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# Risk, Uncertainty and Utility
# A Review of the Use of these Concepts in Fisheries Management

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*Abstract*

The terms risk and uncertainty have become commonplace in the fisheries management literature but are used with a variety of technical meanings. This report reviews recent common usage and considers the alternate applications of the concepts within the framework of Decision Theory. A case is made for increased use of Decision Theory methods with particular attention to the identification of Utility as the basis of a possible new management approach.

## 1. Introduction

Few involved in fisheries management deny the difficulty of what they try to achieve. Commonly, the practitioners have less than full confidence that the models they use accurately describe the dynamics of the processes they are investigating and often, they are unsure how accurate are the parameters that their models use. Not surprisingly, a common, if not usual, experience, is that what happens, eg, in terms of stock biomass, catches or recruitment, differs considerably from what was predicted. Usually it is expected that the models will not provide a certain prediction of future yields or recruitment for a given stock size and a major difficulty is how to handle this ignorance so that the best decisions can be made about future management actions. Specifically, how can decision makers, people who often have little or no training in the discipline they are involved in, be provided advice that is comprehendible to them and so encourage 'optimal decisions', ie, those that are most likely to result in management actions that lead to a maximum of what ever particular benefits are desired?

One method of tackling this problem that, as yet, has been little used in fisheries management, is to explicitly incorporate into management procedures consideration of the degree of ignorance about the state of the fisheries system so that some understanding of the possible hazards of the different management actions that exist may be known. The techniques that are used in this type of analysis form an established, and well developed discipline, often referred to as *Decision Theory*. Central to this discipline are the concepts of *Risk* and *Uncertainty*, and the associated concept of *Utility*. As is common in many technical disciplines, words that are used to convey specific concepts are taken from the general vocabulary and often are used side-by-side in both a general and technical sense, resulting, at the best, in poorly written documents, and at the worst, in ambiguity or confusion. The field of statistics is rich in such examples, eg, consistent, efficient, precise and accurate are some terms that frequently do this double duty.

The same danger exists in the application of Decision Theory to fisheries management. Outcomes of decisions regarding management actions may be described as uncertain, likely or unlikely, probable, possible, risky, etc. An issue is how well do such terms help managers to make the 'best' decisions? Even what comprises the 'best' decision will be seen to be a non-trivial question. The purpose of this paper is to discuss the meanings of the terms uncertainty and utility, and that of risk in an attempt to give decision makers (who are, of course, most unlikely to read this paper - they are too busy) insights into the concepts and to encourage fisheries technocrats to take care to avoid confusion when using the terms in reports and papers. Ultimately, the concepts, touched on rather lightly in this paper, lead directly into the field of decision making. It is in this discipline that I believe, the next major contribution to the effectiveness fisheries management might be made.

## 2. Common Usage of the Word Risk

Most are familiar with the noun *risk* in the sense of hazard, danger, exposure to mischance or peril. For example, Goffinet (1992) in discussing fishery management problems faced by developing nations refers to short-term solutions which place the resource-base at risk and that the relative effectiveness of other countries' management plans may place the resources of these less-developed countries at greater risk as fishermen weigh the costs of entering various fisheries and choose those with ineffective management. McAllister & Peterman (1992) in discussing the potential of experimental management refer to the risk of stock collapse as a possible result. Pearse & Walters (1992) in discussing decisions about harvest levels as the most crucial responsibilities of fisheries managers note that while the outcomes are always more or less uncertain, the risk depends largely on the information available and that fisheries biologists, trained to assess the probabilities of outcomes from management decisions, are too often also expected to decide what risks should be taken. Haunschild, Nagel & Oeberst (1991) in discussing the lack of conformity of ageing of redfish (*Sebastes marinus*) note that solving these problems is of great importance for stock assessment and for management recommendations, otherwise the long-living redfish stocks run the risk of overfishing. These examples are typical of many that can be found in the fisheries literature that use the term risk in its substantive sense and without any quantitative meaning. In whaling contexts, Beddington (1978) uses risk as an index of the relative stability of different harvesting strategies for the event of driving a stock beyond MSY. And Beddington and Grenfell (1979) define risk as the probability of movement of a stock to protection status.

