast topic in its own right and has been the subject of many publications (e.g. see FAO, 1999a) and is also discussed in some detail in the Technical Guidelines to the Code of Conduct: Fisheries Management (FAO, 1997). It is essential that the management agency makes best use of the human and financial resources available to ensure that the most appropriate information for management of the fishery is being continuously collected, is accurate, and is processed and stored in a way in which it can easily be accessed and used.

The second topic, incorporating statistical, stock assessment and social and economic analyses, has been discussed even more thoroughly in the literature. The data collected has to be analysed and processed, typically the function of fishery scientists, economists and social scientists, in order to examine the features and performance characteristics of the fishery which are of interest to the decision-makers. Again, this handbook does not go into the details of the methods of stock assessment and bioeconomic analyses, both of which are disciplines in their own right and have been the topic of many high quality publications. For assistance in these topics, the reader is referred to, for example, Sparre and Venema (1992), Hilborn and Walters (1992) and Seijo, Defeo and Salas (1998), all of which are listed under Recommended Reading at the end of the Chapter. This chapter does consider how the results of these analyses can and should be used, and the third step in the process, the use of the results obtained from the analyses to inform decision-makers, is an important part of the chapter.

In recent years, there has been an increasing awareness of the value of the knowledge and insights of the users of the resource, including traditional knowledge. This is recognised in the Code of Conduct in Paragraphs 6.4 and 12.12, where it is stated that "States should investigate and document traditional fisheries knowledge and technologies, in particular those applied to small-scale fisheries, in order to assess their application to sustainable fisheries conservation, management and development." This is discussed further in this chapter and in Chapter 7.

3. HOW MUCH FISH SHOULD BE CAUGHT: HARVESTING STRATEGIES AND REFERENCE POINTS?

In Chapter 1, Section 7, a management strategy is described as the overall set of measures put in place by the fisheries management authority to regulate the fishery. These measures can include: technical measures relating to gear which are frequently long-term and only occasionally adjusted; technical measures relating to closed areas and seasons which can be put in place over a range of time scales; and input controls, output controls or both, which will often be adjusted more frequently, often annually. The input and output controls are usually central to a management strategy and the actual control value, e.g. the total allowable catch or the permitted effort in a year needs to be determined with care so as to optimise the benefits from the resource in a sustainable way. In setting the control, account must be taken of the status and productivity of the resources, the objectives for the fishery, the needs of the interest groups and the fishing practices in use.

The importance of goals and objectives was emphasised in the Introduction to this Handbook (Section 6 of Chapter 1). As discussed there, the goals for fisheries are frequently expressed in broad terms which are typically too vague to be particularly useful to the manager as actual targets for a management strategy and frequently have conflicts between their different requirements. They therefore need to be developed further if they are to be useful in devising appropriate management strategies, and must be translated into operational objectives. The operational objectives should always be the frame of reference for the manager, both to evaluate how well the management strategy is working and also to evaluate how well the management agency is performing. The manager and decision-makers should regularly be reviewing the management strategy and adjusting it as necessary to ensure that it is the best approach to achieving the objectives. Therefore, the operational objectives must be:

- measurable;
- realistic and achievable;
- accepted by the interested parties in the fishery (Chapter 7), and
- linked to a time-frame.

For example, within a particular fishery, it may have been found that the broad goals presented as an example in Chapter 1 could be best achieved through the following operational objectives:

- to maintain the stock at all times above 50% of its mean unexploited level (biological);
- to maintain all non-target, associated and dependent species above 50% of their mean biomass levels in the absence of fishing activities (ecological);
- to stabilise net income per fisher at a level above the national minimum desired income (economic); and
- to include as many of the existing participants in the fishery as is possible given the biological, ecological and economic objectives listed above.

In this form, these operational objectives are much more specific than the goals and, if the information has been reasonably accurate and the decision-making sound, they will have been selected so that they are simultaneously achievable if a suitable management strategy is developed i.e. there should be no irreconciled conflicts between them. In the hypothetical example, in order to address a potential conflict between maintaining net income per fisher and maintaining employment, it was agreed that net income for the fishers must be maintained above what is referred to as the national desired minimum, but that this may require reducing the number of fishers. Therefore it was (hypothetically) decided to set no minimum limit on employment, but that it would be kept as high as possible without reducing the income below the threshold of those allowed access to fishing.

These operational objectives include reference points such as maintaining the stock above 50% of the unexploited level and the national minimum desired income. Reference points are usually used to guide the manager in setting and adjusting the management measures and provide a guideline as to either a desirable state of the resource or the fishery (a target reference point) or a state to be avoided (a limit reference point). In the example above, both 50% of the unexploited level and the national minimum desired income are used as limit reference points. While similar reference points are used in many fisheries (e.g. $F_{0.1}$ or B_{MSY}), the actual value of any given reference point will be particular to a given resource and fishery, and will need to be estimated for each case and be reviewed periodically.

The target and limit reference points provide signposts for the manager: 'here you are doing well' (target) or 'go any further down this route and we are in trouble' (limit). The manager also needs to know the status of the resource and fishery in relation to those signposts and this requires on-going monitoring of both. The specific characteristics to be monitored are known as performance indicators (or criteria) and relate directly to the reference points: the reference points are specific values of the performance indicators. For example, the performance indicator for the limit reference point of 50% of unexploited biomass would be the current or forecast biomass expressed as a percentage of the unexploited biomass. Net income per fisher would be the performance indicator for comparison with the national minimum desired income.

Once operational objectives, their associated reference points and the performance indicators have been agreed upon, a management strategy that will achieve these objectives must be developed (Table 1). Identifying and selecting the best management strategy requires adequate and appropriate scientific data and information covering all objectives. In practice, developing operational objectives and the management strategy that will achieve them are frequently undertaken simultaneously and interactively, as they are so closely inter-related and require similar information and methods.

3.1 Basic harvesting strategies

Input and output controls are usually set on the basis of one of three basic harvesting strategies (not to be confused with management strategies: a harvesting strategy is one component of the management strategy). The three basic harvesting strategies are: constant catch; constant proportion or constant harvest rate (equivalent to constant effort if catchability of the resource remains the same); and constant escapement (Figure 1). A constant catch strategy will, by definition, result in no change in catch from year to year. However, for the manager to implement a constant catch strategy, that catch must be set low enough to apply in bad years as well as in good years, without damaging the future productivity of the stock, and must therefore be set at a relatively low level. Therefore the fisher pays a price for the absence of inter-annual variability in catch in a constant catch strategy by foregoing potential catch in good years. In a constant proportion strategy, the effort remains constant and therefore there will be changes in catch from year to year as the resource varies over good, bad and intermediate years. This variability results in some uncertainty about future catches for the fisher compared to the constant catch strategy. It also has benefits for the fisher, though, as it means the catches will be higher in good years, in contrast to the constant catch strategy, generally leading to a higher annual average catch. A constant escapement strategy (or constant stock size strategy) would aim to ensure that a constant biomass, sufficient to maintain recruitment, was left at the end of every fishing season. This type of strategy tends to achieve the highest annual average catches of the three categories but with the highest variability, in many cases including zero catches in some years.

The decision on which type of harvesting strategy to pursue should be made from a knowledge of the requirements of the fishery and with consultation with the interest groups on the trade offs they would like to make between maximising catch and minimising variability. The much more difficult question is, given one of the strategies, how does the manager decide on the actual catch, effort or escapement which should be set under the strategy. This is discussed in later sections of the chapter. It should also be noted that these harvesting strategies could all be pursued through the use of output control (setting a TAC), input control (setting the effort that can be expended in a year), or even the use of closed seasons (which can be a form of output control – see Chapters 3 and 4).

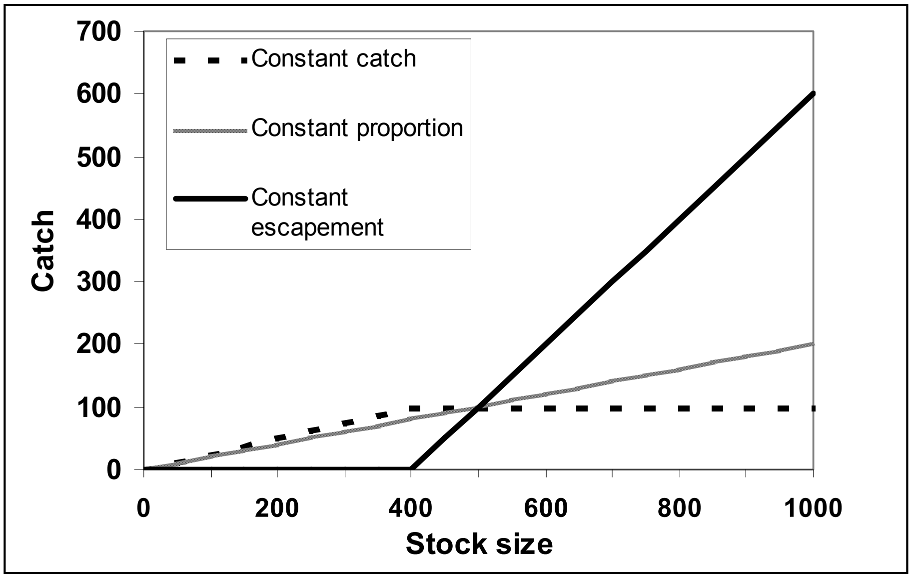

Figure 1. Simple examples of the three classes of harvesting strategy and their relationship to stock size: constant catch (with provision for a linearly decreasing catch when the stock size falls below 400); constant proportion; and constant escapement (after Hilborn and Walters, 1992).

3.2 The classic reference point : maximum sustainable yield

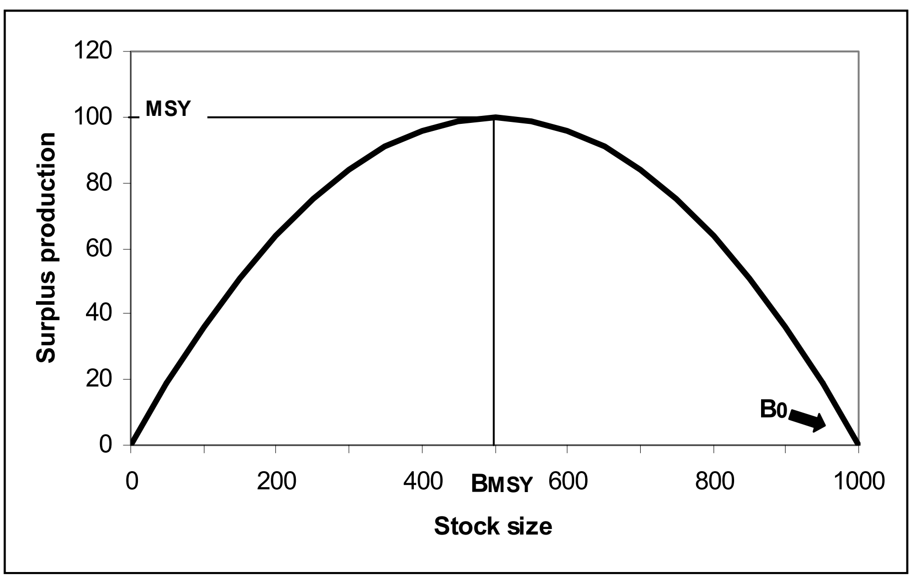

Figure 2. Schaefer model of surplus production (biomass dynamic) as a function of stock size showing the major reference points. Other forms of surplus production model can have BMSY at a higher or lower stock size than the 50% of B0 of the Schaefer model. MSY = maximum sustainable yield; BMSY = the biomass at which MSY occurs; and B0 = the average unexploited biomass of the stock (the average 'carrying capacity').

