PERSPECTIVES

Multiattribute Analysis and the Concept of Optimum Yield

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This paper reviews the origin and operational definition of the optimum yield (OY) concept and demonstrates how techniques of decision analysis can provide an analytical model for OY. The concept of OY was formalized as the guiding principle of fisheries management in the United States and Canada in 1976. The policies of both countries make it clear that a wide range of biological, economic, and social factors are to be taken into account in determining OY. Confusion exists, however, about precisely which of these factors should determine OY in any fishery and what is their relative importance. Uncertainty also exists about how to take biological, economic, and social factors jointly into account as the concept of OY implies one must. Established biological and economic models in fisheries are not adequate for such an analysis because their focus is single- rather than multi-objective. Operational techniques of decision analysis, such as multiattribute utility analysis, are specifically designed to deal with multiobjective problems like OY. I propose that a simple, linear, utility model be used to assess the optimality of alternative yield strategies in fisheries management. I illustrate the application of the model by assessing OY options in the New England herring (*Clupea harengus*) fishery and the Skeena River salmon (*Oncorhynchus* spp.) fishery. The advantages of the model are that it is simple and intuitively appealing, that it permits a wide range of types and qualities of data to be incorporated into the evaluation of management options, that it is amenable to sensitivity analysis, and that it is adaptable to a variety of decision rules.

L'auteur examine l'origine et la définition opérationnelle du concept de rendement optimal (RO) et décrit comment les techniques de l'analyse décisionnelle peuvent générer un modèle analytique du RO. En 1976, ce concept a été reconnu comme principe directeur de la gestion halieutique aux États-Unis et au Canada. Les politiques des deux pays précisent qu'une grande diversité de facteurs biologiques, économiques et sociaux doivent entrer en ligne de compte dans la détermination du RO. Il existe toutefois une certaine confusion quant au choix et à l'importance relative des facteurs qui devraient déterminer le RO de chaque pêche. Une certaine incertitude est aussi présente quant à la manière d'utiliser conjointement les facteurs économiques, biologiques et sociaux, comme l'exige le concept de RO. Les modèles biologiques et économiques établis ne sont pas adéquats pour une telle analyse car ils ne visent qu'un seul et non plusieurs objectifs. Les techniques opérationnelles de l'analyse décisionnelle, comme l'analyse utilitaire à attributs multiples, sont conçues précisément pour l'étude des problèmes à objectifs multiples comme le RO. L'auteur propose l'utilisation d'un modèle linéaire utilitaire simple pour évaluer l'optimalité d'autres stratégies de rendement dans la gestion halieutique. Il applique le modèle à l'évaluation de divers RO de la pêche du hareng (*Clupea harengus*) en Nouvelle-Angleterre et de la pêche du saumon (*Oncorhynchus* spp.) dans la rivière Skeena. Ce modèle a l'avantage d'être simple et intuitivement attrayant, de permettre l'incorporation d'une grande variété de types et de qualités de données lors de l'évaluation des choix gestionnels, de se prêter à l'analyse de sensibilité et d'être adaptable à une variété de règles décisionnelles.

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The management of fisheries is a complex task, involving the overt manipulation of an industry to achieve public goals. In the United States and Canada the stocks of marine and freshwater fishes have always been regarded as public property and it has been the responsibility of governments to administer their use. Until recently, access to the resource for private or commercial purposes was virtually unrestricted. Management measures to restrict fishing effort, when they were enacted, were usually justified on the grounds that depletion of the fish stocks must be prevented. Social goals, such as maximizing employment in the fishing industry or maintaining the economic viability of isolated coastal communities, were ofrten subsumed in management regimes. It was generally accepted, however, that the job of the fishery manager was to ensure that a productive stock size was maintained. If this could be done with minimum interference to the industry it was assumed that the other things would work out for the best. The guiding principle of management was a biological goal, to maximize the sustainable yield (Larkin 1977). A rather elegant theoretical and operational technology developed in fisheries science to permit estimation of fish abundance and stock size for maximum yield.

During the last decade the policy of maximizing the yield of fish has given way to a policy of maximizing the net benefits to society from fisheries. Adoption of this policy has catapulted management agencies into the overt consideration of economic and social as well as biological factors in designing management regimes. While to a large extent it merely legitimized long standing concerns of fishery managers, the new policy has also created confusion and uncertainty. There is confusion over what nonbiological factors should be taken into account in designing management regimes, and who should decide what those factors are. And there is uncertainty over how to incorporate the multiple and conflicting goals implicit in the new policy into an objective evaluation of alternate management regimes.

The purpose of this paper is twofold. First, it is to sketch the evolution of fisheries management policy from emphasis on management of fish stocks to emphasis on management of fisheries. This evolution is exemplified by the change in the guiding principle of fisheries management from maximizing yield to optimizing yield. Much of the confusion and uncertainty that attends this new policy stems from the absence of an operational technology in fisheries to deal with the multiobjective nature of the optimum yield (OY) problem. My second objective, therefore, is to describe a technology that will permit any number of biological, economic, and social factors to be included in an objective evaluation of fishery management options. This technology is ideally suited to the problem of deciding what yield is optimum. I shall illustrate the technology with a discussion of OY in the New England herring (*Clupea harengus*) fishery and the Skeena River salmon (*Oncorhynchus spp.*) fishery.

The Evolution of Fisheries Policy

The scientific management of fisheries was born during the first quarter of this century (Baranov 1918) and grew during the second quarter with the developing theories of population ecology and population dynamics (e.g. Elton 1927; Russell 1931; Nicholson 1933; Ricker 1940; Delury 1947; Fry 1949). The guiding principle of fisheries management came to be the concept of maximum sustainable yield (MSY). For two decades following the second world war, research on methods for measuring population parameters and estimating maximum yield flourished. Classic papers like those of Ricker (1954) and Beverton and Holt (1957) highlighted this period. It culminated in handbooks for the calculation of biological statistics of fish populations that are familiar to every student of fisheries (Ricker 1958; Gulland 1969).

Implicit in the fisheries management literature predicted on MSY were three assumptions: (1) the dynamics of commercial fish stocks are sufficiently predictable that MSY is an achievable goal, (2) knowledge of fish stock dynamics is sufficient knowledge for effective resource management, and (3) MSY is an appropriate societal goal.

An occasional heretic questioned the singlemindedness of the MSY dogma and the missionary zeal (Larkin 1977) with which fishery managers pursued MSY. Challenges to the dogma did not carry much weight, however, until toward the middle of the third quarter of this century. By this time fishing technology had advanced to the point that fish stocks were being overexploited world wide. By 1975 it had become abundantly clear that, in most instances, stock dynamics were neither well enough understood nor sufficiently deterministic to render MSY an achievable goal, that knowledge of stock dynamics alone was not sufficient for effective management, and that MSY was probably not an appropriate societal goal anyway. Thus, the premises that made MSY a logical guiding principle of fisheries management had proven to be false, and the way was opened for the emergence of a new guiding principle.

In the United States and Canada, MSY was formally set aside as the guiding principle of fisheries management in 1976 with the publication in Canada of *Policy for Canada's Commercial Fisheries* (Department of Environment, Fisheries and Marine Service 1976) and passage in the United States of the Magnuson Fisheries Conservation and Management Act (MFCMA). Both of these documents state that the overall goal of fisheries management is to maximize the net benefits to society that can be derived from the fishery. The Canadian document is extremely prolix in describing what this means. Larkin's (1977) summary is as precise as any:

> ...The goals are to maximize food production, preserve ecological balance, allocate access optimally, provide for economic viability and growth, optimize distribution and minimize instability in returns, ensure prior recognition of economic social impacts of technological change, minimize dependence on paternalistic industry and government and protect national security and sovreignity...