In the general sense given above, Peterson & Smith (1982) explicitly categorise risk in an analysis of risk reduction in fisheries management. They give four general sources of risk: (1) the resource and its changing environment, (2) scientific research, (3) markets for the products and factors of production, and (4) management measures, though the generality of these categories makes them of rather doubtful use on operational situations when all sources of risk must be considered simultaneously, and the source of the risk is of secondary importance. In the above examples, the use of the term risk is, in general, clear and to advocate that some other word be used could be considered unnecessarily didactic. However, confusion can creep into usage without care. For example, Swartzman, Getz &

Francis (1987) equate risk and probability when, in using an age-structured stochastic recruitment model to examine a Pacific hake (*Merluccius productus*) fishery they refer to their model as calculating the 'risk' (= probability) that the stock falls into a critically low condition but use probability when referring to finding an algorithm that maximizes expected yield over a short-term planning horizon while constraining the 'risk' of critically low stock conditions.

The word risk is also used as a verb, ie, in the sense of to hazard, endanger or expose to chance of injury, danger or loss, or to take the chances of such outcomes. For example, Lanfersieck & Squires (1992) in evaluating ITQ management systems note that in some situations "The quota market risks becoming thin, noisy, and hampered by non-competitive forces, potentially requiring limits to quota transfer and concentration.

The adjective, risky, is also used in the sense of being dangerous or hazardous, ie, fraught with risk. For example, Fahrig & Atkinson (1991) in discussing a fishery for two species of redfish that are fished together in the Gulf of St. Lawrence and off Newfoundland attempt to identify fishing patterns that would be particularly risky in terms of the survival probability of the two species. Miller, Pietrafesa & Smith (1990) draw attention to the need for greater understanding of relationships between the hydraulics and productivity of lagoon fish and shellfish and that the productivities of many lagoons could probably be enhanced by hydraulic manipulations, but that hydraulic manipulation is presently risky, except in dystrophic lagoons.

## 3. The Decision Theoretic Sense of Risk

For the purposes of Decision Theory, the term risk has a meaning that is well defined and there could be benefits in adopting this meaning for use in fisheries management. To give this definition meaning it will help to introduce the context in decision theory in which it is commonly used.

Situations requiring decisions about future actions abound in fisheries: how many sea days should be assigned to an acoustic survey of some stock? What estimate should be made about the size of a stock given that information is available from VPAs, trawl and acoustics surveys? What amount should be chosen in setting the minimum spawning biomass for stock that shows no discernable stock recruitment relation? How much money should be given to fishermen if their fishery has been closed and the decision maker wants to be re-elected and simultaneously to reduce the number of fishermen in the fishery? Even with little mental effort it is clear that the potential for misery is endless. There are, however, common features to these questions.

First, (let us assume) an action must be taken that will depend on a decision that is made about information pertinent to the problem being considered. For example the action to be taken may be to decide how much fish ($\theta$) exists in an area based on an acoustic survey. The acoustic survey may have consisted of n transects, where each transect gives an average area-scattering cross section of $\bar{s}_{a,i}$. One decision function would be take the arithmetic mean of the transect $\bar{s}_{a,i}$ estimates. If there was little confidence in the survey data another decision function could be to use the results to update a prior distribution function of $\theta$ based on the likelihood of obtaining the survey results and using Bayes' Theorem. The number of possible decision functions that can be identified will depend on the ingenuity of the analyst.

In the example relating to the length of the research cruise, the number, in theory, could be any number from the positive set, ie, $0 \leq$ days $\leq \infty$. But the example is still clear and more realistic, if the number of days must be, say, between 30 and 60, ie, between one and two months. The action that is taken, ie, the number of days assigned to the cruise will depend on the information that is available, eg, are the fish likely to be more dispersed than usual; is the fishery of particular political importance this year; what are the opportunity costs of the vessel, ie, does someone else want to use the vessel?