In the 1960s and 1970s, maximum sustainable yield (MSY) was seen as the ideal target to aim for in managing fisheries, and managers attempted to obtain MSY through striving to set the MSY as a target catch level or to determine the fishing mortality rate that would generate MSY (F_{MSY}). The maximum sustainable yield concept is based on a model, referred to as a surplus production or biomass dynamic model (Figure 2), which assumes that the annual net growth in abundance and biomass of a stock increases as the biomass of the stock increases, until a certain biomass is reached at which this net growth, or surplus production, reaches a maximum (the MSY). This biomass is referred to as B_{MSY}, and the fishing mortality rate which will achieve MSY is similarly referred to as $F_{MSY.}$ As the biomass increases above B_{MSY}, density dependent factors such as competition for food and cannibalism on smaller individuals start to reduce the net population growth which therefore decreases until at some point, the average carrying capacity of the stock, net population growth reaches zero. In reality, an unexploited stock will tend fluctuate about this biomass because of environmental variability.

MSY was such a well established target for managing fisheries that it is included in the 1982 United Nations Convention on the Law of the Sea (LOS), where it is stated that coastal management agencies should "... maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield, as qualified by relevant environmental and economic factors".

This requirement of the LOS is equivalent to specifying a limit reference point of B_{MSY}. This is not the same as setting MSY as a target reference point for catch, however, and using MSY as a target reference point has been found to be dangerous. This is because it is impossible to estimate MSY precisely for any stock. If MSY is over-estimated, then a fishery will be allowed to take more than the maximum production of the stock which will cause a reduction in the biomass every year. In a new fishery this could drive the biomass down to the level at which MSY is produced (B_{MSY}) but if continued after that will drive the biomass down further, where annual production gets smaller and smaller, making the situation even worse. Even if average MSY could be precisely determined, the productivity of a stock varies from year to year under the influence of environmental variability. Therefore if the stock is at $B_{MSY,}$ in some years production may still be less than MSY and, if MSY is taken as the catch, the biomass will be driven below B_{MSY}, possibly driving the stock into a downward spiral. Therefore MSY is no longer seen as a target reference point for fisheries managers to strive for, although it can still be used as a limit reference point i.e. as an upper limit to the annual catch, which should be avoided.

3.3 Reference points based on fishing mortality rate

A standard assumption in stock assessment is that:

Catch = (Fishing effort) X (Catchability per unit of effort) X (Abundance of the stock)

From this, it can be seen that if catchability remains constant each year, then the fishing mortality rate (catch as a fraction of abundance) is directly related to effort: the higher the effort the higher the fishing mortality rate i.e.:

Catch/(Abundance of the stock) = (Fishing effort) X A constant

Therefore, a strategy which attempts to maintain a specific fishing mortality rate is equal to a constant effort strategy as long as catchability remains constant. A desirable (target) fishing mortality rate should be determined from examining the productivity of the stock (through a stock assessment) and could be based on, for example, yield and biomass-per-recruit considerations or, as with MSY, on surplus production considerations.

Yield and biomass-per-recruit methods examine the individual growth and mortality rates of a species or stock and use these to model the proportion of each recruit (perhaps easier to think of as a percentage of 100 recruits) that would be caught by a fishery at a given fishing mortality rate. As with the surplus production model, it is usually found that this yield-per-recruit increases with increasing fishing mortality (or effort) up to a maximum, and then begins to fall as effort increases above that maximum (Figure 3). The fishing effort which results in the maximum yield-per-recruit is referred to as F_{max} and could be used as a target reference point. However, before selecting this as a reference point, the affect of F_{max} on the spawner biomass should be checked. As shown in Figure 3, surviving spawner biomass falls continually as F is increased and one needs to select a fishing mortality rate that not only achieves a good yield-per-recruit but also leaves a sufficiently high spawner biomass (as indicated by spawner biomass-per-recruit) in the water to ensure good recruitment is maintained. It is commonly accepted that for many stocks the minimum desirable spawner biomass is between 30 and 40% of the spawner biomass in the absence of fishing. Figure 3 shows the fishing mortality that would result in spawner biomass being reduced to 40% (referred to as F_{SB40}). In this example, F_{SB40} is considerably lower than F_{max}, so some trade off in short-term maximum yield would be required in order to ensure spawner biomass is kept high enough to ensure sustained recruitment.

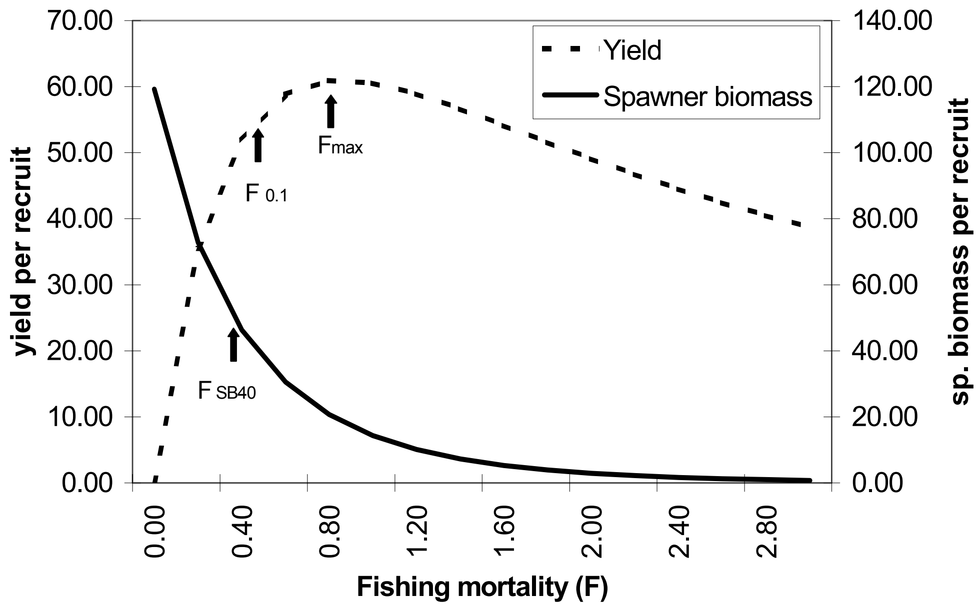

Figure 3. Yield and spawner biomass-per-recruit plots for a hypothetical snapper stock, showing common reference points for fishing mortality: F_{max}; $F_{0.1}$; and $F_{SB40\%}$. See text for explanation of the different reference points.

The third reference point shown in Figure 3 is $F_{0.1}$, which is widely applied as a target reference point. Although the definition of $F_{0.1}$ may seem confusing, it is relatively easily calculated from a yield-per-recruit curve using, for example, a spreadsheet and a minimisation routine (e.g. Solver in Excel). $F_{0.1}$ is defined as the F value at the point where the slope on the yield-per-recruit curve is 10% (0.1) of the slope at the point where F is 0 (the initial slope). There is no theoretical rationale for the use of the $F_{0.1}$ reference point except that it will always be less than F_{max} and hence result in a higher spawner biomass after fishing (e.g. Figure 3) and it has been found, in general, to be quite robust to important uncertainties. In the example shown, in order to choose between an $F_{0.1}$ and a F_{SB40} strategy, the scientists and decision-makers would need to consider the accuracy of their per-recruit data and results, and aspects of the biology of the species such as variability in average recruitment and the natural mortality rate of the species.

3.4 Reference points based on size-limits

In many fisheries there is little information available on the biomass of the stock and estimates of F and M, even if available, may be very unreliable. This frequently applies in small-scale fisheries, especially (but not exclusively) in developing countries. In such cases, a minimum precautionary approach could be to ensure that no immature fish are caught in the fishery and that a reasonable proportion of the fish in the stock have the opportunity to reproduce. This requires specifying the minimum size of fish (typically expressed as a length measurement) which can be caught. The minimum size would then be a limit reference point for the fishery. Clearly this could only be considered when the fishing gear or method being used is sufficiently selective for fishers to be able to target specific size ranges and when the regulation can be enforced. Size-based reference points would typically be implemented through gear restrictions (Chapter 2), possibly complemented by area or time closures (Chapter 3). An appropriate minimum size to be set as a reference point could be identified by looking at the relationship between the size of the species and the percentage which have reached maturity or by looking at spawner biomass-per-recruit curves with different ages at first capture. Size-based reference points to set limits on minimum size at first capture have been widely applied in invertebrate fisheries and, with suitable minimum sizes and good enforcement have frequently been successful. As with all management measures, however, they would normally not be adequate as the only measure and would be implemented in combination with others in order to address the full range of objectives.

3.5 Multi-species and ecosystem-based reference points

The reference points discussed above are all single-species reference points and assume that only one species is being fished for and managed. In practice very few fisheries are truly single-species and range from fisheries with a small bycatch of other species to those with a wide diversity of species in the catch, perhaps without any single-species being dominant. The Code of Conduct requires that "... catch of non-target species, both fish and non-fish species, and impacts on associated or dependent species are minimised" and also that "biodiversity of aquatic habitats and ecosystems is conserved and endangered species are protected" (Paragraph 7.2.2). These stipulations require that multi-species and ecosystem impacts are also taken into account when determining management strategies and should therefore be considered at the same time as selecting appropriate reference points to guide management of the fishery.

In order to achieve responsible ecosystem-based fishery management, the manager should identify and apply ecosystem reference points and then set a management strategy in accordance with those reference points. However, genuine ecosystem-based reference points are rarely, if ever, used and the best approach at present is usually to develop a suite of single-species or single-factor indices and to manage according to those. Under this approach, not only would reference points be developed and applied for the major target species, but also for key by-catch species, indicator species and species identified as being vulnerable or depleted. The strategy would be developed based on the full suite of reference points and make use of gear regulations, closed areas and/or closed seasons to minimise undesirable impacts on non-target species. In addition, if sustainable catch of a vulnerable by-catch species required a lower amount of effort in a fishery than the desirable target effort for the main target species, the effort should be set at the lower level to ensure sustainable fishing on the vulnerable species. In practice, this approach could well lead to a need for more conservative fishing, and hence a short-term reduction in social and economic benefits. In the longer-term, however, such an ecosystem-based approach applied to many existing fisheries should lead to an increase in the quality and hence value of the catch through allowing valuable depleted species to recover from decades of over-exploitation. In many cases, where over-exploitation has been severe and sustained, it could also lead to an increase in quantity as the many over-exploited species recover to more productive biomasses.

Alternative, or additional, indicators could be, for example, monitoring over time the percentage contribution of species to catches, tracking indices of species diversity in the catches or population, and monitoring length frequencies of indicator species or taxa to check for signs of growth over-fishing.