The MFCMA is more concise. According to this legislation the goal of fisheries management is to achieve OY, which is defined as the amount of fish "(A) which will provide the greatest overall benefit to the Nation, with particular reference to food production and recreational opportunities; and (B) which is prescribed as such on the basis of the maximum sustainable yield from such fishery, as modified by any relevant economic, social, or ecological factor."

Clearly, the concept of MSY survives in these new policies, explicitly in the MFCMA and implicitly in the Canadian goal to maximize food production. But MSY is only one of several goals articulated in these documents. The new buzzword is "optimum yield" and it implies an amalgum of biological, economic, and social goals among which MSY could have a rather low priority.

Operationally Defining OY

The emergence of OY as a guiding principle of fisheries management constitutes explicit recognition in the United States and Canada of the multiobjective nature of fisheries management problems. The transition from MSY to OY in the operational sense, however, is proving difficult. The debate about what OY means and how it can be calculated has been extensive (Roedel 1975; Orbach 1977; Larkin 1977). The operational techniques that were developed to satisfy the MSY concept clearly could not be generalized to satisfy the OY concept. A recurrent complaint about the MFCMA, which legally constrains the Regional Fisheries Management Councils to harvest at OY, has been that the act is too vague. Alverson (1977) and Apollonio (1982) both noted that the act fails to state which social, economic, and ecological factors are to be taken into account in determining OY, and what is the relative importance of these factors. Larkin (1977) voiced similar complaints about the lack of specificity in the Canadian policy document and in published definitions of OY. He warned that vagueness in the definition would inevitably lead to political manipulation of management. As we shall see later, however, the vagueness of the definition need not be a problem.

The MFCMA confuses the issue further by stating that OY in excess of domestic fishery needs must be allocated to foreign fleets. This seems to equate OY with surplus production, which was the basis of the MSY concept. The necessity of allocating "unused" OY to foreign fisheries was clarified somewhat by the Subcommittee on Fisheries and Wildlife Conservation and the Environment (Breaux 1981), which stated that this was not an absolute requirement of the legislation. The impression remains, however, that OY is a number of fish, determined in an unspecified way, but determined independently of decisions about how the fish are to be allocated. The concept of OY, however, implies that decisions about allocation are fundamental to determining what yield is optimum.

The operational definition of OY is equally confused in Canada. Recent Canadian policy documents (Department of Fisheries and Oceans, Fisheries and Marine Service 1981, 1982) continue to stress the importance of economic and social considerations in the fisheries. The operational technique, however, appears to be to calculate a total allowable catch (TAC) based on biological models of yield per recruit at $F_{0.1}$ (The rate of fishing mortality at which the increase in yield per recruit with a small increase in fishing mortality is 0.1 × the rate of increase in yield per recruit at very low rates of fishing mortality, after Gulland and Boerema 1973). This TAC is then distributed among competing user groups in accordance with a set of guidelines that emphasizes such things as minimizing social and economic disruptions, satisfying the needs of native Indian fishermen, increasing economic viability and stability, encouraging independent ownership of fishing vessels, etc. Optimum yield in Canada, therefore, appears to mean a biological yield close to MSY distributed according to some set of social and economic guidelines. There is little discussion in Canadian policy documents about how regional management regimes could be tailored to meet these goals. Neither the MFCMA nor the Canadian policy documents give any guidance about how conflicting goals are to be reconciled or on what basis trade-offs are to be made.

The most incisive comments on OY occur in the literature on fisheries economics. Economists were among the first to challenge the emphasis on MSY in fisheries management (Taylor 1951) and among the first to employ the phrase optimum yield (Gordon 1953, 1954). When MSY was supplanted by OY the economists were ready with a theory and an analytic methodology for optimizing yield. The only viable approach, according to some economists (e.g. Turvey 1964; Crutchfield 1975; Pontecorvo 1977) was to equate OY with maximum economic yield (MEY). Four basic arguments have been used to support this point of view: (1) the real objective of fisheries is to benefit mankind, and economic yield is a recognized measure of benefits to mankind; (2) MEY always involves less effort in the fishery than MSY, so that stock conservation goals are generally met by managing to MEY, at least in single species fisheries; (3) any local social disruptions (e.g. redundancy in segments of the industry) consequent on rigorous management to MEY are small on a national scale, or even on a regional scale, and are insignificant compared with the theoretical economic benefits of not wasting labor and capital in the fishery; (4) although certain intangible nonmarket benefits of fishing may be ignored by the MEY paradigm there is, currently, no better way to capture the net benefits of fishing to society. Thus, managing to MEY, although not perfect, is the best we can do at the moment.

Despite these compelling arguments, MEY has not been adopted as the operational definition of OY. In fact, the MFCMA specifically guards against such a definition (National Standard No. 5: "Conservation and management measures shall, where practicable, promote efficiency in the utilization of fishery resources: except that no such measure shall have economic allocation as its sole purpose."). Nevertheless, economic analysis has become an important aspect of fisheries assessment and has had significant impact on the design of management regimes in recent years (Popper 1978; Needler 1979).

The impact of social factors on fishery management planning under the new policy is more difficult to assess. The importance of social factors beyond those captured by MEY is readily acknowledged (Crutchfield 1975, 1979; Christy 1977) and vigorously advocated (Orbach 1977, 1978; Pollnac and Littlefield 1983). However, no rigorous theory or set of empirical relationships has been put forward that would permit management regimes to be adjusted objectively and quantitatively for social considerations. A development along these lines with considerable potential is Pollnac and Littlefield's (1983) model of job satisfaction. While the empirical relationships presented by these authors are promising, they remain to be generalized into a prescriptive model of benefits from the fishery. The analytic tools available to the fishery manager remain, therefore, those for calculating MSY and MEY. In the current climate of disenchantment with MSY, it is not surprising that MEY has had a strong impact on recent management regimes for Canadian and United States fisheries.

My major objection to MEY as the operational definition of OY is that it amounts to substituting another single objective paradigm (maximizing return on capital and labor) for the old MSY paradigm. Adopting MEY as the operational definition of OY would mean sacrificing the great flexibility of the OY concept, flexibility which permits the weight given to biological, economic, and social factors in a fishery to be varied according to regional circumstances. The current approaches to determining OY in the United States and Canada do not capture this flexibility either. While they are not wholly based on either MSY or MEY, neither do they embody in a conjoint way the biological, economic, and social goals implicit in OY. It is the flexibility inherent in the OY concept that, if it could be captured within the bounds of a logical and objective analytical model, would constitute the greatest strength of OY as the guiding principle of fisheries management.

Thus, while the OY concept has considerable intellectual appeal, its practical application has been mired in controversy. The controversy revolves around the fact that no acceptable analytic methodology has emerged in fisheries management for ranking, weighting, and combining the multiple objectives that should determine OY. This has made the concept appear woolly, elusive, and, therefore, vulnerable to abuse (Larkin 1977).

Multiattribute Analytic Techniques

The failure of a multiattribute analytic methodology for dealing with problems like OY to emerge in fisheries is surprising, since a well-developed methodology exists (Keeney and Raiffa 1976). This methodology has been effectively employed in other areas of natural resource management to resolve issues of resource allocation and to incorporate social, economic, and ecological goals into a single analysis (e.g. David and Duckstein 1976; Freeling and Seaver 1980; Ulvila and Seaver 1982). In a fisheries context, Bishop et al. (1981) argued for the use of multiattribute analytic techniques in designing fishery management regimes under the MFCMA, and Keeney (1977) and Hilborn and Walters (1977) applied one technique (multiattribute utility analysis) to the problem of managing Skeena River salmon. These papers appear not to have aroused much interest among fishery scientists or managers. Yet the analytic techniques proposed by these authors derive from a logically appealing and objective decision model that is useful for exploring a wide range of fishery management problems. The literature on multiobjective decision making is extensive. Here I shall attempt only to introduce the reader to the rich literature on multiattribute analytic techniques and show, through a discussion on OY in the New England Herring Fishery and the Skeena River salmon fishery, how these can provide an analytic framework for defining OY.