Based on available information a decision is made that leads to an action. For example, if conditions have markedly changed from the time of the last survey, the action may be to undertake a longer survey. The list of possible actions to be considered should be exhaustive, ie, it should include all possible realistic options. For example, in the acoustic survey case the scientist may know that getting more than 60 days for his cruise is impossible but that a minimum of 30 days has been guaranteed. What decision is to make about the maximum possible size of a stock is more complicated, but not, as it turns out, an intractable problem. And, the list of possible actions must be exclusive, though this in practice is not a problem. For example one can not decide to have both a survey of 35 days and 45 days, or a stock estimate of 15 000t and 25 000t. In the case of the survey results, then

$$a = d(\bar{s}_{a,1}, \bar{s}_{a,2}, ..., \bar{s}_{a,n})$$

where the set of all possible actions, a, may be called A and $d$ is the decision function or strategy[1]. Many different decision functions exist and the best one should be selected. This can be done by evaluating the consequences of the actions through determining the loss that occurs in taking an action, a when the state of the system is $\theta$. If the best action is taken then the loss should be zero. However, as in most problems in fisheries, as $\theta$ will be unknown, then the best action will likewise be unknown.[1] Instead the decision function is applied to the observations (or information) that exist. In the case of the acoustic survey this will be the random observations comprising the transect estimates of the area backscattering cross section. Thus the corresponding loss can be denoted:

$$l(a: \theta) = l[d(x_1, x_2, ..., x_n); \theta],$$

where the $x_1$ are the respective observations, in the case of the survey, $\bar{s}_{a,1}$. It is clear that while the loss function $l(a; \theta)$, and decision function $d$, are specified, the actual loss will depend on the particular observations, or information that are used in making the decision. The observations may be random variables as in the case of the acoustic survey (assuming the transects were randomly selected in the survey ares), or information that is subject to error in other decision making situations.

In Decision Theory, the expectation of the loss, $l(a; \theta)$, is referred to as the '**Risk**', ie, $R(d; \theta)$ and will depend on the decision function $d$, the loss function $l$, and the value of the parameter $\theta$, or true system state. Thus $R(d; \theta)$, the *Risk Function*, can be written as,

[1] The term *strategy* has become so widely used that often as not, it adds little and can lead to confusion; can this term be avoided with little loss?

$$R(d; \theta) = E[l(a; \theta)] \tag{1}$$

$$= \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} l[d(x_1, x_2, \cdots, x_n); \theta] \, f(x_1;\theta) \, f(x_2;\theta) \cdots f(x_n; \theta) \, dx_1 \cdots dx_n$$

As Mood and Graybill (1963) note, a good decision should minimize the risk for all values of the unknown parameter, $\theta$.

The challenge in fisheries management is the specification of realistic loss functions. What is the consequence of deciding on a stock size estimate that is too high? Too low? And thus TACs that may too high or too low? If the loss function was symmetrical about $\theta$, ie, an over harvest of $x_i$ tonnes in year i would be balanced by a decrease in harvest of $x$ in year i+1 (appropriately discounted), then an incorrect choice about $\theta$ may not be too serious as the loss or gain would be balanced the following year. But if $\theta$ is such that the fishery collapses in year i+1, or remains seriously depleted for several years then the risk will be highly asymmetrical. It may be better to take a conservative harvest; if M is low, most of the fish will still exist the following year and the catch can simply be increased in future years and the loss may be quite small depending mainly on the relevant discount rate. If M is large, the situation is more complicated; fish that are not caught in year i, may not survive to be caught in subsequent years, eg, as in tropical penaeid fisheries. In this case, a *use 'em or lose 'em* approach may be appropriate.

However, what in fact is usually considered in dealing with losses or gains, are utilities and these are usually not direct functions of the losses, ie, amounts of dollars or tonnes of fish. For example, if major political unrest, arising from perceived social costs to stake holders, might arise from a decision to temporarily reduce a TAC, despite the increase in future landings and revenues that it would generate, then a decision maker might decide that his utility from a temporarily reduced TAC is less than leaving it unaltered.

## 4. Analyses of Risk in Fisheries Situations

Actual analyses of risk in fisheries situations in the sense outlined in Section 3 are few though papers frequently refer to the term risk analysis. For example, Androkovich & Stollery (1991) note that they "model risk" but do not show any actual treatment of 'risk' in their paper. Linder, Patil & Vaughan (1987) introduce their own definition of risk analysis which they define as the evaluation of the probability of end events interpreted in terms of sequences of earlier events. They use an event tree analysis that couches the uncertainty (probabilities?) of projections in terms of relative risk associated with various management options. In an approach for comparing the implications of alternative fish stock assessments, with application to the stock of Cape hake, *Merluccius spp.*, Punt & Butterworth (1991) suggest a "risk analysis" approach to contrast the implications of different estimates of Total Allowable Catch provided when different assessment methodologies are applied to a stock. The approach involves deterministic forward projection of the biomass trajectory implied by each assessment under the TACs or target levels of effort indicated by that and the other assessments. None of these approached would satisfy the description of "risk assessment" as described in Section 3.