3.6 Economic and social reference points

Other reference points consider the economic performance of the fishery and include maximum economic yield (MEY) and the fishing mortality rate (F_{MEY}) and effort (f_{MEY}) which achieve maximum economic yield. They can be estimated from, for example, the Gordon-Schaefer model (Figure 4) which combines a surplus production curve for the stock in question with the relationship between the cost of fishing and fishing effort. The Gordon-Schaefer model can also be used to estimate the theoretical bioeconomic equilibrium (BE) in an open access fishery, at which point costs and revenues are equal so that there is no incentive for new entrants to join the fishery (Figure 4).

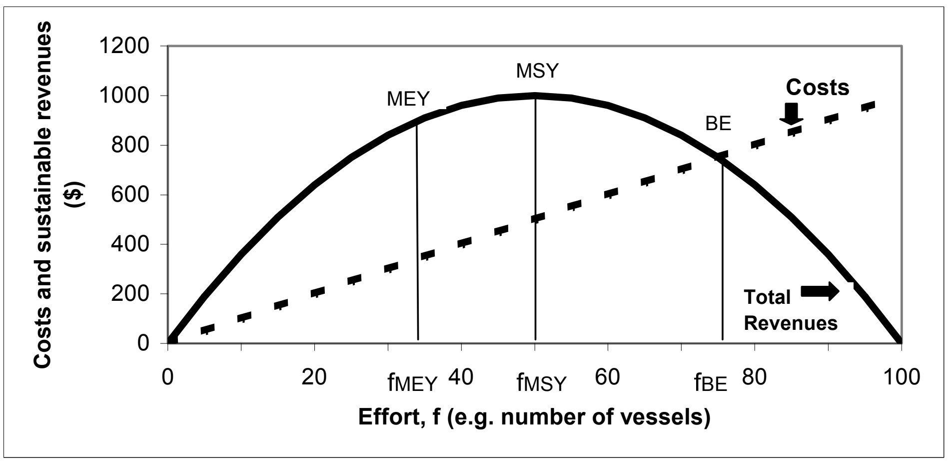

Figure 4 Gordon-Schaefer bioeconomic model of costs and sustainable revenues for a fishery as a function of fishing effort. MEY = maximum economic yield, MSY = maximum sustainable yield, BE = the bioeconomic equilibrium (see text for explanation). The suffix f indicates the effort at each of those reference points.

Reference points can also be set on the basis of other economic or social performance indicators and should be established from the operational objectives of the fishery and consideration of the monitoring capacity of the management agency and fishing groups. They could include indices of employment, income per person or fishing unit, age composition of the fishers, levels of satisfaction or any other measure of the benefits, or opposite, being generated by the fishery or fisheries.

4. WHAT TOOLS CAN BE USED TO GENERATE INFORMATION TO ADVISE MANAGEMENT?

In the case of, for example, a pharmaceutical company trying to develop a new drug, the best medication (management strategy) to cure an illness (the operational objective) will be determined by undertaking an intensive series of laboratory tests. The results of these tests will inform the company as to whether any of the drugs they have been developing will provide a cure and should be commercially produced. Unfortunately, controlled tests of this nature are not possible in fisheries management but, wherever enough data on the fish and fishery are available, mathematical calculations and projections, ranging from relatively simple to very complex, can be used as a type of laboratory and thereby to advise the decision-makers on the status of the fisheries and what, if any, adjustments are needed in the existing management strategies. A primary purpose of the data collected by the management agency is for these purposes.

A message emphasised in this Handbook is that fisheries science is still an imprecise science and there are limits to our knowledge of the dynamics and behaviour of individual stocks and even more so of communities and ecosystems. In many cases what we don't know far outweighs what we do! Nevertheless, by monitoring trends in populations and communities, by observing their responses to fishing and to environmental factors, we can gain invaluable information on how they are likely to respond in the future, including to changes in management strategy. In keeping with most aspects of human knowledge, the closer the forecast situation is to circumstances that have been experienced before, the more reliable it is likely to be. Put another way, beware of long-term forecasts and forecasts that go far beyond previously experienced conditions.

Just as laboratory tests can be good and bad, so can mathematical tests and models. The scientific staff of the management agency are responsible for trying to develop the best mathematical methods with the resources and data that they have available in order to:

- provide the information required by the decision-makers;
- be sufficiently accurate to minimise the chances of making incorrect decisions; and
- reduce the uncertainty remaining in the answers to a low enough level for the decision-makers to be reasonably confident that their selected strategy will work.

They must also ensure that the decision-makers are aware of uncertainties and potential errors in the estimates and forecasts. Fisheries managers and interested parties are generally interested in the net production of a resource and how much of that can be taken by a fishery. Net production is composed of three basic processes: recruitment of new individuals to a population through reproduction; the sum of the individual growth of all the members of a population; and the total mortality, which can be divided into the individuals caught and killed or removed by the fishery (fishing mortality) and the members killed or dying by any other cause (natural mortality). All stock assessment methods attempt to determine those rates directly or indirectly, and to consider how they could change at different population sizes, under different management strategies and, where considered, under different environmental and ecological conditions.

4.1 Single-species methods

Single-species methods of stock assessment, as their name implies, consider only the population or stock of a single-species or species-group at a time and generally make the assumption that the dynamics of the population (recruitment, growth, mortality) are affected only by the abundance or biomass of that stock and the affect of fishing on it. This assumption obviously ignores the effects of the environment and of other populations, such as the abundance of predators and prey, on the stock . The reasons why single-species methods make these blatantly incorrect assumptions is because there is an underlying population effect which is important to understand in managing fisheries and because the interactions between environment, community and the stock of interest are frequently so complex and so poorly understood that it is often impossible to build models that reflect any verifiable understanding of this reality. The underlying population affect is sufficiently important that in most cases where good single-species assessments are undertaken using reliable data, they do provide invaluable information for the management of that stock. Despite their limitations, they should therefore not be discarded but every effort should be made to ensure that the method is appropriate for the resource and the questions being asked, and that the data are as reliable and complete as practically possible. Results from these models should also be supplemented by information on the fishery and ecosystem from other sources, including the interested parties, socio-economic studies and the use of ecosystem indicators and models.

Table 3. Main categories of single-species stock assessment methods and their characteristics.

METHOD	MAIN INFORMATION REQUIRED	COMMENTS
A. Production models	-Annual catch -Annual index of abundance e.g. cpue or biomass estimate	- Do not consider age structure of catch or population - Estimate parameters and variables such as MSY, effort at MSY, mean unexploited stock size, biomass time series etc. - Very widely applied e.g. tuna commissions, south east Atlantic - Caution should be used, especially when fitting with equilibrium methods - Good estimates require good data contrast in effort and biomass
B. Size and age-based models		
B1.Yield and biomass-per-recruit	-Somatic growth rate -Natural mortality rate -Age/size at recruitment to fishery - Selectivity of gear for different age/size classes -Mean size at sexual maturity	- The Beverton and Holt per-recruit models assume knife-edge selectivity and constant fishing mortality and natural mortality for all ages. The general models avoiding these assumptions are preferred. - Assume the stock is in equilibrium i.e. that the biomass and age –structure are constant from year to year. - Assume that recruitment is constant from year to year, which is likely to be false at high fishing mortalities when low spawning biomass may reduce recruitment.
B2. Virtual population analysis (VPA) and cohort analysis	- Number of fish caught per age class.	- One of most powerful assessment methods available. - Provides estimates of past stock abundances, size-selectivity in fishery and estimates of recruitment to fishery. - Requires independent estimate of F for cohorts still present in the fishery (terminal F's), either from assumption or by direct estimate from surveys or mark-recapture. - Assumptions on terminal F's and M are probably the greatest source of error in VPAs.
C. Stock recruit models	- Separate estimates of stock and recruitment over a number of years	- Recruitment will almost certainly drop if the stock size is reduced sufficiently and managers must take this into account. - Stock size is only one determinant of recruitment, and recruitment will vary substantially around the mean stock-recruit relationship i.e. uncertainty in forecast recruitment will be high even when a good relationship has been determined.

Single-species methods have been intensively studied and applied for decades and many different approaches now exist for different circumstances and different fish types. These are summarised in Table 3. While there are different ways of categorising the methods, in this table they are listed under three categories: surplus production or biomass dynamic models, size/age-based models and stock:recruit models. Each has different data requirements, makes different assumptions and enables different questions and scenarios to be addressed. This is summarised in the table. None of the stock assessment methods are perfect and, as discussed in Section 9, the results of all will be affected by process, observation and estimation uncertainty. The manager must be informed of this uncertainty and how it could affect the results of the stock assessment. The known uncertainties must be considered when choosing management measures and strategies, by considering the potential errors in assessment and decision-making and by choosing options which are robust to the more likely errors. This is an important example of where intelligent application of the precautionary approach is essential.

4.2 Multi-species methods

Single stocks and populations can be affected by other species in the ecosystem in two ways, through biological interactions and technological interactions. Direct biological interactions occur when a species is a predator, prey or competitor of another, in which case any change in abundance and distribution of either species will affect the dynamics of the other. These effects are ignored in single-species models. Indirect biological interactions also occur, for example when a third species, not directly interacting with the first, is affected by changes in the abundance of the first through their impact on a second species directly interacting with both.

Technological interactions occur when one species is affected by the fishing activity on another species, for example if it is caught as a bycatch, whether landed or discarded. In general technological interactions are easier to quantify and hence consider in fisheries management than are biological interactions which are more complex and dynamic. Multi-species per-recruit models are particularly useful for consideration of technical interactions and not especially demanding of data and expertise.

The sum of all these interactions leads to a fundamental principle of fisheries management: that the yield from a multi-species fishery will always be less than the sum of the potential sustainable yields of all the separate species (see Table 1, Chapter 1). Recognising this principle, fisheries managers should be supplementing the information from single-species approaches with that from multi-species and ecosystem tools, allowing them to consider the implications of this principle on their overall objectives and to identify strategies to optimise the yields that realistically can be obtained from the ecosystem as a whole.

It is therefore being increasingly recognised that fisheries management must move from seeing fisheries as dealing with single-species to considering fisheries as the multi-species, ecosystem-based activities that they invariably are. However, the amount of uncertainty is generally much higher as one attempts to include more factors in a problem and this certainly applies in fisheries. Further, as one considers more and more issues and objectives, which is an inevitable consequence of considering the whole ecosystem, the number of potential conflicts and constraints increases dramatically. For these reasons, the necessary move from single-species to ecosystem-based management has barely started in most countries and fisheries. Nevertheless, there are some important tools available for considering these interactions and they should be used to help inform managers in making decisions, with the same careful and precautionary consideration of likely uncertainties and errors as discussed for single-species methods.

The better developed and more commonly applied approaches are shown in Table 4. Of these, multi-species virtual population analysis will be too demanding of data for application in most fisheries and multi-species surplus production approaches are likely to be equally impractical. Aggregated production models, multi-species per-recruit models and dynamic trophic level models have all been applied and found to provide information of relevance and use to fisheries management objectives and strategies.