The New England herring fishery and the Skeena River salmon fishery are quite different in character. The New England sea herring fishery currently harvests mainly from one stock of herring (the Gulf of Maine stock) although two other stocks (the Georges Bank and Southwest Nova Scotia stocks) contribute to the catch. The fishery is particularly important to Maine and Massachusetts but New Hampshire and Rhode Island also have a stake in the fishery. The bulk of the Maine fishery is an inshore fishery using fixed gear to catch juvenile herring for the sardine trade. This fishery is particularly important in the economy of isolated coastal communities in Maine. The fisheries in the other states are mobile gear fisheries for adult herring to supply filleting and specialty product markets. Adult herring are caught partly in state territorial waters where they are under the jurisdiction of the state management agencies and partly in the Fishery Conservation Zone where they are under the jurisdiction of the New England Fishery Management Council (NEFMC). The stocks supporting the fishery migrate back and forth across the international boundary and are harvested by both Canadian and U.S. fishermen. Thus, the herring fishery is an example of a single-species fishery involving multiple stocks, multiple user groups with conflicting objectives, and several political jurisdictions.

Keeney (1977) described the Skeena River fishery. Briefly, it involves five species of Pacific salmon and one species of anadromous trout (steelhead, *Salmo gairdneri*), a commercial fishery prosecuted by three different gear types, an active sports fishery, and a native Indian subsistence fishery. The Department of Fisheries and Oceans (DFO) is the single regulatory agency responsible for management of the fishery. The fishery is economically important to the Skeena region. Thus, the salmon fishery is a multispecies fishery involving several user groups but only one regulatory agency. Both the herring and the salmon fisheries present complex, multiobjective management problems involving important biological, economic, and social concerns.

The analytic models used in designing and assessing management regimes for both these fisheries have been of the traditional single objective type. Yet managers have clearly had more than one goal in mind in the management of these fisheries. Presumably, a multiattribute analytic solution would have been useful to them.

The general analytic solution to the multiobjective problem may be stated simply as follows:

$$(1) \quad U_i = \left[\sum_j a_j^p S_{ij}^p \right]^{1/p}$$

where U_i is an aggregate measure of the performance of the ith solution (e.g. management regime) against $j = 1 \ldots n$ attributes of the problem, a_j is the preference weight associated with the jth attribute of the problem, S_{ij} is a measure of the performance of the ith solution against the jth attribute, and p is an integer specified in the range $1 - \infty$ (usually 1, 2, or ∞) depending on the choice of decision rule and the choice of performance measure for each solution. In this formulation, p can only take values other than 1 if S_{ij} is a measure of the difference between the actual score of a policy i on an attribute j and the ideal score for attribute j.

Here I shall discuss only solutions in which

$$p = 1, \ \sum_j a_j = 1,$$

and S_{ij} scores are scaled from 0 (worst) to 100 (best), i.e.

$$(2) \quad U_i = \sum_j a_j S_{ij}.$$

This is the linear weighted solution to the optimization problem in which the optimum solution is the solution that maximizes U. Cohen and Marks (1975), Keeney and Raiffa (1976), Starr and Zeleny (1977), Bell et al. (1977), and Duckstein and Opricovic (1980) discussed the application and interpretation of numerous other optimization solutions.

This analytic framework finds a natural application in the problem of defining OY. The concept of OY implies that biological, economic, and social factors are all to be taken jointly into account in determining the yield to be taken from the fishery. We can specify the factors that are important to us, those that should play an important role in determining OY. These become the attributes, or criteria, that we will use to evaluate the overall suitability of any particular yield of fish. For any specified set of attributes we can, either objectively or subjectively, determine how well any particular yield of fish satisfies each attribute (the S_{ij} of eq. 2). We may also presume that not all attributes are equally important to us and that we can specify our preference weightings, or that we can research the preference weightings of any affected group, for the set of attributes (the a_j of eq. 2). The optimum yield is that yield that maximizes U in eq. 2.

This process constitutes a practical application of multiattribute utility theory (MAUT). There are essentially six steps in the application of this theory to the resolution of multiobjective problems like determining OY (Table 1).

Bounding the Problem

The first step is that of bounding the problem, deciding what is to be included in the analysis and what is to be left out. In the case of OY, there are three primary dimensions along which to bound the problem, biological, economic, and social. There are no hard and fast rules for establishing boundaries; it is wholly a matter of judgement on the part of the fishery manager. The choice of problem boundaries should not be regarded as a trivial

TABLE 1. The six steps in the application of multiattribute utility theory to determining optimum yield.

1. *Bounding the problem:* Deciding which factors and which constituencies are to be taken into account and which are to be left out in determining optimum yield
2. *Determining the feasible policy alternatives:* Deciding what is the range of technically feasible yields within which the optimum yield must lie
3. *Deciding on the attributes of the problem:* Selecting a comprehensive, mutually exclusive, and preferentially independent set of attributes against which the feasible yields will be judged
4. *Setting the attribute weights:* Determining the relative importance of the attributes as criteria for distinguishing among yields
5. *Scoring the policies:* Objectively scoring each feasible yield against each attribute
6. *Applying the decision rule:* Combining the scores and attribute weights for each yield according to the predetermined decision rule and selecting the optimum yield

matter, however. The decision about what will be included and what left out of the analysis is likely to affect the optimum yield, and a poor choice of boundaries could come back to haunt the manager when he tries to implement his OY policy. On the other hand, since the analysis is quantitative, the manager can evaluate a variety of boundary decisions and search for unexpected consequences (Holling 1978).

A significant aspect of bounding the OY problem is to decide who has a stake in the management regime, and who are the constituencies the regime is expected to serve. For example, Keeney (1977), in his MAUT analysis of the Skeena River salmon fishery, identified five principal affected groups, four "types" of fishermen and a composite regional group whose welfare was tied to fishing such as cannery operators, lodge operators, etc. (Table 2). The definition of these groups was restricted to the Skeena region. Clearly, other groups and geographic boundaries could have been devised. Hilborn and Walters (1977) reviewed a broader group of constituencies in their analysis of enhancement options for the Skeena River. I have also listed some groups outside the Skeena region who have an important stake in the fishery (Table 2). Keeney's way of bounding the problem reflected what he saw as the primacy of the well being of regional fishermen to regional management decisions, the secondary importance of other regional activities associated with fishing, and the relative unimportance of affected groups outside the region. The aggregation of lodge owners, cannery operators, etc., into a regional development group also reflected a judgement by Keeney that the members of this group would react similarly to any potential policies.

In a similar way, I have identified groups likely to be affected by management of the sea herring fishery in New England (Table 2). Like Keeney (1977), I have kept the fishermen segregated by gear type. Herring fishermen could be aggregated into offshore and onshore groups, since these groupings also reflect state and product dichotomies. A herring management plan prepared in 1977 (NEFMC 1978), however, showed that management regimes can affect the gear types differently. It seemed, therefore, appropriate to disaggregate the onshore and offshore fisheries. I have also disaggregated the processors into sardine, fillet, and meal processors, since sardine processing occurs predominantly in Maine and fillet and meal processing predominantly in Massachusetts. I segregated meal processors because state statutes require that food uses of herring take precedence over reduction. Other regional groups with a stake in herring management include state legislators and state fishery management agencies. Groups outside the region include foreign fishermen, federal legislators, National Marine Fisheries Service (NMFS), and the public at large. The inclusion of the regulatory agencies, or even the decision making body itself (e.g. DFO in Canada or the NMFS and the Regional Councils in the United States) among the affected groups is, in my view, an important part of the accounting process. The prestige accorded these groups and the self-esteem of their members is affected in important ways by the mangement regimes that are adopted. It would be naive to imagine that the regulatory agencies are indifference to the management regime and will not use their position to influence the regime.

TABLE 2. Groups considered to have a stake in decisions about optimum yield in the Skeena River salmon fishery and the New England herring fishery.