Francis (1991) in an analysis of the management of an overexploited population of orange roughy (*Hoplostethus atlanticus*) in New Zealand expresses risk as the "probability that the fishery would collapse within 5 yr" for different management decisions; more generally he defines risk as "the probability of 'something bad' occurring within a given time period." As such, nothing is added by using the term 'risk' for the term 'probability of collapse'. He calculates the probabilities of collapse using Monte Carlo simulations and then continues to discuss "biological risk" but without an explicit explanation of the term. He does however, in this paper and elsewhere (Francis 1991) pose the critical question of "What is an acceptable level of risk", a topic beyond the scope of this paper.

The approach of Francis to Risk Analysis is similar to others examining fisheries management issues. Hoenig, Restrepo & Baird (1991) examine the uncertainty in the results of sequential population analysis by a Monte Carlo simulation to obtain histograms that describe (personal) probability densities for the quota necessary to obtain a given fishing mortality and for the fishing mortality that would result from a given quota and to describe the risk of not meeting a given management goal as a function of the quota selected. Following a similar quantitative approach, Mohn (1991), in a "Risk analysis" uses a Monte Carlo method to examine a three year TAC strategy for the 4VsW cod, a stock found on the Scotian Shelf; six model parameters were simulated. Mohn provides no definition of risk but does refer to the usage of Francis (1990).

## 5. Attitude to Risk and the Concept of Utility

A related concept that is central to the manner in which many management decisions are made is that of a decision maker's propensity to risk. A common method of illustrating this concept is by consideration of a simple gamble. For example in the (fair) toss of a coin, say for one pound, each participant has a probability of 0.5 of winning the pound and an equal chance of its lose. The expected monetary value of the bet (ie, the decision to say heads or tails) is

$$EMV = \sum_{i=1}^{2} P(\Theta_i)\, A_i = £0.5$$

Many people would consider this a reasonable bet and would not be adverse to flipping a coin. Consider another situation as shown in the table below: an event, $\theta$, has a chance $P(\theta)$ of occurring and a person has the option of one of two actions, $a_i$, (three really if he chooses to do nothing).

| $\theta_i$ | $P(\theta_i)$ | $a_1$ | $a_2$ |
|---|---|---|---|
| $\theta_1$ | 0.5 | 200 | 1000 |
| $\theta_2$ | 0.5 | 0 | -800 |
| Expected monetary value | | 100 | 100 |

A person may choose $a_1$ where he has a 0.5 probability of winning £200 given event $\theta_1$ occurs or gains nothing if event $\theta_2$ occurs. Or he may choose $a_2$ where he has a 0.5 probability of winning £1000 or an equal probability of loosing £800. Each action has the same monetary expectation. But in the first action one would loose nothing; in the second case one could loose £800 and many people will not be indifferent to the two bets (= actions), ie, the utility of winning £1000 may not equal to the utility of loosing £800.

A person who would forgo the opportunity of the bet may be described as *risk averse*. The opposite are people who are *risk preferrers*. Such a person would bet based on the flip of a coin, even if his potential loss would be £1 and his potential gain, say, 90p[2]. I believe (based on my attitude to utility) that such a person is irrational and will make what I consider to be inconsistent decisions such as subsidising vessel construction in fisheries already suffering from excess fishing capacity.