Table 4. Main categories of multi-species and ecosystem-based assessment methods and their characteristics

METHOD	MAIN INFORMATION REQUIRED	COMMENTS
A. Multi-species extensions of single-species methods		
A1. Multi-species surplus production models	Same as for single-species + indices of abundance +, preferably, abundances of all species with important inter-actions with the 'dependent' species.	In theory, enable consideration of biological interactions, but of little practical value because: - if only indices of abundance are available for the species included, then enormous statistical problems will be encountered in estimating the parameters; and - as for single-species, good data contrast is required for good estimates.
A2. Aggregated production models	- Annual catch aggregated into appropriate species groups -Annual index of abundance e.g. cpue or biomass estimate for same aggregated groups	-Has proven informative in some cases where tried -Provides a feasible source of information for ecosystems with high species diversity -Caution required as the selected reference point for the aggregation could lead to depletion of some vulnerable species while producing sustainable yield for the aggregation as a whole
A3. Multi-species per-recruit models	- As for single-species per-recruit analyses. - The relative catchability of each species for a unit of fishing effort - The relative recruitments of the different species	- Can be used for more than one fishery at a time as well as more than one species - Consider technical interactions, not biological interactions - Involve the same assumptions and limitations as single-species per-recruit methods - A useful tool for assisting in setting reference points in multi-species fisheries
A4.. Multi-species stock recruit models	- As for single-species method - Abundance estimates of other predators and competitors on the species of interest.	- Extends single-species stock recruit models to consider the effect of other species on a given species
B. Multi-species VPA	- As for single-species method - Estimates of the number at age of individuals of the species of interest consumed by all other species	- Has the potential to provide very useful information taking into account some biological interactions - Very data intensive and therefore probably not applicable in most circumstances
C. Food web and trophic level models	- Estimates of biomass of all major species or species groups - Production per unit biomass for each group - Consumption per unit biomass per group - Average diet composition per species group	- The requirements listed here are for a simple food web type model, models incorporating e.g. physical factors require more - In equilibrium form useful for gaining insight into trophic relationships and direct and indirect interactions - In dynamic form (e.g. Ecopath with Ecosim) can be used to explore multi-species implications of harvest policies - Invariably include substantial uncertainty which must be rigorously explored, reported and considered

4.3 Considering the benefits to society

Fisheries exist to provide benefits to humans, and fisheries management should be attempting to optimise those benefits within its objectives. The single-species and multi-species methods described in the previous two sections were focused on the resources, and the benefits in the methods described there are reduced to a single measure: the catch or yield. In a simple single-species, single fleet fishery where all the interested parties have the same objectives, this may be an adequate measure of benefits. Nevertheless, even then the costs of fishing, and hence the net profits, are likely to change with stock abundance, and fishing effort should be explicitly considered. In more complex cases, such as where different fishing groups using different methods are exploiting the same resources or where multi-species resources are being exploited, maximising the yield on a sustainable basis is unlikely to be a full or adequate socio-economic objective, and information on the economic and social benefits for the different groups that can be expected under different management strategies will also be important for decision-making.

Just as there have been many stock assessment tools developed to deal with different types of data and different questions, so there have been many different models developed to extend such assessments to include, particularly, economic performance. A commonly applied bioeconomic model is the Gordon-Schaefer model which, as its name implies, uses the Schaefer surplus production model shown in Figure 2 as the underlying biological model. The Gordon-Schaeffer model was discussed earlier and illustrated in Figure 4.

Age structured bioeconomic models, some including spatial distribution of the resource and fleets have also been developed, allowing the investigation of management strategies that exploit different size or age classes of the resources and in which spatial patterns are significant. Good examples of such models can be found in, for example, Seijo et al. 1998 and Sparre and Willmann 1993, both of which are listed in the Recommended Reading list at the end of this chapter.

In the same way that bioeconomic models can be developed from the standard stock assessment models, so they could be adapted to include social factors. For example, it may be useful to consider effort in the Gordon-Schaefer model in terms of number of fishers, giving a measure of employment as well as revenue. Similarly, if there is a relationship between yield from the fishery and the number of fishing and shore-based jobs, these models can be used to investigate how different management strategies will affect employment. Ecopath with Ecosim can include basic social and economic characteristics of the different fleets fishing on an ecosystem and can therefore be used to investigate the biological, ecological, economic and social impacts of different harvesting strategies within the ecosystem as a whole. This facility has the potential to provide useful information to supplement that obtained from the single-species models, which typically contain more detailed information on that specific resource.

5. HOW IS THE INFORMATION USED TO DEVELOP A MANAGEMENT STRATEGY?

5.1 What sort of biological information is needed?

A primary consideration in selecting a management strategy is the impact of each strategy on the status of the stock, stocks or fish community. In cases where time series of catch and effort information are available, it may be possible to analyse trends in the catch-per-unit-effort, which with careful interpretation may provide an indication of trends in resource abundance. Such trends can indicate when adjustments in the management strategy are required, for example to prevent on-going declines. Catch and effort data may also permit more sophisticated analyses, such as the application of biomass dynamic (surplus production) models and, with additional information on the length or age structure of the catch, virtual population analysis (VPA). More sophisticated analyses allow more sophisticated biological reference points to be determined, enabling the management agency to aim for, for example, obtaining the maximum average sustainable catch, instead of simply aiming to avoid on-going declines. Figure 5 shows the estimated biomass obtained from fitting a biomass dynamic model to catch and effort information from the sardinella fishery in Angola. From this information, the manager could see that the sardinella stock had been recovering from a period of over-exploitation since the catches had declined, and the estimated reference points showed there was scope for increasing the annual catches from their levels in recent years.

Catch and effort data from a fishery are generally the cheapest and easiest information to obtain, and collecting (and using!) good estimates of annual catches and effort should be a fundamental task of the scientific branch of the management agency.

Yield and biomass-per-recruit calculations can also be used to provide information on the status of the stocks, the impact of fishing on them and how to adjust fishing mortality to achieve desired operational objectives through appropriate management strategies. Per-recruit methods require estimates of the growth rate of the species being assessed, their natural mortality rate (which can be approximated from knowledge of the growth rate), and the selectivity of the fishing gear for different size groups or, at least, the size at which the species become vulnerable to capture (Table 3). While this information may appear more difficult to acquire than simple time series of catch and effort, it can be obtained from good time series of the length frequencies of the catches and in some countries these have been collected, even though monitoring of catch and effort has, regrettably, been discontinued.

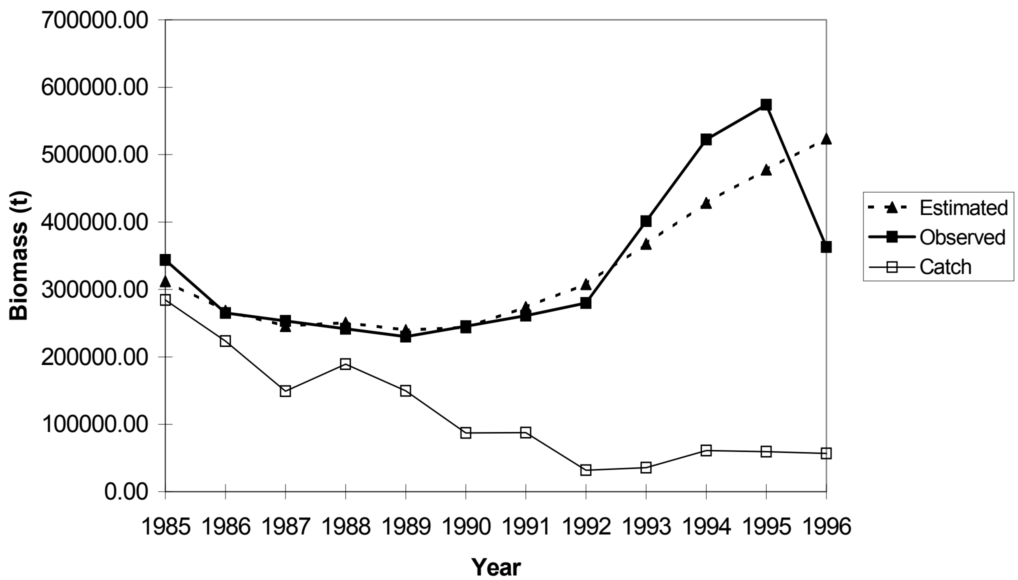

Figure 5. Estimates obtained from fitting a biomass dynamic model to catch and effort data for the fishery for sardinella in Angola. The chart shows the Catch, and the Observed biomass (indicated by catch-per-unit-effort data) compared to the biomass Estimated from a biomass dynamic model.

Consideration of the yield and spawner biomass-per-recruit curves for a particular species and gear type (Figure 3) enables the manager to determine what level of fishing mortality will achieve a good yield-per-recruit while at the same time maintaining a high enough spawner biomass-per-recruit to sustain recruitment. In addition to estimates of appropriate reference points, it is also necessary to consider the current level of fishing mortality in relation to the fishing mortality required to achieve the target. With the same data, an initial estimate of fishing mortality can be obtained through undertaking a catch curve analysis on good estimates or samples of the population length frequency (see e.g. Sparre and Venema, 1992). However, as with all stock assessment methods, accurate and precise estimates are best obtained through the use of time series (minimum 3-5 years, depending on the application and data) of at least good catch and effort information.

The potential yield from a stock is dependent on the average size and age of the fish taken by the fishery and there is generally an optimum average size, below which there is considerable risk of over-exploiting the stock and above which potential yield from the resource is lost. The size-selectivity of the gear used in the fishery is therefore important in managing the fishery, as discussed in Chapter 2. Per-recruit analyses can provide useful information on how changes in selectivity of the gear can influence the potential yield from the resource and the probable survival per-recruit, helping in the selection of appropriate gear. Figure 6 shows the biomass-per-recruit for a western Atlantic snapper caught in two different fleets: as bycatch in an offshore trawl fleet targeting mainly shrimp and in a nylon gill net fishery targeting fish. The former, designed to catch the smaller shrimp species, catches the fish at a smaller size than the gill net, and hence has a considerably greater impact on spawner biomass of snapper at a lower fishing mortality. Per-recruit analyses on the two species indicated that at a fishing effort suitable for sustainable utilisation of shrimp, the snapper and other fish species will be severely over-exploited. Using such approaches, it is possible to consider the trade-offs required, for example, in foregoing yield in the shrimp fishery in order to ensure the sustainable use of the snapper resource.

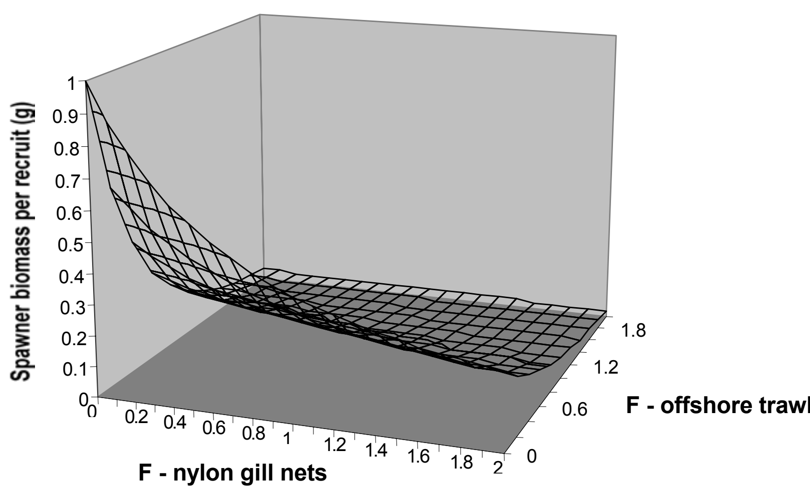

Figure 6. Spawner biomass-per-recruit of a snapper species under different fishing mortalities (F) for two different gear types[1]. The nylon gill nets catch the snapper at a much larger size than the shrimp-directed offshore trawl gear.