Skeena salmon fishery	New England herring fishery
Fishermen	
Lure fishermen (trollers)[a]	Offshore fishermen (seiners, pair trawlers)[b]
Net fishermen (seiners, gillnetters)[a]	Onshore fishermen (wiers, stop seiners, purse seiners[b]
Sport fishermen[a]	
Native Indians	
Other regional groups whose welfare is tied to fishing	
Cannery companies[a]	Sardine canneries[b]
Motel operators[a]	Fillet processors[b]
Sport lodges, etc.[a]	Fish meal processors
	State legislators
	State fishery managers
Groups outside the region whose welfare is tied to fishing	
Federal legislators	Foreign fishermen
Provincial legislators	Federal legislators
Public at large	Public at large
Fishermen and processors in other regions	National Marine Fisheries Service
British Columbia Hydro Authority	

[a] Groups considered by Keeney (1977) in his MAUT analysis.

[b] Groups considered by the NEFMC in developing their 1978 herring management plan.

The set of affected groups that I have identified for the problem of OY in herring and salmon is rather broadly defined. This is to emphasize the range of choices open to the manager and the need for careful consideration in identifying whose concerns are to be taken into account in designing the management regime and what are their natural groupings. For example, the groupings in Table 2 emphasize technological or functional associations. In other instances, geographic or community associations might be more appropriate. By whatever means the final list is determined it should include all those groups whose views are likely to influence the final decisions about fishery management. The importance of carefully selecting these "stakeholder" groups will be more important later on. Suffice it to say at this stage that their preference structures will have an important impact on the determination of OY.

A second important aspect of bounding the OY problem is to decide on the time horizon for OY. Since fish are a common property resource, management agencies typically have a strong conservation mandate, and their tendency is to adopt a long time horizon. Despite the fact that, for the sake of expediency, sustainable yield was often exceeded, the goal of management in the past was always to achieve a yield close to MSY. Even though MSY has now been replaced by OY, both U.S. and Canadian policy still asserts that any optimum yield must be a yield that can be taken on a "continuing" basis. What continuing means, however, is left to the discretion of the fishery manager and this opens the door to management options that include short-term overfishing. A variety of circumstances can be imagined in which the short-term advantages of overfishing outweight the benefits of a longer term view. Provided full account is taken of the price that must be paid later if sustainable yield is exceeded now, I see no objection to serious consideration of such options. In fact, the multiattribute analytic techniques that I am discussing are ideally suited to evaluating the trade-off between short- and long-term benefits of a management option in a realistic way. For the purposes of this paper, however, it is appropriate and simpler for me to take a long-term view, as this will permit me to use traditional equilibrium fisheries models in my discussion. This is not to discount the importance, or the difficulty, of short-term decision making. Often the most contentious decisions the manager will have to make will involve what to forego now to achieve increased future returns. Suffice it to say that this trade-off could also be incorporated into the analysis but at the cost of a considerable increase in complexity.

Other aspects of bounding the problem include the more familiar fishery management tasks of deciding geographic and stock boundaries and delineating important ecosystem interactions that might be influenced by a change in management regime. For the New England herring fishery the stock boundaries are the three broadly defined stocks of herring found in the Gulf of Maine: The Southwest Nova Scotia stock, the Georges Bank stock, and the Gulf of Maine stock. Geographic boundaries extend from Rhode Island to Maine and from the Shoreline to 200 mi (320 km) offshore. These are generally the boundaries set by the NEFMC in their 1978 fishery management plan for herring.

For the Skeena River salmon fishery the stock boundaries include the six species of Pacific salmon and anadromous trout that spawn in the river and its tributaries. The geographic boundaries include the watershed of the Skeena River and the marine waters off northern British Columbia which comprise the nursery and migratory pathways for the salmon.

Determining the Range of Feasible Yields

The second step in MAUT is to determine the set of feasible policy alternatives (Table 1). In the case of OY this means deciding on a set of feasible yields. Here I shall assume that the Schaefer model (Ricker 1975) is an adequate description of the long-term relationship between fishing effort and yield for both the herring and salmon fisheries, and that all yields from 0 to MSY are technically feasible. Thus, the feasible set of yields, which includes OY, ranges from 0 to MSY. It is important to remember, however, that for every yield other than MSY there are two possible levels of effort, and thus, two possible sets of economic, social, and ecological values.

The determination of feasible yields for the herring fishery is complicated by the fact that not only are there three stocks contributing to the fishery but also that the juvenile and adult fisheries harvest different components of the same stocks. Fortunately, it appears that maximum yield per recruit occurs at about the same fishing mortality for all the stocks. Strictly on the basis of yield per recruit, the adult fishery has the potential to provide the greatest biomass of harvest (Fogarty et al. 1981). The juvenile fishery is an old and established component of the fishery, however, and is economically important to the State of Maine. Part of the problem of OY then is to determine the appropriate trade-off between the adult and juvenile fisheries.

While all yields between 0 and MSY are feasible, and all combinations of juvenile and adult fisheries, I shall restrict my analysis to three points on the yield curve, MEY, MSY, and the bionomic equilibrium. I shall also restrict my analysis to three combinations of adult and juvenile harvest, all juvenile, all adult, and 50:50 juvenile and adult. This gives a total of nine different yield policies for comparison. While none of these may be strictly optimum, they will suffice to illustrate the method. In addition, their relationship to one another may point the way to a true optimum.

Selecting an illustrative set of feasible yields for the Skeena River salmon fishery is more difficult. All six salmon species are highly vulnerable to the suite of modern gear in the fishery so that yields from 0 to MSY are certainly feasible. The species differ in productive capacity, however, ranging from less than two recruits per spawner for chum (*O. keta*) to approximately four recruits per spawner for chinook (*O. tshawytscha*), they differ in their vulnerability to the various commercial and recreational fishing gear, and they differ in their market value. The determination of OY in the salmon fishery is, therefore, much more dependent on how the fish are allocated than is the determination of OY for herring. This makes it difficult to choose a small set of yields for the six species that captures the essence of the OY problem in this fishery.

Some simplifying assumptions must be made. All the species in the Skeena River fishery are presently overfished, lightly in the case of sockeye (*O. nerka*) and pink (*O. gorbuscha*) salmon, the most abundant species, moderately in the case of coho (*O. kisutch*), and heavily in the case of chum, chinook, and steelhead. The majority of the catch is taken in the commercial fishery. I shall assume, therefore, that the most critical trade-offs affecting OY will be the allocation trade-offs among the commercial gear types, and the trade-off between maintaining current levels of commercial fishing effort with catches below MSY or reducing effort to obtain greater catches in the long run. This is not to say that the allocation trade-off between commercial/recreational/subsistance fisheries should not be a concern of the manager. It only means that I shall ignore this trade-off in my sample analysis. A thorough analysis of OY in the salmon fishery would certainly take this trade-off into account just as it would take account of the trade-off between short- and long-term costs and benefits as noted earlier. I shall take the point of view that the recreational and subsistance fisheries will both benefit from a restriction in commercial effort and an increase in salmon runs to the Skeena.

The illustrative yields for the Skeena River salmon fishery will be, therefore, the current biomatic equilibrium yields for all species (estimated as the recent average yields in the fishery) and the yields that can be projected to result from about a 30% decrease in total commercial fishing effort (close to the combined species MSY). I shall combine these yields with three

TABLE 3. Attributes of optimum yield for the Skeena River salmon fishery and the New England herring fishery and the range over which each attribute might vary with different management policies.