In the case shown in the table above, if the $P(\theta_i)$ are sufficiently changed a risk averse person might change his mind about which action to take. This can be demonstrated by considering the following possible choice of actions:

| $\theta_i$ | $P(\theta_i)$ | $a_1$ | $a_2$ |
|---|---|---|---|
| $\theta_1$ | 0.5 | 1000 | 500 |
| $\theta_2$ | 0.5 | 0 | 500 |
| Expected monetary value | | 500 | 500 |

A risk averse person would prefer $a_2$, ie, £500 for certain rather than a 0.5 probability of either winning £1000 or gaining nothing. But should the sums awarded for $a_2$ be reduced to £450 for each of the probabilities he might prefer taking the bet $a_1$. I.e., his *certainty equivalent* for the action $a_1$ is £450. Note, when:

certainty equivalent < expected monetary value implies risk aversion,
certainty equivalent = expected monetary value implies risk indifference,
certainty equivalent > expected monetary value implies risk preference,

In this case,

$$0.5U(1000) + 0.5U(0) = U(450).$$

Utility has been described as "a number measuring the attractiveness of a consequence - the higher the utility, the more desirable the consequence - (Lindley 1985[3]) and it is central to the theory of decision making. A considerable literature exists that explicitly considers this topic, (eg, De Groot 1970) and no attempt is made here to provide a comprehensive review, though the concept is discussed further in Section 7.

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[2] I believe many of the problems relating to fisheries managers result from management decisions taken by politicians, who appear to be risk preferrers. In terms of their utility functions their decisions are rational, while more generally, society is risk averse.

[3] This excellent book on the theory of decision making written, for people with non-technical backgrounds, was first published in 1971 and offers a comprehensive approach to the topic. I think it offers fisheries management much by providing an explicit manner of handling the necessarily subjective approach to uncertainty of day-to-day fisheries management decisions. Lindley's approach also facilitates integrating the decision setting process with operational decision making by forcing 'those in power' to express their objectives so permitting analysts to know what management objectives and goals are.

The phenomenon of attitude to risk appears to be central to fisheries management concepts such as *the precautionary principle* or biological reference points such as minimum spawning stock sizes. If a decision maker was completely averse to risk, on might argue that no fishery would be prosecuted. Of course no utility would be derived, other than that arising from the satisfaction of the knowledge that the species or stock remains in existence. This appears to be the attitude of some groups involved in the controversy about harvesting certain species of whales.

A few papers in fisheries have been written that explicitly consider attitude to risk through the nature of a utility function. Lewis (1981) derives allocation "strategies" to maximize the expected utility of the Eastern Pacific yellowfin fishery. He used a Markov Decision Model and to allow for risk averse preference, uses a utility function of the form,

$$U(R) = ln\,(R + G)$$

where,

R = Rent or net benefits, and,
G = revenues.

He found that for small population sizes, optimal allocation of effort and the resulting catch for risk averse strategies was equal or greater than the corresponding values for risk neutral policies. This unexpected result arose because of decreasing marginal utility so that a greater weight is placed on catches at low population sizes. This occurred because the addition to utility for a small increase in R is greater when returns are small. In addition, when there are variations in price and catch, these effects are greater at large population (and thus catch) sizes. At small population sizes, the variation in returns is shown to be smaller. Lewis notes that the risk averting manager, compared to the risk neutral manager, will increase his catch at the lower population sizes. Mendelssohn (1982) examined the effects of changes in discount rates compared with the effects of changes in risk aversion for a stochastic fish population dynamics model and came to similar conclusions. He viewed risk averse utility functions as total revenue curves; the two utility functions he examined had the forms,

$$U = 0.5\,ln\,Z$$

where, Z is a measure of catch or revenues, and,

$$U = Z^{\lambda}, \quad 0.05 \le \lambda \le 0.95.$$

He shows that with low $\lambda$, an optimal policy is to harvest more at low population sizes for the higher risk makes it desirable to harvest and be certain of obtaining the catch. Little advance appears to have been made since the papers of Lewis and Mendelssohn in this approach to incorporating attitude to risk into decision making in fisheries management.

Incorporating *attitude to risk* in fisheries management involves two challenges. First, to determine the probabilities and payoffs for each of the different decisions that can be taken, and second, to determine the risk preference of the decision maker, ie, what is his certainty equivalent given the different options available to him. Neither task is simple, but I believe that partial success in either challenge would provide insight and improve decision making in fisheries management. The approaches of Lewis and Mendolssohn seem to offer interesting potential and it is not clear why there has been no development beyond these two applications. Risk analysis in agriculture management appears better developed than for fisheries (see, for example, Anderson, Hardaker & Dillion, 1977, or Anderson & Dillon, 1992) and there should be benefits from cross-fertilization of methods.