All stock assessment approaches require making certain assumptions about the data and the dynamics of the resource. Two common and important assumptions are that catch-per-unit-effort (CPUE) is proportional to the abundance or biomass of the resource, and that natural mortality rate, M, is constant for all ages of fish and in all years. The assumptions behind any stock assessment, in fact any source of information and decision, are important and should be

[1] From FAO (1999). Meeting report of the second CFRAMP/FAO/DANIDA stock assessment workshop on the shrimp and groundfish fishery on the Brazil-Guianas shelf. Georgetown, Guyana, 18-29 May 1998, FAO, Rome. 41pp.

considered when using information and when making decisions. The use of per-recruit analyses (and most of the length frequency analyses that are often used to estimate parameters such as growth rates and total mortality rate for per-recruit analyses) assume that recruitment will remain constant. In practice, one of the greatest sources of uncertainty in resource dynamics, and hence in fisheries management, is the very high variability from year to year in recruitment of young animals to a stock, which can vary by an order of magnitude or more from one year to the next (Figure 7). When providing advice on the effect of management measures, the scientists should also consider the impact of variability of recruitment on their results and on the attainment of the operational objectives.

Useful information on the status of the stocks can also be obtained by examining their size structure to determine whether there have been any major changes over time. A significant decrease in the average size (normally indicated by length) of a stock may indicate growth overfishing, suggesting that the larger individuals are being removed at a rate too high for sustainable utilisation. Conversely, the decrease may be the result of good recruitment in recent years. The two different scenarios would require very different responses in management and the scientists need to ensure that they have the data and undertake the analyses necessary to determine the cause of the change. Similarly, an increase in the average size may indicate poor recruitment in recent years resulting in older and larger animals being exploited at proportionately higher fishing mortality rates, or a decrease in effective fishing mortality rate possibly leading to more fish surviving through to attain larger sizes. Again, the underlying cause for this should be investigated and the appropriate management response considered. Where relatively sedentary species are being considered and where closed areas are in existence, comparing the length frequency of the exploited portion of the stock with that of the sub-population in a closed area may also give an indication of the effects of exploitation (see Chapter 3).

Figure 7. Time series of recruitment biomass estimates in the South African anchovy stock demonstrating high variability in this short-lived species. The vertical lines show one standard deviation of the estimated mean on either side of the estimate, giving an indication of the uncertainty in the estimates. The 95% confidence limits of the estimate would be approximately double the length of each vertical line.

The above examples do not discuss in depth how to take uncertainty into account in the analyses but this topic is introduced in the Appendix to this chapter. Methods for including uncertainty in assessments include the following.

- Sensitivity analyses, for data and assumptions, in which the impact of a change in a parameter or assumption on the output from a model is explored.
- Monte Carlo analyses, in which, instead of undertaking an analysis once with fixed values of all 'known' parameters and variables, the analysis is run a large number of times, each time selecting a different value of the parameters from a pre-specified distribution. These analyses will generate a large number of estimates of the unknown parameters and variables, giving an indication of the range and distribution of possible values for each unknown.
- Bayesian approaches are essentially extensions to existing deterministic methods, as are Monte Carlo approaches, with the important advantage that they can make use, in a formal statistical manner, of other sources of information in addition to the data available for the stock under consideration. For example, Bayesian approaches could use estimates of key parameters from other stocks or expert opinion on possible parameter values in fitting a biomass dynamic model to fisheries data, to help "inform" the estimation procedure of likely values of these parameters in a particular case. They therefore have particular potential value in fisheries where there are only limited data available from the fishery itself.

5.2 What sort of ecological information is needed?

Table 2 showed that including ecological considerations in fisheries management adds to the demands on the data collection and analysis requirements of the responsible agency, increasing the number of species which need to be monitored as well as requiring information on ecosystem interactions and the state of the different habitats occurring in the ecosystem. This could be seen as a luxury but has come to be recognised as being essential to sustainable and efficient use of the resources. The target species are dependent for their survival and productivity on the ecosystem in which they live, and changes in that ecosystem will affect the resources. The manager needs to be aware of any such changes, whether natural or caused by fishing or other human activities. This not only enables an assessment to be made of the likely impacts of the changes, and the management strategy to be adapted accordingly, but also allows for the adoption of management strategies which minimise damage to the ecosystem. Minimising damage will require reference points to be developed for those ecosystem components identified as being of particular importance or particularly useful as indicators of some ecosystem property (FAO, 1999b). The status of the ecosystem can then be monitored against those reference points.

In the case of impacts of a management strategy on non-target, associated and dependent species, the performance indicators are likely to be similar to those for the target species. However, there may be less data and information available for the former with which to estimate the performance of the strategy, and the types of reference points may need to be modified from those typically used for target species, so as to require less precise information. Similarly, the impact of different fishing gears on the physical habitat may be impossible to estimate quantitatively, and gear types or strategies may need to be ranked against such criteria as, for example, good, neutral, or harmful. Table 1 in Chapter 2 provides a useful approach to ranking the ecological impact of different fishing methods. When such rankings can be made, the information should be provided to the decision-makers. In cases where no information is available for setting reference points or evaluating the ecosystem against important reference points, this should be clearly stated by the scientists to ensure that the decision-makers are aware of the uncertainties and lack of information on these issues.

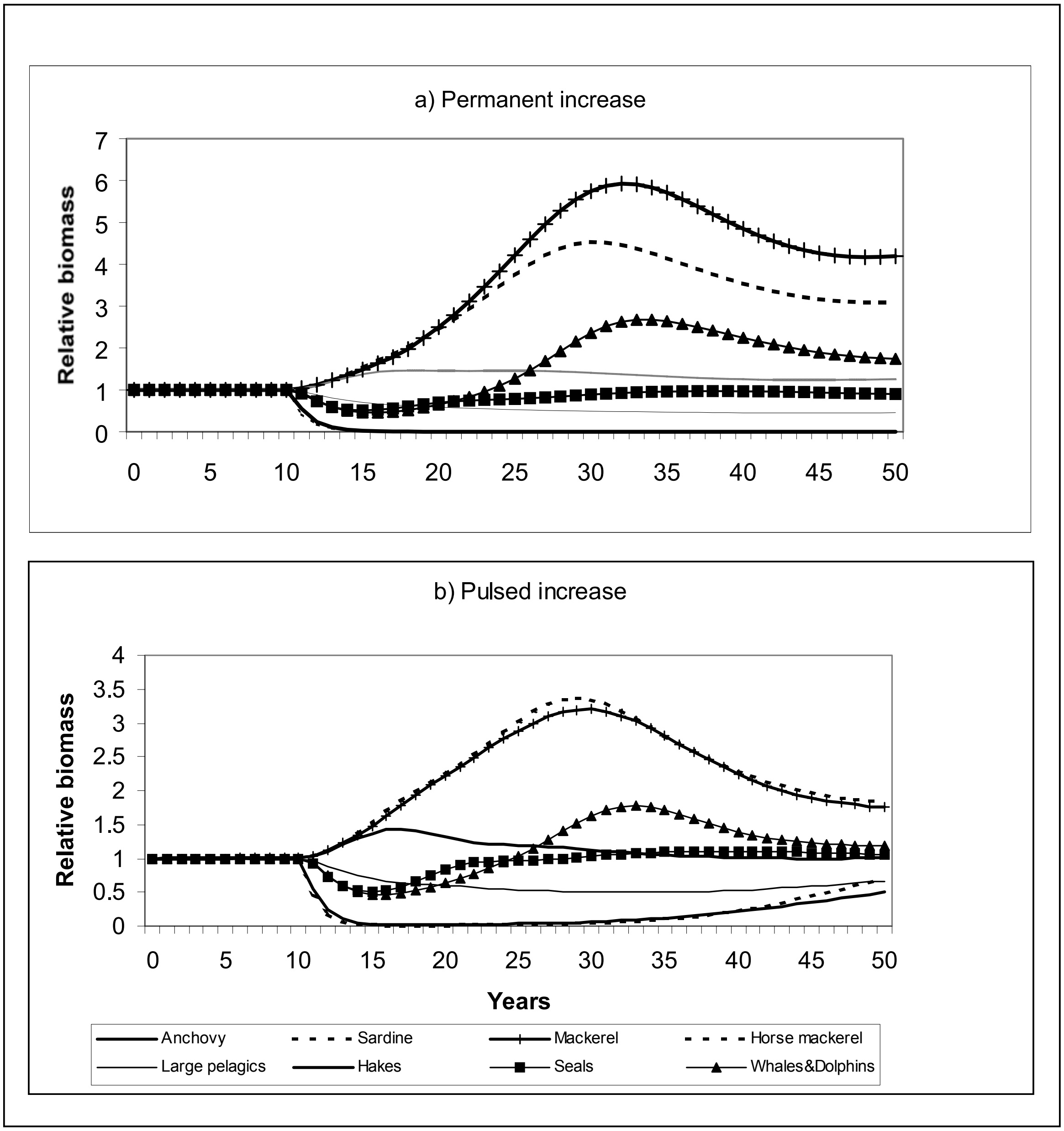

Figure 8. Simulated effects of increased fishing effort in the small pelagic fishery on selected taxonomic groups in the southern Benguela ecosystem. a) Results from a fourfold increase in fishing mortality on small pelagics from year ten onwards and b) from a fourfold increase in F from years 10 to 15 only. Relative biomass is the biomass as a proportion of the biomass at the start of the simulation. Figure modified from Shannon, L.J., Cury, P.M. and Jarre, A., 2000. Modelling effects of fishing in the southern Benguela ecosystem. *ICES Journal of Marine Science* **57**:720-722.

Our knowledge of ecosystem dynamics is notoriously incomplete but suitable models representing our best understanding can still be informative. Figure 8 shows a simulation from an Ecopath with Ecosim[2] model of the southern Benguela ecosystem under two different management strategies, in this case both a simple modification of fishing mortality on the main commercial small pelagic species: sardine, anchovy and roundherring. The simulation estimated that in addition to the target species, a large number of other species will also be affected by the changes in fishing mortality. For example, the biomass of chub mackerel is estimated to increase by up to 6 times its starting biomass while that of large pelagics will decrease by nearly one third of its starting biomass when the increased fishing mortality is maintained (Figure 8a). Scientific understanding of ecosystem interactions and dynamics is still very limited and there is therefore a high degree of uncertainty in any predictions of ecosystem behaviour but scientists should still consider the ecosystem implications of different management strategies, and models can assist in this, as they can in single-species cases.

5.3 What sort of social and economic information is needed?

Fisheries exist to provide social or economic benefits to society, and it is a task of the manager to ensure that these benefits are obtained in an appropriate and sustainable manner consistent with the national fisheries policy and the goals for that particular fishery. Management actions nearly always involve the fisher and hence affect him or her directly. They also influence the abundance, and hence availability, and the size structure of the stocks affected by the fishery. These changes will affect the fisher and other users. Operational objectives for the desired economic and social performance of any management strategy therefore need to be developed, and alternative strategies evaluated against these objectives. The results of the social and economic analyses should be presented to the decision-makers so that they can be considered in making the decision, in the same way as for the biological and ecological information.