Skeena salmon			New England herring		
Attribute	Best	Worst	Attribute	Best	Worst
Biological and conservation goals					
Spawning escapement (thousands)			Stock size (MT × 10^3)		
Sockeye	900	300	Southwest Nova Scotia	500	200
Pink	1500	500	Georges Bank	500	200
Chum	50	5	Gulf of Maine	110	40
Coho	150	20	Predator stock (relative)	2.0	1.0
Chinook	60	10	Fish species diversity	1.9	1.5
Steelhead	50	5			
Economic goals					
Net fishermen income ($ × 10^3)	50	0	Offshore fishermen income ($ × 10^3)	90	0
Lure fishermen income ($ × 10^3)	50	0	Inshore fishermen income ($ × 10^3)	12	0
Recreation income ($ × 10^6)	10	0	% profit sardine processor	10	2.0
Cost of salmon ($/lb.)	0.2	10	% profit fillet processor	15	7.0
Management cost ($ × 10^6)	0	10	Management cost ($ × 10^6)	0	2.5
Social Goals					
Days fishing (nets)	100	0	Harvest sector jobs	500	150
Days fishing (lures)	100	0	Processing sector jobs	1500	500
Sport catch (×10^6)	1.0	0	Days fishing	150	30
Indian catch (×10^3)	200	0	Days processing employment	200	60
Regional jobs	5000	0	Trip length (days)	1.0	3.0
			Plant environment (relative)	2.0	1.0
			Injuries (annual)	0	20
			Foreign catch (MT × 10^3)	60	0

allocation options for the commercial fisheries: (1) allocation according to the recent landings by each gear type, (2) allocation of more sockeye and pink to the lure fishery in return for a reduction in effort by the lure fishery on chinook, coho, and steelhead, and (3) allocation of the total catch to the net fishery. This gives a total of six different yield alternatives. While this is a small set of the potential alternatives for this fishery, it is a set that touches on some of the important management concerns in the Skeena River fishery and should give a sense of the power of MAUT in evaluating policy alternatives for such a complex multispecies fishery.

Establishing the Attributes of the Problem

The third step in MAUT (Table 1) is to establish the attributes of the problem. These are the criteria against which the yields will be judged in order to determine which is optimum. Just as decisions about inclusion or exclusion of stakeholders were judgemental, so are decisions about which attributes adequately describe the problem. There is no unique set of attributes for any OY determination. The set that is chosen, however, must meet four criteria: (1) it must be comprehensive; i.e. it must reflect all aspects of the problem as it is bounded; (2) the attributes must be mutually exclusive, i.e. the same things may not be counted twice; (3) the attributes must be independent, i.e. the preference for a particular trade-off between any two attributes should not be dependent on the amount of any other attribute present in the system; and (4) the attributes must be additive, a scaling problem for which there are a number of solutions.

Keeney (1977) defined 12 attributes of the Skeena River salmon management problem. He arrived at these by taking advantage of the hierarchical nature of goals. As I noted earlier, Keeney focused on regional needs in his analysis, and the attributes he chose reflect this. The only attribute in Keeney's (1977) set not designed to satisfy some regional economic or social goal was the annual government expenditures on management. DFO, which administers the Skeena fishery, has, however, a responsibility for resource conservation that goes beyond satisfying the immediate needs of the resource industry. For example, a policy that clearly promoted the extinction of one or more of the species of salmon in the Skeena River would be unacceptable even if the policy scored very high on the set of regional attributes Keeney identified. I have, therefore, added an attribute for the spawning escapement of each species to Keeney's list and dropped the attribute "number of salmon species." The total number of attributes for the Skeena OY problem is then 16 (Table 3). There is also a range of possible values that the attributes might take depending on the management policy (Table 3). I have set the lower bounds on escapement for each species above 0 to reflect the probable lower limit of escapement that would precipitate drastic management action by DFO. Keeney (1977) discussed the range of possible values for the other attributes and their relevance to the problem of managing the Skeena River fishery.

The hierarchical nature of goals also provides a way to decompose the OY problem for New England herring into a set of attributes (Table 4). Twenty attributes appear to describe the herring OY problem (Table 3). Five of these are biological. A major concern of herring managers is the possibility of stock collapse. There are no agreed upon or infallible indicators of stock collapse, but the probability of collapse is presumably inversely related to stock biomass, so I have included stock biomass as a proxy indicator of probability of collapse. Genetic diversity is a long-standing concern of fishery managers, which

TABLE 4. A hierarchy of goals for the New England herring fishery.

Maximize net benefits to society		
Conservation of resources goals	Economic development goals	Social development goals
1. *Conserve target species:* Maintain productive stock biomass for Georges Bank, Gulf of Main, and Southwest Nova Scotia stocks	1. *Maximize net income:* Offshore fishermen, onshore fishermen, sardine processors, fillet processors, meal processors	1. *Maximize employment in the industry:* harvesting jobs, processing jobs
2. *Conserve other valued species:* maintain biomass of commercially valuable herring predators	2. *Minimize costs:* Enforcement costs	2. *Maximize satisfaction:* Days fishing, days processing employment, trip length, plant environment
3. *Conserve marine ecosystem:* maintain species diversity of Maine/Georges Bank	3. *Maximize economic efficiency:* Economic rent	3. *Maximize safety:* Injuries to fishermen and processors
		4. *Foreign relations:* Foreign catch

has become even more fashionable lately (Berst and Simon 1981), and is now measurable by a number of techniques. The concern for genetic diversity is satisfied by disaggregating the three stocks of herring and considering their biomasses separately. Concern for interaction among species of commercial value and the possibility that reduced herring biomass might affect the forage base for predatory commercial species, like the cods, is satisfied by the inclusion of predator biomass as an attribute. Concern for the effects of man's harvesting activities on the ecosystem in general is satisfied by the inclusion of fish species diversity (Shannon–Wiener Index) as a proxy measure of ecocystem stability (Tables 3, 4).

There are seven economic attributes. These include net income to fishermen and processors disaggregated by gear and product type to satisfy concern for how the total income from the fishery is distributed. The concern of regulatory agencies over the costs of administering any regime is satisfied by the inclusion of enforcement costs as an attribute. The concern of economists over the efficient use of capital and labor in the fishery is satisfied by inclusion of economic rent as an attribute. Regional legislators are likely to be concerned about continued economic development in the fishery. In my view this concern is also satisfied by the attribute of economic rent, since presumably any rent generated by the fishery will either be reinvested in the fishery or in other regional developments.

There are eight social attributes. These include employment opportunities in both the harvesting and processing sectors. Harvesting and processing employment are kept separate because the harvesting sector employs predominantly men, while the processing sector employs predominantly women. The attributes of job satisfaction for fishermen are days spent fishing and length of individual trips, two factors that Pollnac and Littlefield (1983) found closely related to fishermen satisfaction. Similar attributes score for job satisfaction among plant workers. I have considered safety to be a relevant management goal with injuries to fishermen and processors as the attribute. The issue of foreign fishing poses some problems, as much of the impetus for the MFCMA was to eliminate foreign fishing. For some stakeholders any amount of foreign fishing is bad, while for the State Department the licensing of foreign fishing provides some international leverage. Also, the Law of the Sea convention prohibits coastal states from denying access to foreign fishermen if there are identifiable unutilized fishery resources in coastal waters. From a purely nationalistic point of view there is no reason ever to permit foreign fishing within territorial waters. Such fishing will only reduce the catch-per-unit-of-effort of national fishermen and provide competition in the marketplace for domesticly produced goods. Thus, in my view, foreign fishing is a social issue that falls in the context of foreign relations. The value of fish as a foreign relations tool must be considered in relation to their value if used some other way, even if that alternate use is simply to provide a cushion against the possibility of stock collapse.

Weighting the Attributes

The fourth step in MAUT (Table 1) is setting preference weights on the attributes, the a_j's of eq. 2. In a decision problem with as many powerful stakeholder groups as there are in fisheries, determining a set of preference weights acceptable to all groups is likely to be difficult. The first step is to assess the specific preference pattern of each stakeholder. Nominally, this is an iterative process whereby the stakeholder first ranks the attributes from the least to the most important. Then the stakeholder assigns successively to each attribute, from the least important to the most important, a score that reflects the relative importance of that attribute to the one next below it in rank. Giving the lowest ranking attribute a score of 10 provides some flexibility in scoring those attributes immediately above it (Edwards and Newman 1982). Careful cross referencing among the attributes and their scores is required to ensure that the final weights are a true reflection of the preferences of the stakeholder. It is also important in assigning weights to attributes that the stakeholder consider not only the philosophical importance of an attribute but also the likely impact of any feasible policy on values of the attribute. If none of the feasible

TABLE 5. Weights for the attributes of optimum yield in the Skeena salmon fishery and the New England herring fishery.