## 6. Uncertainty

As with the term risk, so the term uncertainty is used in a wide range of senses fisheries management applications (eg, Hilborn 1987, Restrepo & Fox 1988). Its use in the sense of a state not being definitely known or perfectly clear, vagueness or doubtfulness is common. Botsford (1991) refers to the uncertainty involved in the understanding of egg production and its impact on recruitment in crustacean harvest. Hilborn (1992), in examining the learning ability of fisheries agencies, refers to the need to identify uncertainties and the methods for resolving uncertainty. Francis (1992) refers to the uncertainty inherent in stock assessments of a population of orange roughy (*Hoplostethus atlanticus*). Hoenig, Restrepo & Baird (1991) refer to the uncertainty in the results of sequential population analysis which they quantify by Monte Carlo simulation. Walters (1984) and Hilborn & Walters (1992) in their comprehensive book on fish stock assessment (and whose title includes the term uncertainty), use uncertainty to variously refer to ignorance, parameter error, standard error and the probability of the future occurrence of different events. Tallman (1991) in a study of American plaice concludes that discarding at sea is a major source of uncertainty in management of the resource.

Just as risk has been described in the sense of the probability of possible outcomes, so authors have used the term uncertainty in the same manner. Sebenius (1981) used the term uncertainty in a probabilistic analysis of the "optimum sustainable population" of dolphins taken in tuna purse seine operations and to refer to the calculation of the probability of different populations sizes. Walker, Rettig & Hilborn (1983) use the different sources of uncertainty to define the probability of possible system states for which a utility is calculated. The uncertain states they considered were the occurrence of high upwelling, interaction between wild and hatchery coho and the nature of the stock-recruitment model.

Papers on fisheries have also used uncertainty to refer to the confidence interval, ie, the standard error, of parameters, eg, Hilborn and Walters (1992). Ludwig & Walters (1981) investigate uncertainty in parameter estimates for a stock-recruitment relation by examining a probability density distribution based on the likelihood of the data. The uncertainty is shown as confidence intervals on a spawner-recruit relation. Subsequently they measure uncertainty about the model they investigate as the ratio of the likelihood of alternative models as appropriate system descriptions.

Uncertainty is also frequently used simply to refer to the possible error in a model or its results, For example, Getz, Francis & Swartzman (1991) refer to uncertainty in estimating long-term productivity of a fishery caused by unknown degree of density dependence in a stock-recruitment relationship and Hilborn and Walters (1992) also use uncertainty in the same sense. Restrepo & Fox (1988) use a Monte Carlo approach to model "parameter uncertainty" in a Beverton and Holt yield model by random (uniform probability distribution) selection of the values of the rate of exploitation, the length at first capture and the ratio of M/K; an approach akin to sensitivity analysis.

Economists can have their own specific meaning for uncertainty which they have used in fisheries contexts. While risk and uncertainty can refer to situations where the outcome of a future event is unknown, when the future event has a measurable probability of occurrence, then, for them, the term **risk** is appropriate: uncertainty is used when the probability of a future event is unmeasurable (Knight 1965, Brent 1990). Peterson & Smith (1982) make this distinction in an analysis of risk reduction in management of fisheries from, primarily, the New England region.

Uncertainty has a more specific sense in Decision Theory. Rather than referring to the ignorance about that value of some parameter, or perhaps more correctly, its error, *uncertainty* usually means that it is unknown what will happen on some future occasion (Lindley 1985). Thus it is usually tied to some event that will occur, or may have occurred but whose outcome is unknown. The amount of recruitment of northern cod in 1994 is (I believe) uncertain; the amount of transfer payments that will be paid to subsidise Nova Scotia fishermen in 1994 is, in the same manner, uncertain as is the level of cod block holdings by US wholesalers in mid 1994. Pearse and Walters (1992) refer to the uncertainty of the outcomes of decisions about harvest levels, presumable, in the sense that what will happen is not known.

Unlike predicting the outcome of a toss of a coin, which can make use of statistical laws based on observations of past exactly repeatable events, predicting the outcome of future events in fisheries is far less amenable to analysis. Consider a situation where a decision is to be made about investing in a new fishery, eg, a fishery for mesopelagic fishes for the manufacture of fishmeal. One set of future and exclusive outcomes, $\theta_i$, regarding catch is:

$\theta_1$: Catch rate does not enable costs of the investment to be recovered and operations cease,

$\theta_2$: Catch rate permits costs to be covered but profitability is insufficient to justify additional investment; operations continue until capital assets are depleted,

$\theta_3$: Catch rates are sufficiently high to justify additional investment, operations expand.