In nearly all cases, the quantity of most interest to the fisher is the magnitude of the catch they can expect in the near future, as this is translated directly into income for them. The scientists should therefore attempt to estimate how changes in management measures or strategy are likely to affect the future catches by the fishers. Fishers will probably also be interested in likely changes from year to year in future catches, species and size composition of the catches and, where relevant, in distribution of the fish. These features of the expected future catches can be translated into probable gross income for the fishers, an important item of information for them and for the managers.

Gross income is not the only economic variable that affects fishers' livelihoods, and the costs associated with their fishing activities are as important to them as their income. Different management strategies may affect both fixed and variable costs and hence the total cost and profitability of fishing. Decision-makers need to be aware of the economic and social implications of alternative management strategies and the scientists should include criteria reflecting these consequences and estimate the performance of the different strategies against them. The fishers themselves will be essential sources of this information and should be key participants in the assessment process. However, as with all information, it is important to verify the information obtained from the fishers. In some cases their perceptions may be erroneous, while in others they may see it as being to their advantage to provide incorrect information. Their information should therefore be supplemented from alternative sources as far as possible.

Two examples of economic information that could be useful to the manager in setting general and operational objectives for a fishery are shown in Figure 9. The estimated combined net

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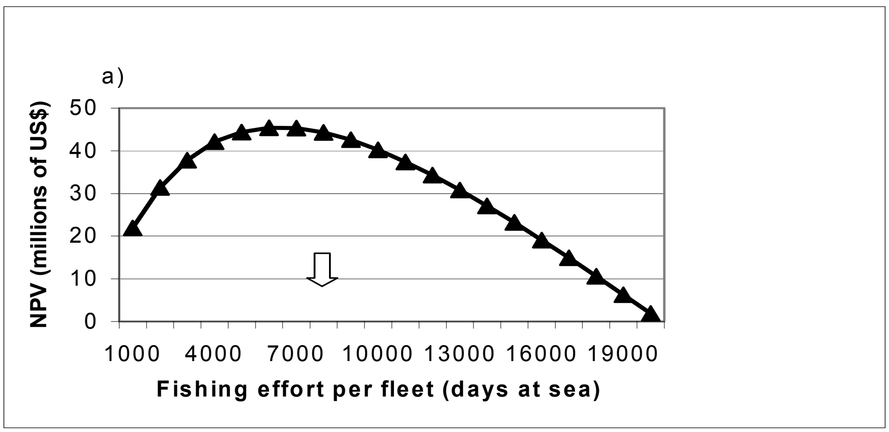
[2] For further details on Ecosim, see Walters, C.W., V. Christensen and D. Pauly. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. *Rev.Fish Biol.Fish.* **7**:139-172 or http://www.ecopath.org/

present value of the shrimp trawling fleets of Trinidad and Tobago and Venezuela, both fishing on the same stock, is shown in Figure 9 a). The results indicate that, from an economic perspective, there is too much capacity in these two fisheries, and that effort should be reduced in both national fleets if an important objective is to maximise net present value. However, there may also be social objectives that need to be considered, for example maintaining employment and earnings per fisher and shore worker. The impact of a reduction in effort on these may also need to be examined and then a decision made which results in a desirable balance between the social and economic goals. In the study from which this figure was taken, the authors provided this information, and some measures of uncertainty, giving the manager very valuable information for identifying, or pursuing the optimal operational objectives.

The implications of having an open access fishery are reflected in Figure 9 b), in terms of the estimated change in rent (gross earnings) per day from the groundfish fishery in Trinidad. The figure demonstrates how, if access is not limited, the gross earnings per unit of effort will decrease with time as more and more fishers enter the fishery, competing for the same fish resources and driving their abundance and yield lower and lower. Such economic and social information is essential to inform the manager on the impacts on the interested parties of different management decisions, including (Figure 9b), a decision to leave things as they are.



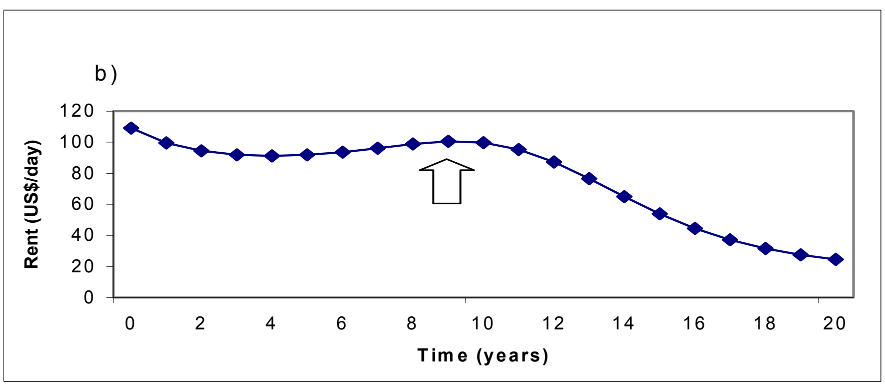


Figure 9. a) Net present value (NPV) of the shrimp landings for the combined trawling fleets of Trinidad and Tobago and Venezuela for different levels of effort. b) The estimated rental obtained per unit of effort in the Trinidad groundfish fishery under open access conditions. In both cases the arrow indicates the current level of effort estimated in those two fisheries. Figures taken from Ferreira, L. and S. Soomai (2000)[3].

[3] Management Report: Trinidad and Tobago. In: Report of the 4th Workshop on Assessment and Management of the Shrimp and Groundfish Fisheries on the Brazil-Guianas Shelf. Cumana, September 2000. FAO, Rome (in press).

Different strategies may also have other social implications. For example, in many artisanal fisheries, women and children are involved in processing or selling the landings and changes in management strategies that influence the landings by such fleets may have wider social consequences than the direct impacts on the fishers themselves. Management actions may also have the effect of increasing or decreasing conflicts between different users, and managers should "regulate fishing in such a way as to avoid the risk of conflict among fishers using different vessels, gear and fishing methods" (Code of Conduct, Paragraph 7.6.5). Target and limit reference points should be established for social criteria such as these to enable their consideration in selecting management strategies. As for some other criteria, it may not be always possible to obtain quantitative estimates of the performance of strategies against some of these criteria. and in these cases, the best available qualitative estimate could still provide valuable information. As discussed in Chapter 7, the users themselves form an essential source of such information.

6. THE ROLE OF THE SCIENTIST: PROVIDING OBJECTIVE INFORMATION

The discussion above has highlighted the role of the scientist, which here is taken to include the full spectrum of fisheries scientists including biologist, economist, sociologist, technologist and others, as a provider of scientific information to the decision-makers. If this information is to be useful and to contribute to making the best decisions to achieve the agreed operational objectives, it is essential that the information the scientist provides is accurate, complete and objective. It is then up to the decision-makers to decide on the trade-offs and, where necessary, the sacrifices that need to be made. It is not the task of science to make such policy decisions, science can and should only advise and inform.

Unfortunately, a common problem in fisheries management agencies, and also with other scientists working in resource management, is that the scientists do not always see their role as being limited to the provision of scientific advice, and they may consider themselves to be there to work for a particular cause. In some cases, the management agency may see itself as being there to serve the fishers, perhaps even to serve mainly one section of the fishers, such as the small-scale fishers or the large-scale industry. Under these circumstances, the scientists working for that agency may also adopt, or are pressured to adopt, this partisan role. Conversely, many fisheries scientists are biologists by training and interest and this strong interest in nature can lead them to see themselves as defenders of the resources against a destructive fishing industry.

Any of these prejudices can lead scientists, whether deliberately or through unknowingly succumbing to pressures, to generate advice that is biased towards their interest. For example, they may avoid giving the decision-makers results on strategies that, in their opinion, could result in the resource being driven to too low a level, or they may ignore signs that growth rate or recruitment have been decreasing in recent years to avoid having to recommend a reduction in fishing. Such biases should be avoided at all times. The scientist should not attempt to determine policy or to try to influence policy by manipulation or careful selection of the information he or she presents. Policy decisions should be made transparently and formally by the designated decision-makers in the appropriate forum and, if they are to have confidence that they are making the best decisions, they need to have confidence that they are receiving full and unbaised results from their scientific advisers.

Of course, a scientist may also serve on a decision-making body, where he or she adopts the role of a decision-maker. This is perfectly legitimate, provided the scientist makes it very clear, to themselves and to the others, when they are acting as a scientist, and providing unbiased scientific advice, and when they are expressing an opinion as a member of the decision-making body.

7. HOW SHOULD DECISION-MAKERS AND THE PROVIDERS OF INFORMATION WORK TOGETHER?

When a change to a management strategy is considered, there are obviously many different combinations of management measure, i.e. different management strategies, which could be examined. The selection of which ones to examine in the analyses and which simulations should be undertaken should be a consultative process between the decision-makers and the scientists undertaking the analyses. Only certain changes to the existing strategy may be feasible or desirable, and these should clearly be considered first. There is little point, for example, in considering a management strategy that sets a total allowable catch in a fishery where it is impossible to monitor the catches or landings of all the fishers (see Chapters 4 and 8).

The approach should therefore be to establish first whether any change is necessary (where, for example, an annual TAC is set this may be automatic), and then to discuss which management measures can or should be altered first in an attempt to bring about the desired changes. The scientists can then undertake a series of analyses, using suitable models, to simulate the impact of the new management measures on the resources and fishery. The effects of the changes should be described in terms of the operational objectives and reference points for the fishery.

It may be that the work by the scientists indicates that while the changes in management strategy which have been tested result in some improvements in relation to the operational objectives, none results in fully acceptable results. These results should still be shown to the decision-makers, who may nevertheless compromise and adopt one of the simulation-tested strategies or may request the scientists to undertake further analyses on alternative strategies, seeking one that performs better than those already tested. In this iterative way, the management strategy, or the changes to a strategy, which come closest to achieving the desired results can be identified, making use of the best scientific information available (Figure 10).

8. PRESENTING INFORMATION TO DECISION-MAKERS

Decision-makers in fisheries have to consider several different objectives in deciding on optimal management strategies. Because of potential conflicts in these objectives, there will never be a solution which simultaneously maximises all the potential benefits and minimises all the potential risks. The decisions made will therefore invariably require deciding on suitable trade-offs between these conflicting requirements, and the decisions tend to be of a political nature but, if they are to be good decisions, need to be informed by the best available scientific information.

Enormous advances have been made in stock assessment in recent decades, fuelled especially by easy access to powerful computing capacity. In contrast, formal approaches to decision-making in fisheries have probably progressed very little. There has been an important growth in awareness of the need to involve all key interest groups in the management process, often including in decision-making (see Chapter 7), but once these groups are assembled, the approach to making decisions still usually centres on open debate and argument with all the flaws and problems such an approach involves. The greatest weakness of such informal approaches is that they are heavily influenced by personalities and therefore tend to be subjective and prone to bias arising from, for example, self-interest, short-term objectives prompted by immediate problems, and hidden agendas. Succumbing to any of these may compromise achievement of the agreed long-term strategies and goals.