Skeena salmon fishery		New England herring fishery	
Attribute	Weight	Attribute	Weight
Spawning escapement		Conservation	
Sockeye	0.04	Southwest Nova Scotia stock	0.09
Pink	0.04	Georges Bank stock	0.12
Chum	0.08	Gulf of Maine stock	0.16
Coho	0.08	Predator stocks	0.03
Chinook	0.11	Species diversity	0.01
Steelhead	0.10	Subtotal	0.41
Subtotal	0.45		
Income and costs		Income and costs	
Net fishermen	0.08	Offshore fishermen	0.09
Lure fishermen	0.08	Inshore fishermen	0.09
Recreational revenue	0.07	Sardine processors	0.08
Cost of salmon	0.02	Fillet processors	0.05
Cost of management	0.05	Meal processors	0.02
Subtotal	0.30	Cost of management	0.03
		Economic rent	0.01
		Subtotal	0.37
Social satisfaction		Social satisfaction	
Days fishing nets	0.02	Harvesting jobs	0.05
Days fishing lures	0.02	Processing jobs	0.04
Sport catch	0.05	Days fishing	0.02
Indian catch	0.06	Trip length	0.02
Regional jobs	0.10	Days processing work	0.02
Subtotal	0.25	Plant environment	0.02
		Injuries	0.02
		Foreign catch	0.03
		Subtotal	0.22

policies is likely to have much impact on an attribute then it should receive a low rank and a low weight regardless of its philosophical importance. Species diversity is potentially such an attribute in the herring OY problem (Table 3). Important as the concept of ecosystem stability might be, there is little likelihood of any OY having a large impact on species diversity among the fishes of the Gulf of Maine and Georges Bank, even though herring is an important forage fish. The reverse is, of course, also true. Attributes of moderate philosophical importance should receive greater weight if their value is likely to be strongly influenced by the range of feasible policies.

Once the attributes are ranked and assigned their relative weights the weights may be normalized so that their sum equals 1.0. This is done simply by dividing each weight by the sum of weights for all attributes. This step, although not essential, keeps the aggregate utility scores in the range 0–100.

Differences in preference patterns among stakeholders are inevitable and these may be sufficient to affect significantly the choice of OY. According to Gardiner (1981), however, the MAUT process encourages agreement among the stakeholders when compared with wholly intuitive approaches to policy evaluation. This is because, in the absence of a structured decision analytic model, stakeholders tend to key on attributes that are most important to them and to discount heavily, or disregard, other attributes of the problem. Nevertheless, the weighting process may reveal substantial disagreement among stakeholders (e.g. Hilborn and Walters 1977). The operational decision maker (the Regional Councils in the United States and DFO in Canada) will have to take such disagreements into consideration when developing OY. Particularly important will be the degree to which such disagreements may frustrate attempts to achieve OY in the fishery. Affected groups may, for example, refuse to comply with regulations they regard as unfair.

One approach to resolving disagreement among stakeholder groups is to include those groups with conflicting preference structures as a level in the hierarchy of goals. A goal of the analysis then becomes to satisfy maximally the desires of the conflicting groups. This was the approach taken by Keeney (1977) in developing a utility function for the Skeena salmon problem. In this approach the central decision maker must determine a set of preference weights for the trade-off among conflicting stakeholders. Any arbitrary assigning of weights to the affected groups, however, may be regarded as unfair and could result in just as much opposition to the OY solution as would have been generated by the original preference conflict. A more satisfactory approach may be to confront the stakeholders with the differences in their preference weights and negotiate a compromise.

In the case of the Skeena fishery, I determined the preference weights for use in the sample OY analysis from preference data in Keeney (1977) and my knowledge of this fishery (Table 5). In the case of the New England herring fishery, I determined preference weights from informal discussions with NEFMC members and detailed discussions with Dr Susan Peterson (Woods Hole Oceanographic Institution, Woods Hole, MA), an anthropologist who served on the Scientific and Statistical committee of the NEFMC for several years.

For both fisheries the combined weight of conservation attributes is greater than the combined weight of either economic or social attributes alone (Table 5). This reflects the emphasis that most fishery managers place on resource conservation. The combined weight of social and economic attributes taken together is greater than that for conservation goals, however, indicating that policies that totally disregard economic and social attributes will never win out over those that emphasize these attributes at the expense of some conservation goals.

Scoring the Yields

The fifth step in MAUT analysis is to score the policy options against the attributes they must satisfy (Table 1). I derived scores for the biological and economic attributes from the familiar bionomic relationships based on the Schaefer model (Fig. 1).

The yield curves in Fig. 1 for the six salmon species in the Skeena River are an approximate representation of surplus production based on unpublished information in reports of geographic working groups within DFO. The relative heights of the curves are in proportion to projected maximum yields for each species in the Skeena. The total yield curve is simply the sum of the individual yield curves. The cost line was drawn from the origin to intersect the total yield curve at a level of effort consistent with current yields in the fishery and the degree of overexploitation of the individual species. The yield curves for chum, coho, chinook, and steelhead are scaled along the effort axis to reflect their vulnerability to the suite of gear in the fishery and their current levels of overexploitation, high for chum, chinook, and steelhead, moderate for coho.

The yields of each species at current fishing effort (E_2, Fig. 1) and fishing effort for MSY (E_1, Fig. 1) can be deduced from the figure (Table 6). Escapement may be presumed proportional to yield. Although not all the yield curves are symmetrical, escapement for all species appears closer to optimum, as defined by the geographic working groups, at E_1 then at E_2. I have presumed, however, that the allocation option that eliminated the lure fishery but maintained total effort at E_2 would potentially permit significant recovery of the coho, chinook, and steelhead stocks, since effort in the net fishery could be directed more toward pink and sockeye. This allocation option, therefore, scores well on escapement for the heavily exploited species.

Income for net and lure fishermen is presumed proportional to catch with some adjustment for different prices paid for the different species. The alternative that allocates a greater share of sockeye and pink to lure fishermen presumably would reduce the income of net fishermen, while the alternative that eliminates the lure fishery presumably drops their regional income to zero. Sport catch I presumed to be proportional to escapement of the principal recreational species (coho, chinook, and steelhead) and Indian catch proportional to total escapement. I presumed regional jobs to be approximately proportional to total catch but adjusted somewhat for elimination of the lure fishery in some policies (Table 6).

The yield curves for adult and juvenile herring were derived from Fogarty et al.'s (1981) yield per recruit analysis (Fig. 1). The relative positions of the cost lines are subjective and based on information in Hu et al. (1983) and the Sea Herring Fishery Management Plan (NEFMC 1978). The positions of the nine yield alternatives that I shall analyse (MEY, MSY, and bionomic equilibrium for an all juvenile, all adult, and a 50:50 juvenile/adult fishery) are shown in Fig. 1. I deduced scores for the biological and economic attributes of the herring OY problem from Fig. 1 and information in Fogarty et al. (1981), Hu et al. (1983), and the Sea Herring Fishery Management Plan (NEFMC 1978) (Table 7). I also based scores for the social attributes on information in these documents about employment in the various sectors of the industry and working and fishing conditions in the industry.