Catch rates will depend, among many other things, on the stock size and its productivity and the vulnerability of the resource to capture. This may depend on the degree of contagiousness of the stock in its spatial distribution. For example, it may be that no matter what stock size exists, if it is uniformly dispersed in some year, profitable catch rates may be impossible. Of course, other factors, such as the future price for fishmeal, will too, be important determinants of which outcome of the three events listed above eventuates.

What is needed to apply methods of Decision Theory is to assign probabilities to the factors determining which of the $\theta$ will come to pass. Probability density functions may be specified based on existing data and possible modified by subjective views about future performance. In this way the risk, in the sense of the expected loss, can be determined for any investment decision, given the future catch rate which will depend on different outcomes of resource abundance, school contagiousness and fishmeal price.

## 7. An Alternative: Maximizing Utility

A case can be made for not using the measure of risk in its technical sense (Equation 1). Lindley (1985) uses an equivalent form (in his notation),

$$\bar{u}\ (d_i) = \sum_{j=1}^{n} u(d_i, \theta_j)\ P(\theta_j)$$

where;

$\bar{u}(d_i, \theta_j)$ = utility of the action resulting from the $i^{th}$ decision function given that event $\theta_j$ happens,

$p(\theta_j)$ = probability of event $\theta_j$.

In this case, the decision that should be taken is the one that maximizes $\bar{u}(d_i)$, the expected utility, or as Lindley writes, "a decision problem is one that is solved by maximizing expected utility."

As mentioned earlier, the challenge is not so much the formulation of the conceptual model but rather its parameterization. Deciding on an action in a fisheries management situation requires determining the different utility functions for all those who have a stake in the fishery and reconciling the trade-offs among competing objectives, an approach termed Multiattribute Utility Analysis by Keeney and Raiffa (1976) in their comprehensive treatment of the technique.

The concept of maximizing utility as a management objective has been used in few fisheries situations. Keeney (1977) uses a multiattribute analysis model to examine policy affecting management of salmon stocks in a British Columbian river. He identified 12 "attributes" sought by the different stakeholders, ranging from annual per capita income for the participants in the different gear sectors to the number of species of salmon maintained in the drainage system. The attributes were grouped into five utility functions, those for gill netters, trollers, recreational fishermen, Indians and the government. Keeney's analysis was, I believe, non-trivial, but even so it relied on perceptions of the utilities of the stake holders that were held by two academics, albeit well versed in the problems of the fishery. Despite the detail of Keeney's study it was considered a 'first go round' and he concluded that the main benefits from the study were that (1) they should help to more clearly articulate the substantive issues of the problem and sensitise relevant individuals to the issues; (2) by addressing preference issues, identify inconsistencies in the problem structure; and (3) through use of individual utility functions aid communications among team members working on the same problem.

Walker, Rettig & Hilborn (1983) used a similar approach in an analysis of a coho salmon fishery. They elicited from managers the utility of different ratios of wild and hatchery-reared smolts, given a desire to maximize catches and maintain wild populations susceptible to competition from hatchery-reared fish. Using the multiattribute utility theory of Keeney and Raiffa they specified a single attribute utility function. The probabilities of possible states controlling yield and survival of wild coho were determined using a simulation model. Walker et al. were able to conclude what decisions would maximize utility given the management's objectives, their trade-off between competing objectives and their attitude to risk. This analysis, apparently initially done as a university thesis, offers a good example of the application of decision theory methods to fisheries management problems but there appears to have been no further development, or application, of Walker et al.'s approach.

## 8. Discussion

Many will (rightly) claim that simply identifying utility as the management measure that must be maximized doesn't contribute much, or at least, maximizing utility is what we implicitly do anyway. For example, a biologist who advocates managing to maximize the yield in biomass, implicitly declares his utility to be measured in terms of tonnes of fish (and ignores, eg, fish-size/revenue-dependent implications); an economist might measure utility in terms of rent measured by dollars. Their utility functions are, of course, often irrelevant as they don't make the final management decisions and it is the decision makers' utility that must be maximized[4].