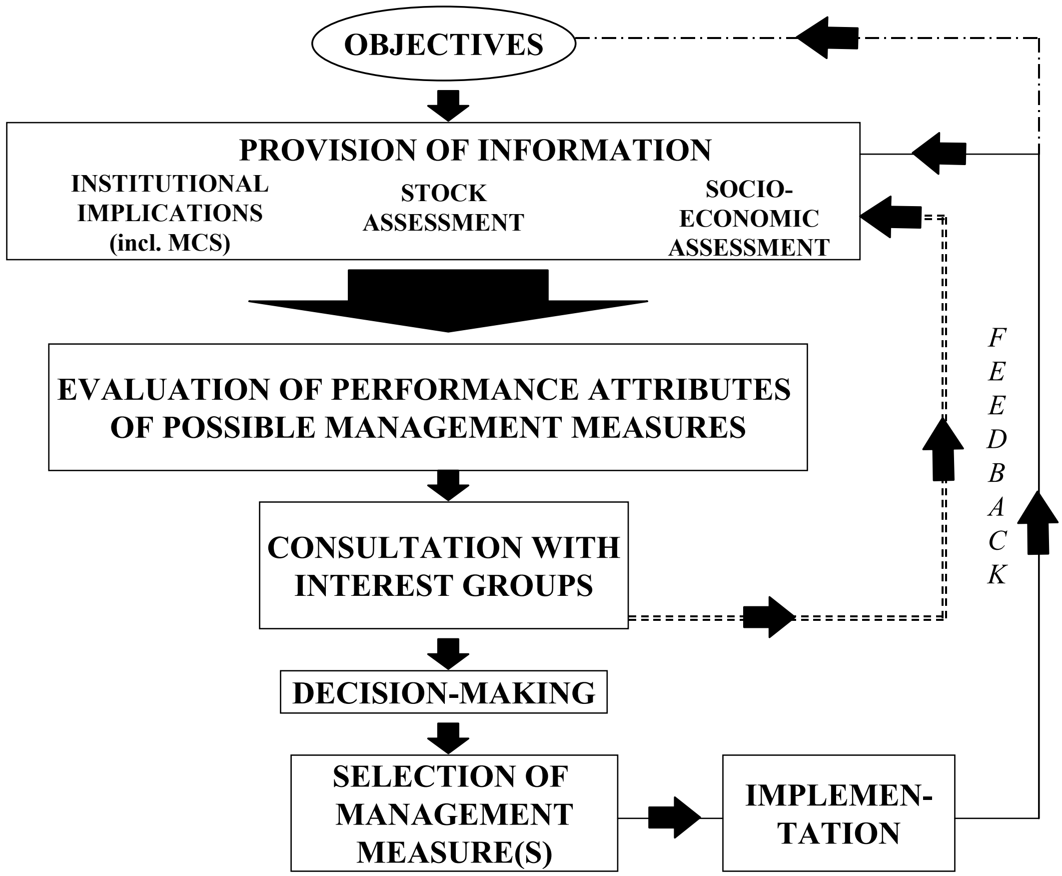


Figure 10. Idealised representation of decision-making in the fisheries management process. Decision-making occurs on a variety of time scales e.g. over days or weeks (double broken-line), annually (solid line) and less frequently e.g. every 3 to 5 years (solid/dashed line).

Some formal statistical methods of decision-making have been developed and some of these have been applied to decision-making in fisheries. Amongst these are multi-attribute analysis, analytic hierarchy process and the use of multi-criteria objective functions. However, these approaches have not proven very popular and do not seem to have been widely applied or adopted for routine application. A likely explanation for their lack of popularity is that they may be perceived to be restrictive and to replace free will with automation. Put another way, they are seen to reduce the opportunity for people to exercise fully their skills in getting their own way!

Where a decision-making body is open to the use of formal statistical methods to assist them in decision-making, these should be used as they have a useful role to play in identifying key issues, setting priorities and minimising the opportunity for hidden prejudices. However, where the decision-makers prefer to operate in the traditional manner of discussion and debate, this has to be recognised and accepted. It seems likely that decisions in fisheries management will continue to be made in (now) smoke-free rooms by committees consisting of individuals representing specific interest groups or selected on the basis of office or expertise. It is essential for these committees to be provided with relevant, objective and easily understood information by the fisheries scientists.

One of the more useful ways in which information can be presented to decision-makers in a form facilitating comparison and decision-making is in a decision table (e.g. Table 5). A well-structured and complete decision-table will not only summarise and present key results from the analyses, but can also serve to remind the decision-makers of their operational objectives, and how different management strategies perform against each of them.

Table 5.Hypothetical decision-table for presentation to decision-makers, enabling comparison of different strategies against some operational objectives. The hypothetical 95% confidence limits are show in parentheses.

Performance Indicator	Management Strategy1 (existing)	Management Strategy 2	Management Strategy 3
Mean annual biomass of stock as a proportion of unexploited level	36 (18-54)	53 (26-79)	28 (14-42)
Mean annual biomass (proportion of unexploited) of bycatch species most heavily impacted by fishery.	49 (22-66)	63 (28-98)	19 (7-31)
<u>Economic Indicators</u>			
Mean annual catch ('000t)	20 (16-24)	17 (12-22)	23 (17-29)
Mean annual income per fisher ('000 US$).	18 (14-22)	15 (11-19)	20(15-25)
Inter-annual variability in mean annual income per fisher (% of mean income)	12	9	14
Change in the number of fishers in the fishery compared to the existing level (%)	0	-15	+1

The hypothetical results in Table 5 would present decision-makers with some difficult decisions. They indicate that the present strategy (Management Strategy 1) is having a substantial impact on the target stock, reducing it to an estimated 36% of its mean unexploited level, with a possibility that the stock is as low as 18%. The alternative 2, which could involve a reduction in effort and/or a change in gear selectivity, would have substantial benefits for the target stock and the most heavily affected bycatch stock but would both reduce the average earnings of the fishers and require a reduction of 15% in the number of fishers in the fishery. Strategy 3 would result in a slight increase in the number of fishers and a substantial rise in their average annual earnings in the short-term but with a substantially greater impact on the resource, generating a real possibility of reductions in recruitment (not taken into account in these 'simulations' because of a lack of information) and a downward spiral in biomass and yield. Based on these results, there would be no easy options for the decision-makers in this fishery. Taking the uncertainty into account (in this case that includes the possibility that the stock is as low as 18% of its pristine level), Strategy 2 is clearly the best strategy, and possibly an essential strategy, for ensuring the sustainability of the resource and bycatch species and therefore of the fishery. However, the social and economic impact of Strategy 2 may be considered highly undesirable. Under such circumstances, the decision-makers may choose to go back to the scientists and ask them to attempt to identify alternative strategies that provide a compromise between Strategies 1 and 2, providing adequate protection to the resource but with less severe social and economic implications. This may or may not be possible, but the possibility could be investigated before a final decision was made.

The implications of the different management strategies for the institutional and operational aspects of a fishery should also be considered before final decisions are made. For example, if the decision-makers are considering a choice between managing the fishery purely on the basis of effort regulation or by TAC, the implications for monitoring and control of catches would be important considerations which would have to be brought to the attention of the decision-makers (see Chapter 4). Similarly, the ecosystem effects of a strategy should be considered.

Graphic output, such as that shown in Figures 2 to 9, is usually helpful to the decision-makers. It is essential for the fisheries scientists to communicate with them and find out what sort of information is most useful and how best to present it. Both groups will learn with experience the formats which are most useful. However, this should not be seen as meaning that the scientists should only provide the information requested of them. If they have results or information which they consider important for the decision-makers to see and consider, it is their responsibility to ensure that this information is provided.

Overall, these steps should lead to an approach such as that reflected in Figure 10. An important feature of this figure is the indication of consultation and feedback which should characterise the link between the decision-makers and those providing the information.

9. WHAT ABOUT UNCERTAINTY?

The introduction to this chapter emphasised how big a problem uncertainty, or lack of knowledge, is in fisheries management. Trying to estimate the abundance of fish and their productivity is difficult enough, and the estimates we obtain of these values are always just that, estimates, with considerable uncertainty associated with them. When we try to forecast or predict what the abundance of fish will be next year we introduce even more uncertainty, and when we try to forecast how the stock, fish community or fishers will respond to management actions we introduce even more.

There are many sources of uncertainty in fisheries stock assessment and management and these can be summarised as[4]:

- *process uncertainty*, or random variability, in the biological and ecological processes themselves, such as in recruitment to a stock;
- *observation uncertainty*, from attempts to measure factors such as total catch, biomass (e.g. through a survey), or effective effort in a fishery;
- *estimation uncertainty* in our final estimates of quantities, such as the status of the stock or B_{MEY}, arises from process and observation uncertainty above and also because our models are usually simplifications of the true ecological processes;
- *implementation uncertainty* arising in the implementation of management measures, including how effective they will be and how well the fishers will comply with them; and
- *institutional uncertainty* which refers to the uncertainty in how well participants in the process can communicate with each other, to what extent people are willing to compromise and how the scientific information is understood, all influencing how decisions will be made and therefore how good those decisions will be.

We can estimate values for some of these uncertainties and use these values in stock and bioeconomic assessments and decision-making. For example, by measuring recruitment to a stock over a number of years, an estimate can be obtained not only of the average recruitment but also of the variability from year to year, which could be expressed by measures such as the

[4] From Francis, R.I.C.C. and R. Shotton. 1997. "Risk" in fisheries management: a review. *Can. J. Fish. Aquat. Sci.* **54**: 1699-1715.

standard deviation about the mean, the 95% confidence intervals of the mean or simply the range of observed recruitments. Similarly, it may be possible for the uncertainty in abundance, biomass or the potential yield from a resource to be estimated. For example, the best estimate of the biomass of a stock of sardine, based on a hydroacoustic survey or a biomass dynamic model, may be 100 000 t but when the uncertainties are calculated, it is found that the 95% confidence limits of the estimated biomass are from 60 000 t to 140 000 t. This means that the most likely estimate is 100 000 t but that there is 95% certainty that it lies between 60 000 and 140 000 t. Ninety-five percent confidence limits of at least 40% on either side of the mean, as used in this hypothetical example, would be typical of many estimates from well monitored fisheries.

In some cases, good numerical estimates of uncertainty may not be available, but the scientists should then provide a carefully considered statement of how good their estimate is. For example, they could indicate whether their estimate of total landings is very good, good, reasonable or only an approximation. Implementation uncertainty and institutional uncertainty are generally much more difficult to estimate than the other types of uncertainty listed above. In most cases the best information that may be available for these types is, for example, that there is a high or a low probability of serious violation of regulations (see Section 5 of Chapter 8), or that there is a high, medium or low level of confidence that the management measures selected will achieve the desired result. Even information such as this will assist the decision-makers in interpreting the information and making the best decisions.

In the past, fisheries management tended to ignore the uncertainties and act on the best estimates as being the correct answers. However, with increased computing power and greater understanding of how much we don't know in fisheries management, the modern tendency is to try to estimate the various uncertainties (risk assessment) and to consider them in determining and implementing management measures and strategies (risk management). Risk assessment is discussed in more detail in an Appendix to this Chapter.