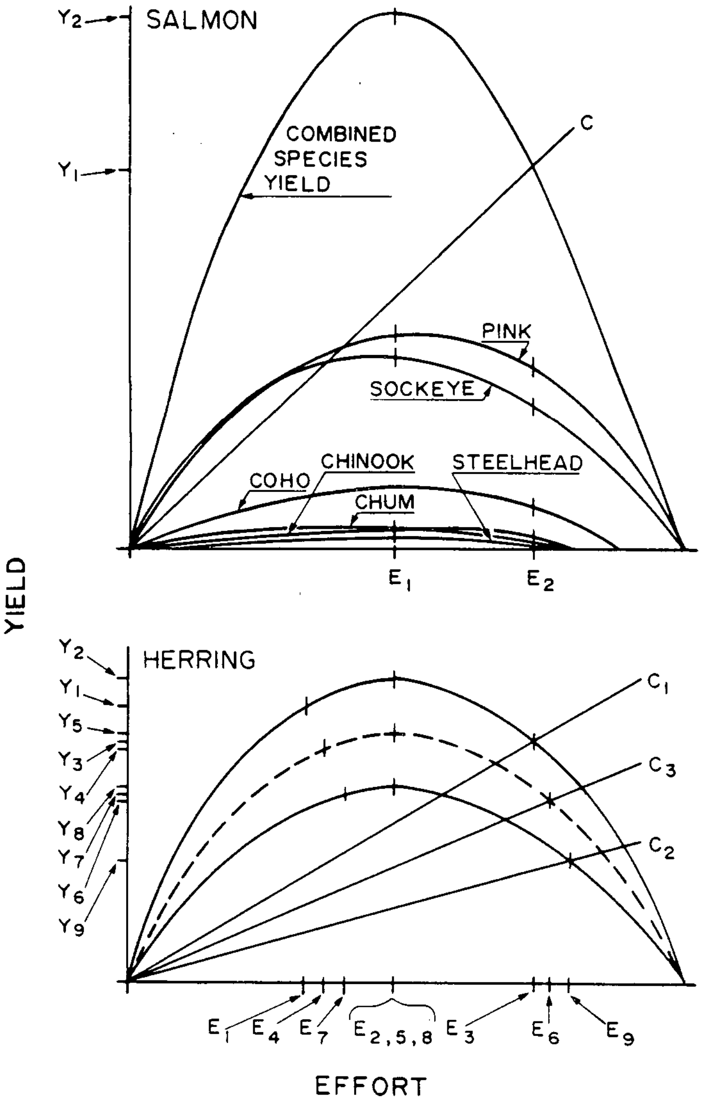

FIG. 1. Yield (fish or $) and cost ($) in relation to fishing effort for the Skeena River salmon fishery and the New England herring fishery. The cost line for the salmon fishery is drawn in relation to the combined yield line for all species. Effort level E_1 (yield Y_1) for the salmon fishery is the effort level for the combined species MSY, while E_2 (yield Y_2) is the current bionomic equilibrium. The relative yields by species at each of these effort levels may be determined from the individual species yield curves. The yield curves for the herring fishery represent an all adult fishery (upper curve), an all juvenile fishery (lower curve), and a 50:50 adult/juvenile fishery (broken curve). Cost lines C_1–C_3 represent harvesting costs for the adult only, juvenile only, and mixed fisheries, respectively. Effort levels E_1–E_9, and corresponding yields Y_1–Y_9, represent effort and yield for MEY, MSY, and bionomic equilibrium in the adult only, mixed, and juvenile only fisheries, respectively.

It was a fairly simple matter in either fishery to identify the

TABLE 6. Scores of yield alternatives against attributes for six alternatives in the Skeena River fishery (scores are scaled form 0 (worst) to 100 (best)).

	Current level of effort: Allocation option			MSY level of effort: Allocation option		
	(1) Status quo	(2) More pink and sockeye to lures	(3) No lure fishery	(4) Status quo	(5) More pink and sockeye to lures	(6) No lure fishery
Biological attributes						
Sockeye	0	0	0	100	100	100
Pink	0	0	0	100	100	100
Chum	0	0	20	60	100	80
Coho	0	20	60	50	80	100
Chinook	0	20	60	50	60	100
Steelhead	0	20	60	50	60	100
Economic attributes						
Net fishermen ($)	40	0	60	80	60	100
Lure fishermen ($)	10	0	60	80	60	100
Recreational ($)	0	20	40	80	90	100
Cost of salmon	0	0	0	100	100	100
Management cost	40	0	80	60	20	100
Social attributes						
Days net fishing	20	0	60	80	60	100
Days lure fishing	70	80	0	90	100	0
Sport catch	0	20	60	50	80	100
Indian catch	0	20	40	60	80	100
Regional jobs	0	20	60	80	100	90

TABLE 7. Scores of yield alternatives against attributes for nine alternatives in the New England herring fishery (scores are scaled from 0 (worst) to 100 (best)). MEY, maximum economic yield; MSY, maximum sustained yield, BE, bionomic equilibrium.

	Adult fishery			50:50 Adult/Juvenile			Juvenile fishery		
	(1) MEY	(2) MSY	(3) BE	(4) MEY	(5) MSY	(6) BE	(7) MEY	(8) MSY	(9) BE
Biological attributes									
Southwest Nova Scotia stock	100	65	10	92	65	5	85	65	0
Georges Bank stock	100	65	10	92	65	5	85	65	0
Gulf of Maine stock	100	65	10	92	65	5	85	65	0
Predators	100	65	10	92	65	5	85	65	0
Species diversity	100	65	10	92	65	5	85	65	0
Economic attributes									
Offshore fishermen	100	75	50	50	37	25	0	0	0
Inshore fishermen	0	0	0	50	37	25	100	75	50
Sardine processors	0	0	0	47	50	30	95	100	60
Fillet processors	90	100	78	46	50	39	0	0	0
Meal processors	40	48	0	71	74	16	91	100	31
Management costs	75	37	0	100	62	25	87	50	12
Economic rent	100	86	0	83	76	0	69	67	0
Social attributes									
Harvesting jobs	0	12	25	37	50	75	62	87	100
Processing jobs	0	25	12	50	62	37	87	100	75
Days fishing	0	12	25	37	50	62	75	87	100
Trip length	100	75	0	100	75	0	100	75	0
Days processing	0	25	12	50	62	37	87	100	75
Plant environment	87	100	75	50	37	62	12	25	0
Injuries	87	100	25	62	75	0	37	50	12
Foreign catch	87	100	75	50	62	37	12	25	0

best and the worst performer among the yield alternatives for a particular attribute. I gave these yields scores of 100 and 0, respectively, on that attribute. It was also, in all instances, possible to rank order the other yields between these extremes. For the relationships depicted in Fig. 1, I could determine the relative value of a particular yield on an attribute and assign scores according to those values on the scale of 0–100. Where I could only determine rank ordering, I assigned scores at equal intervals along the scale 0–100.

Obviously, where quantitative production and economic models exist for a fishery these should be used in scoring yield alternatives. Subjective decisions may still have to be made about the impact of a particular alternative on some attributes. Additionally, there may be strong differences of opinion among experts about the interpretation of quantitative models and empirical data, so that several "objective" scores are available for a particular attribute. A thorough analysis should always test the sensitivity of the model to contentious scores. The scores that I have assigned are rather subjective and this could affect the outcome. The skeptical reader, however, may easily determine how a change in any score might influence the analysis.

Since the analytic model is not sensitive to either the units or the original scale of measurement, attributes for which there is no clear empirical evaluator may be included in the analysis. An example of such an attribute might be the value of the "recreational experience" associated with sport fishing or the "social value" of fishing as an occupation. Scoring alternative policies against such attributes may only be possible by soliciting expert opinion. Other attributes, for which there is a clear objective scale of measurement, but insufficient data to permit precise location of an alternative on the scale, may also have to be scored by expert opinion. Approaches to the use of expert opinion differ. Edwards (1971), for example, believes that one does not attempt to average several opinions. One simply identifies an appropriate expert, solicits his opinion, and goes on with the analysis. For those who mistrust the opinion of a single expert, however, techniques for achieving concensus among experts may be attractive (e.g. Zuboy 1981).