A prerequisite for defining a utility preference function is setting objectives desired from the fishery and Pearse and Walters (1992) note the appeal of formal decision analysis based on utility assessment as a way of forcing clarification of attitudes towards risk.. While this subject is beyond the scope of this paper, it is directly related to the topics covered here. Objectives must be coherent, ie, objectives required, or goals sought, simultaneously cannot be mutually exclusive; that they frequently are is a major cause of management failure. For example, employment can not be maximized and at the same time a reasonable level of profitability ensured. Maximizing output factors from fisheries is not possible if stability of incomes or fishing effort is also an objective. Objectives must be ranked and compromises accepted in terms of equivalent utilities. Where it is uncertain what utility of one or more objectives might be obtained, decision makers should determine their attitude to risk, whether risk preferring or risk avoiding. For example, the extremely risk averse manager concerned about the 'precautionary principle' in relation to the exploitation of a stock might rationally close a healthy fishery depending on his perception of the utility of the possible options.

Practitioners must be able to assist decision makers to articulate their utility preferences of future uncertain events (eg, choice preference between high catches but with a x% probability of stock collapse, or moderate catches, but with a 0.5x% probability of stock collapse, etc.). In this way the decision that maximizes expected utility can be identified.

A well expounded methodology for multiattribute utility theory has been around since at least 1976, but apart from the applications of Keeney (1977) and Walker, Rettig & Hilborn (1983), which were both 'academic applications', ie, university studies, the application of utility based methods (apparently) still remains untested in operational divisions of departments responsible for fisheries management. Why? Does the approach offer no possible benefit? The proper answer is that it has not been tried. Lindley (1985) offers some germane observations. He notes that literacy not numeracy has been the major talent of those usually involved in decision making and that in his country, administrators are, by and large, either self-made men with little education or arts graduates who, finding little use for their skills move to a field (administration) which, until recently, required little

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[4] I would be grateful to learn of any examples where decision makers have explicitly determined utility preferences that can be used as the basis for selecting among policy options and thus providing management goals.

little use for their skills move to a field (administration) which, until recently, required little expertise. The former gained administrative ability by experience, the latter through use of their academic training. But neither group gathered much in the way of numerate skills. He notes that frequently, **even where engineers and scientists design and operate the machines** (my emphasis) the bosses may be totally innumerate and rely on intelligence, personality and energy to maintain their position. Not surprisingly, Pearse and Walters (1992) note that the techniques [of decision theory] are insufficiently developed and standardized that they can be routinely applied and be readily understood.

In one fisheries management situation I am familiar with, the biological advice provided to managers depends on enormous, highly professional and expensive efforts of teams of scientists and support staff, buttressed by the latest technologies, conferences, workshops and international meetings such as this. Yet, these efforts often achieve meagre success. In that situation, the process of negotiating trade-offs between stakeholders is essentially a verbal activity undertaken around a table often in an atmosphere of political urgency, panic or crisis. The failure of present methods of reconciling conflicting objectives of different stakeholders should alone offer compelling support for use of more formal and rigorous methods of determining what decision functions will provide maximum utility.[5]

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[5] A recent press release (23 August 1993) on my desks reads "(AP) ATLANTIC FISH STOCKS CONTINUE THEIR PERILOUS DECLINE AND EVEN FEWER FISH SHOULD BE HARVESTED ... URGENT MEASURES ARE NEEDED TO ADDRESS THE CRITICAL CONDITION OF STOCKS SUCH AS COD ... IN THE ... ST LAWRENCE .. AND NOVA SCOTIA. COUNCIL RECOMMENDS CERTAIN HARVESTS BE HALTED IMMEDIATELY. LOWEST NUMBERS OF FISH EVER OBSERVED ... STATE OF STOCKS VERY NEGATIVE, VERY PRECARIOUS. The week before, newspaper accounts showed longline fishermen blockading a major port in southern Nova Scotia to back their demands for more groundfish quota. Simultaneously, an inshore fishermen's group in the same area has a legal suit against the government for "negligent [mis]management in allowing decline of fish stocks by reckless failure to adequately assess the size, reproduction capacity and migratory patterns." A clear example of incoherent utilities?

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