Risk management is still in its infancy in fisheries management and there are no commonly applied formal ways of doing it. In essence, risk management requires the decision-makers to make the best decision they can based on the information they have but then also to consider the likelihood of that decision being wrong. They should then consider modifying the decision, such as the selected management measures, so that the strategy will not only work well if circumstances and behaviour fall within the expected range, but also so that it won't go too badly wrong if circumstances and behaviour turn out to be very different from the initial expectations. More formally, this can be referred to as making decisions which are robust to the uncertainties. Robustness testing requires the use of models and information to consider how a management strategy will perform under different conditions or states of nature to those considered in the basic assessments, or how it will perform if some of the information used in those basic assessments is incorrect. It provides a means of identifying possible undesirable outcomes from a management strategy before they occur, thereby allowing modifications to be made to the strategy before it is implemented to try to avoid such outcomes. In other words, robustness testing is a means of reducing, in advance, the probability that the selected management strategy will go badly wrong, or ensuring that it can quickly be adapted, if the ecosystem or the fishery or both do not behave in the way they were expected to when the strategy was designed. Being robust to uncertainty could mean being more cautious than the basic assessments suggested in, for example, setting total allowable effort. Alternatively, it could involve ensuring that effort can rapidly be scaled down, without creating unnecessary social and economic disarray, if production by the resource was less than had been expected when the assessments were undertaken.

This approach has to be balanced, of course. If one takes an extreme view of uncertainty and robustness, then the only way to minimise risk in the face of the inevitable uncertainty is to close the fishery. This is not a practical approach and the management strategy should be designed to be robust only to changes which could reasonably be expected to occur.

Including consideration of uncertainty in assessment and management does put much greater demands on all involved in the management process, including scientists, fishers and other interested parties, managers and decision-makers. However, it also results in a much greater chance of good decisions being made and management strategies being implemented that stand the greatest chance of achieving the objectives. Few individuals would set out on a long journey without taking a spare tyre, maps and some extra money in case of unexpected but possible problems. Fisheries management requires, at a minimum, the same level of caution, or risk management.

10. UNCERTAINTY AND THE PRECAUTIONARY APPROACH

Some guidance has been provided in the earlier sections of this chapter on how uncertainty can be taken into account in making decisions but, except in the case of some formal and rigorous statistical approaches, there are no widely accepted and applied methods for incorporating knowledge of uncertainty into decision-making. There has, however, been a lot of discussion about this and this discussion has been reflected in a general philosophy or concept known as the precautionary approach. The application of the precautionary approach in fisheries is included in the Code of Conduct, and is the subject of one of the FAO technical guidelines to the Code of Conduct (FAO, 1996).

The precautionary approach in fisheries management can best be summarised as "the application of prudent foresight" (FAO, 1996). FAO (1996) goes on to list the requirements of the precautionary approach as including (Paragraph 6):

- "consideration of the needs of future generations and avoidance of changes that are not potentially reversible;
- prior identification of undesirable outcomes and of measures that will avoid them or correct them promptly;
- that any necessary corrective measures are initiated without delay and that they should achieve their purpose promptly.....;
- that where the likely impact of resource use is uncertain, priority should be given to conserving the productive capacity of the resource;
- that harvesting and processing capacity should be commensurate with estimated sustainable levels of resource (production), and that increases in capacity should be further contained when resource productivity is highly uncertain..."

It is also suggested (Para. 7d) that, in applying the precautionary approach, "the standard of proof to be used in decisions regarding authorization of fishing activities should be commensurate with the potential risk to the resource, while also taking into account the expected benefits of the activities."

These are important considerations and the reader is urged to study carefully the FAO Technical Guideline on the Precautionary Approach and the relevant sections in the Code of Conduct (Sub-article 7.5).

11. CONCLUSIONS

A consistent theme running through this Guidebook is that fisheries management is a complicated task with broad goals that are usually in conflict but which need to be reconciled through the formulation of operational objectives which aim to provide benefits for society in a sustainable way. The fisheries manager is responsible for seeing that this is done and for ensuring that management strategies are developed and implemented which stand the best chance of achieving these reconciled objectives. There are many tools for doing this but, because of the complexity of ecosystems and their interactions with fisheries, the information required for making the decisions is usually incomplete and includes a lot of uncertainty. This chapter has attempted to describe what sort of information the manager should be asking for from the scientific branch of the management agency, how that information should be presented to the decision-makers and how they should use it in making their decisions.

The most important aspects of this process are that only well-informed decision-makers can make good decisions. Therefore, the best information available, given the staff and resources available to the agency, should be used to advise the decision-makers. It is the responsibility of the scientists to ensure that they are collecting appropriate information to provide the necessary advice, that they store this information in a way which makes it easily accessible in the future, they analyse it using appropriate methods, and provide easily understood, complete (as far as is possible) and unbiased information that is relevant to the decisions that have to be made.

The examples of methods and approaches presented in this chapter are just some of the types of questions which can be expected to arise in fisheries management and of the types of scientific information that may help to answer them. Further information can be found in the fishery assessment books already referred to, as well as in the vast numbers of scientific papers on fisheries assessment and management which are published every year. It is very important that all fisheries management authorities have access to staff familiar with at least the standard approaches to the types of analyses presented here. Without this, properly informed decisions and therefore effective and responsible use of the fishery resources will not be possible.

Good communication is important at all levels, and the decision-makers, scientists and other interested parties should be working together to ensure that the correct information is being provided, and that it is being interpreted properly. Following all these steps will not guarantee that the correct decisions are made, but it will help to ensure that the best decisions are made given the information and resources available. That is all that can be asked of the decision-makers and those whose task it is to provide them with the information they require.

12. RECOMMENDED READING

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APPENDIX: RISK ASSESSMENT

What is a risk assessment?

Risk assessment is usually undertaken by the scientific staff of a fisheries management agency and should include not only assessment of biological risks but of economic and social risks as well. As with all fisheries assessment, risk assessment should be directly related to the operational objectives.

Defining Risk

Risk is commonly defined as the probability of something undesirable happening, but in making use of risk it is necessary to be more precise and the undesirable events must be decided on and quantified. Those of particular concern will relate to the fishery operational objectives e.g. the stock falling below a minimum threshold level, the income to the fishery as a whole or by sub-sector falling below a certain level, or total number of employee days or jobs being reduced below a specified threshold.

In risk assessment, consideration also needs to be given to what is considered an acceptable level of risk for each performance indicator by the different interested parties. There are no rigid guidelines for deciding on an acceptable level of risk for a stock or stocks, and this must represent one of the greatest areas of potential disagreement and hence of weakness, in resource risk assessment (Butterworth *et al*. 1997). However, an appropriate threshold level of risk should be able to be identified by, for example, comparison with the level of risk for an event in an unexploited population or during some previously observed period when it was considered productive. When considering sustainability of a resource, a fundamental measure of risk should be the probability of recruitment failure brought about by low spawner biomass and, clearly, this risk should not be allowed to be too high.

Meaningful economic and social measures of risk, such as those related to income and employment, will also be difficult to agree on and to define. While the choice of a threshold to avoid crossing may be relatively easy, such as avoiding making a loss or avoiding any reduction in employment, it may be more difficult to agree on the point at which the risk of crossing these thresholds becomes too high. However, in contrast to defining biological risks, the question is amenable to debate with those most directly affected, the fishers and other interested parties, who should be directly involved in selection of the acceptable risk levels. In addition, it should be easier to determine the consequences of crossing any social or economic threshold than it is for those of falling below some stock biomass threshold.

An integral part of determining an acceptable (or unacceptable) risk or probability of crossing a threshold is the time period over which the risk is measured. For example, the risk of being struck by lightning is partly dependent on the length of time the target is exposed to lightning. Everything else being equal, the risk of being struck by lightning within a ten-year period is ten times the risk of being struck in a one-year period. Discussion on what is an acceptable level of risk must therefore include clear definition of the length of time over which the risk is measured. Where risk is being measured using models, as it normally will be, this means considering the time period over which the model is projected. This should take into account the dominant time-scales of the stock, particularly average life span of the resource, and the fishery (e.g. life span of a vessel etc). Periods of between 10 and 20 years are frequently used in estimating risk in fisheries.

Estimating Risk

Risk assessment is usually undertaken using the standard stock assessment approaches in conjunction with the available data on the resource or resources and the fishery. The first step is to estimate the important parameters and variables which describe the dynamics of the resource and fishery, and the uncertainty or error in these estimates, including the distribution (e.g.

whether a normal, log-normal or uniform distribution) and magnitude of the distribution of errors. These estimates can then be used to construct a forecasting model of the fishery-resources system. The type of model to be used will depend on the questions to be asked and the parameters and variables which have been estimated. For example, at a more simple level, it may only be possible to use per-recruit models to investigate the impact of different levels of fishing mortality and different ages at first capture on relative yield and biomass-per-recruit. Alternatively, if there are estimates of biomass and recruitment as well, it may be possible to estimate average yield and inter-annual variability in yield under different management strategies. If there are only data on catch and effort, a biomass dynamic approach could be used. The same class of model as was used to estimate parameters and their errors should normally be used for forecasting the impacts of management strategies. The model is then used in forecast mode to investigate the impact of, for example, different catches, levels of effort or gear type on biomass, size or age structure and average yield given the estimated uncertainties. The models may, and normally should, also include estimation of social and economic performance, including uncertainty, to allow each possible management strategy to be evaluated on its performance across all operational objectives.

The uncertainty estimates are used in the models which are run in a stochastic or probabilistic mode i.e. the model is run many times in a Monte Carlo manner for each management strategy being tested. Typically the model is run between 1 000 and 10 000 times for each strategy, drawing the values of selected parameters for each model run from a probability distribution defined by the error distribution of the parameter estimates (instead of keeping them all constant). Therefore different parameter values are used in the model in each run, generating different results. When the runs are completed, the average values of the performance indicators, reflecting the operational objectives, and their range or distribution can be calculated. For a risk assessment, the number of runs in which the performance indicator of interest fell outside the selected risk threshold (i.e. the number of times each undesirable event happened) can then be counted, giving an estimate of the risk under the management strategy being simulated.

This sort of analysis leads to information of the type shown in the Table below in the form of a decision table. This example was taken from simulations used to assist in the selection of a management strategy (more formally a "management procedure" see Cochrane *et al*. 1998 for definition of a management procedure) for the South African anchovy fishery. The table shows the performance indicators considered important in this fishery: biological risk to the resource (kept constant at 30% in this example), average annual catch and catch variability. The results shown here allowed the decision-makers (the managers and the fishery interested parties) to weigh-up the trade-offs between maximising average annual catch and stability (including the minimum TAC) which would be best for the efficient management of the fishery. It had already been agreed that 30% risk of biological "failure" was acceptable (using a particular definition of risk as described in the table) but if this was controversial, the simulations could be repeated for different levels of risk to show the trade-offs between changing biological risk and the average catch and catch variability.

Table. Example of performance measures for different management options for the South African anchovy. For all options, the risk of the stock falling below 20% of unexploited biomass within a 20 year period equals 30%. "Management Options" shows aspects of the rules used in setting the total allowable catch (TAC) each year. "Max. reduction" = the maximum reduction in TAC from one year to the next. From Butterworth *et al*. 1992.

Management Option	Performance indicators	
	Annual Average Catch ('000 t)	**Interannual Catch Variability (%)**
'Base Case (BC)' Max. TAC = 600 000 t Min. TAC = 200 000 t Max. reduction between years = 40%	315	25
BC but max. TAC = 450 000 t	314	23
BC but min. TAC = 150 000 t	328	25
BC but max. reduction = i) 50% ii) 25%	 321 285	 25 22

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