Applying the Decision Rule

The final step in MAUT analysis (Table 1) is to calculate the aggregate utility value for each yield option (eq. 2). Each weight by score product for an attribute is a utility value for that option on that attribute. The performance of any option may be examined over any subset of attributes as well as over the whole set. I have, therefore, aggregated utilities over biological, economic, and social attributes for each fishery as well as over the whole set of attributes (Table 8).

The outcome of the analysis for the Skeena salmon fishery is quite straightforward. All the yield alternatives involving a reduction in effort scored higher than the policies involving the current level of effort. For all alternatives except status quo allocation at current levels of effort the scores were well distributed among the biological, economic, and social attributes. Somewhat surprisingly, however, the alternative involving elimination of the lure fishery scored much better on virtually all attributes than the other alternatives. This result is, of course, a consequence of the set of weights and scores that I used in the analysis. I doubt that the lure fishermen would agree with the wisdom of any analysis that predicted an increase in general welfare associated with their elimination. This result may be spurious, since I have not attempted to determine rigorously the preference structure of stakeholders in this fishery. The result is also dependent on my assumption that greater control could be exercised over coho, chinook, and steelhead escapements in the absence of the lure fishery. It is important to remember, however, that I did not conduct the analysis with this outcome in mind. It is also important to ask how much of a change in attribute weights would be required to make the "no lure fishery" option less attractive than the "status quo" option. If the division of preference among the biological (0.45), economic (0.30), and social (0.25) dimensions is kept the same, then putting all of the economic and social weight into attributes associated with the lure fishery still does not make the "no lure fishery" option less attractive than the status quo. Thus, a pretty fundamental change in preference structure would be required in order to change the outcome of the analysis with respect to the desirability of the lure fishery.

TABLE 8. Aggregate utility scores for six yield alternatives in the Skeena salmon fishery (Table 6) and the nine yield alternatives in the New England herring fishery (Table 7). Scores are aggregated across biological, economic, and social attributes as well as across all attributes.

	Utility scores aggregated across:			
Policies	Biological attributes	Economic attributes	Social attributes	All attributes
	Skeena salmon fishery			
Alternative				
1	0.0	6.0	1.8	7.8
2	5.8	4.6	5.8	16.2
3	19.0	11.6	12.6	43.2
4	27.3	21.0	17.5	65.8
5	35.0	22.1	22.0	79.1
6	43.4	22.0	22.0	87.4
	New England herring fishery			
Alternative				
1	41.0	17.7	8.1	66.8
2	26.6	14.7	10.8	52.1
3	4.1	8.4	6.7	19.2
4	37.7	20.3	11.3	69.3
5	29.2	17.3	12.8	59.3
6	2.0	9.9	9.6	21.5
7	34.8	21.7	13.2	69.7
8	29.2	18.9	15.8	62.9
9	0.0	10.3	11.7	22.0

The results for the herring fishery are less straightforward. All the MEY options scored best. MEY in the juvenile only fishery had the highest score, but only marginally higher than MEY in the mixed juvenile/adult fishery. All MSY options also scored well, and again MSY in the juvenile only fishery scored highest among these options. The bionomic equilibrium options all scored poorly relative to the other options. What the analysis suggests is that there is little to choose among the MEY and MSY options for any of the allocation policies examined and that some other attributes or some other decision rule would have to be invoked to distinguish among these options. It is a little surprising that the "adult only" option scored relatively poorly considering the potential improvement in yield associated with this option. The apparent social and economic advantages of the juvenile or mixed juvenile/adult fishery, however, outweighed the loss of production in these alternatives.

Discussion

A detailed evaluation of the yield options for either the Skeena salmon fishery or the New England herring fishery is probably not warranted. The attribute weights and the scores used in the analysis are preliminary and are intended to illustrate the method rather than solve the OY problem in these fisheries. The preference weights and the scores are, nevertheless, plausible so the analysis results should not merely be dismissed as unrealistic. The analysis suggests that a reduction in the lure fishery on the Skeena River salmon stocks would significantly benefit the hard-pressed runs of chinook, coho, and steelhead. This result is consistent with current thinking among regional managers in DFO. But the analysis also suggests that cutting back the lure fishery would increase the general welfare of the region, although, of course, the lure fishermen would suffer. In a similar way the analysis of the New England herring fishery suggests that a reduction in fishing effort would incrase the general welfare of the region, although some fishermen would presumably suffer.

The degree to which a few should suffer so that others might benefit has always been a contentious question in fisheries management. In part, this relates to the trade-off between short- and long-term benefits mentioned earlier. One decision analytic approach to this trade-off is through appropriate choice of decision rule. The rule that I chose in the analysis of OY for the salmon and herring fisheries was to maximize aggregate utility. This rule is indifferent to the negative side effects of a policy because it reacts only to the net positive effects. Other rules are possible, in particular, rules that seek to minimize the sum of negative effects of a policy. Suppose, for example, that I had used the following scoring procedure:

$$(3) \quad S_{ij} = I_j - A_{ij}$$

where I_j is the ideal score for the jth attribute and A_{ij} is the actual score for the ith solution on the jth attribute. Equation 1 then becomes an analytic solution that is sensitive to departures from an idealized set of attribute scores. The yield solution that minimizes U when $p = \infty$ is a solution that minimizes the negative effects of a set of attributes (Duckstein and Opricovic 1980). In practice it is desirable to use several decision rules in evaluating any set of management alternatives so that the positive and negative effects of each can be explored.

The MAUT techniques that I have described are among the less sophisticated of the decision analytical methods. Considerably more sophisticated, and intellectually more rigorous, techniques exist. The sophisticated methods have the disadvantage, however, that they are more difficult for the decision maker to identify with. I consider that there are four principle advantages to applying simple MAUT techniques to the solution of complex fishery management problems like OY. First, the techniques are specifically designed to help with the practical solution of multiattribute decision problems. This is the class of problems to which OY and related fisheries management problems belong. Second, the techniques are designed to mimic the natural decision making process so that they are intellectually appealing and understandable to the decision maker. Third, they provide a structured analytic framework for quantitatively evaluating alternative solutions. This means that any decision supported by such an analysis is not only transparent but is also amenable to sensitivity analysis. Fourth, the techniques permit a broad range of types of information and levels of measurement to be brought together into a single objective decision rule. Differences in measurement units, scales, accuracy, and precision are not a problem, so far as the analysis is concerned. Tangible and intangible attributes can be incorporated with equal ease. Thus, the manager can bring all the information at his disposal, or any set of it, to bear on the problem and can feel confident that decisions will not be flawed because he was unable to incorporate objectively some piece of information.

Value judgements are clearly a large part of the application of MAUT. In the past, fishery managers have shunned any appearance of making value judgements. Of course, they were making value judgements all the time. The decision to manage to MSY is a value judgement. Every regulation to control fishing effort has consequences for allocation of which managers were well aware, and so their application involved a value judgement. It was, however, considered dangerous to be honest about such side effects of resource management. The MAUT techniques not only provide a way to bring the value judgements inherent in any decision about OY out in the open, but also provide a way to absolve the manager of the criticism that he is imposing his values on the industry. Provided the manager is diligent about identifying the important stakeholder groups and capturing their attribute weights then he can reasonably argue that everyone's views were taken into account in determining OY.

There is no escape from the fact that determining OY requires value judgements. The analytic models that I have described, however, provide an objective framework for assessing the value judgements that determine an optimum. Like other analytic models, MAUT models can be abused. For example, it is possible to backtrack from a predetermined solution to a set of attributes and weights that will support that solution. The transparent nature of decisions based on MAUT techniques, however, and the fact that they can be subjected to sensitivity analysis makes such abuse difficult and potentially unproductive. These techniques capture the spirit of the OY concept within a rigorous analytic framework yet they also provide the flexibility that the decision maker needs to deal with the multifaced nature of fisheries management.

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