THE MANAGEMENT OF VIABLE POPULATIONS:

THEORY, APPLICATIONS, AND CASE STUDIES

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Concepts of Risk Analysis as Applied to Viable Population Assessment and Planning

Bruce G. Marcot

SUMMARY

Risk analysis is a facet of decision theory that helps in assessing and planning for viable populations. Two general types of uncertainty are encountered in a risk analysis: scientific uncertainty and decision-making risk. Scientific uncertainty includes variations in the natural system, uncertainty of empirical information and errors in estimation, the validity of models, and the appropriateness of the question being asked. Decision-making risk refers to how uncertain information is used in formulating attitudes toward risk and in making decisions. A new regulation from the Council on Environmental Quality directs agencies to deal with scientific uncertainty by identifying and disclosing necessary information which is incomplete or unavailable for preparing an environmental impact statement.

Conducting a risk analysis consists of estimating probabilities of chance events, estimating results from each possible sequence of decisions, and using the probabilities of chance events in calculating expected payoffs from each decision at any given point in time. The decision-maker uses the results of the risk analysis to help determine a risk attitude and to make the final decision. Risk analysis may be a useful tool in analyzing extinction probabilities of populations and in helping to inform publics and decision-makers as to effects on species viability, impacts on other resources, opportunity costs, and future management options for formulating plans to manage viable populations. The risk analysis tool may be integrated with an adaptive management approach to assess the efficacy of and possibly redirect such plans.

INTRODUCTION

Assessing and planning for viable populations of plants and animals is a complex process. Many factors need to be considered, such as assessing the species' biological attributes and habitat and resource requirements, developing methods to predict species' responses to alternative future environmental conditions, developing and recommending management plans, and accounting for the practicality of instituting plans in light of administrative and political contexts and social and economic concerns. The viable population planning process (see chapter on *Viable Population Planning,* this syllabus) outlines these stages of assessment, which entail biological and technical analyses as well as broader administrative and coordination responsibilities.

A number of areas of uncertainty enter into this process. The biological data and models rarely are adequate and precise enough for predicting species' distributions, abundances, and responses to management activities with little or no error. Also, the administrative contexts are such that management activities seldom can be devised and instituted solely with regard to the biological information. This is true especially in multiple resource management agencies, such as USDA Forest Service and USDI Bureau of Land Management, and when managing for species viability across administrative or national boundaries. Rather, analyses and decisions must involve various degrees of imprecise data, uncertain inferences, limiting assumptions, unforeseen environmental, administrative, and social circumstances, and risks of failure. Such imperfections are always inherent in any analysis or decision-making process, but are especially highlighted when assessing the risk of extinction of a species and alternative uses of finite natural resources.

The field of decision theory and, specifically, the calculation methods of risk analysis address such imperfections and provide a set of concepts and procedures for taking uncertainty into account in an analysis and in a decision-making process. The objectives of this paper are to: (1) provide an overview of the various types of uncertainty encountered in analysis and decision-making processes; (2) discuss Federal regulations that guide how uncertainty is to be used in analyses and decision-making processes affecting natural resource management; (3) review the basic concepts and methods from decision theory for analyzing risk; and (4) discuss the application of risk analysis in assessing and managing for viable populations.

TYPES OF UNCERTAINTY IN ASSESSING AND PLANNING FOR VIABLE POPULATIONS

The types of uncertainty that are encountered when analyzing biological data, making inferences about species' responses to environmental conditions, and selecting and instituting a management plan may be classified as falling under two main headings: scientific uncertainty and decision-making risk (Figure 1). That is, the analysis process is separate from the decision-making process, and sources and implications of various forms of uncertainty from each process are quite distinct. The results of a technical or scientific inquiry, such as a risk analysis of a biological question, is prelude to making an informed decision. Decision-making should often be aided by accounting for and including information on the degree of certainty of the scientific information and of the potential effects of management alternatives.

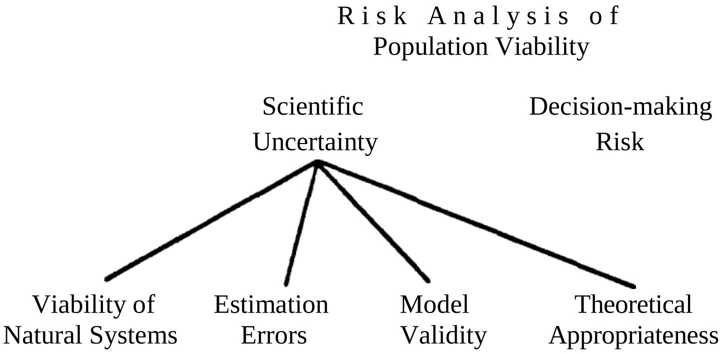

Figure 1. Types of uncertainty in assessing population viability.

Throughout this discussion, the following definitions apply. *Risk is* defined as the making of management decisions when outcomes are less than certain. *Certainty* refers to knowing precisely what will happen during the time period pertinent to the decision being made; *risk analysis* refers to predicting various possible desirable and undesirable outcomes of a decision and their probabilities of occurring; *uncertainty* refers to not being able to specify the relative likelihoods of various outcomes (Levin and Kirkpatrick 1975). Decision-making under uncertainty implies that outcomes may be more desirable or less desirable than predicted.

SCIENTIFIC UNCERTAINTY

Scientific uncertainty refers to the nature of the data and the ways in which information is modeled and used in technical analyses and projections. Uncertainty may arise because (1) the system itself is inherently variable and difficult to predict, (2) the process of estimating the variables of interest is imperfect, (3) the models used to generate predictions or estimations are in some sense invalid, or (4) the scientific question being asked is ambiguous or incorrect. Each source of scientific uncertainty is discussed in more detail below.

Variability of Natural Systems -- Noise in the Message. Many systems are subject to natural variation over time. In particular, political, economic, and ecological systems may be highly variable in some aspects. Predicting characteristics of the system i- the "message" we are trying to interpret -- may often involve observing and modeling attributes that are influenced from outside factors -- "noise" inherent in the message. Such noise introduces a degree of uncertainty in the measurement or estimation of system attributes.

Uncertainty of Empirical Information -- Errors of Estimation. It is often necessary to estimate the value of some parameter of a system from a sample set of observations. A parameter, for example, may be the average number of tree stems per hectare or the variance of litter sizes of black-footed ferrets *(Mustela nigripes)* as can be attributed to individual and environmental variation. When the parameter is estimated from a sample set of observations, from a statistical viewpoint, uncertainty or errors in the estimation may occur. The estimation may be *biased* if each of the values of the observations are consistently lesser or greater than the actual (unknown) values; they may be *inaccurate* if the estimated value of the parameter of interest (such as a mean or a variance) is substantially different from the true value; they may be *imprecise if* the values of the observations vary widely. Each of these errors in estimating the value of a parameter constitutes a different kind of scientific or statistical uncertainty.

Such errors of estimation can arise from a number of sampling problems, such as inadequate sample size, observations taken from disparate times or places, and samples not taken randomly or systematically, depending on the assumptions of the estimator being used. Errors may also arise from applying the wrong kind of estimator, such as a formula for calculating variance that assumes that observations were made independently and randomly when they were actually made over a time series or systematically.

Uncertainty of Modeling Constructs -- Model Validation. Once the inherent variability of the system is in some way accounted for, such as in devising the most appropriate sampling scheme, and once the correct estimator has been chosen and applied, further scientific uncertainty may arise from the ways in which information is modeled and used in analyses and projections. The models, be they statistical, mathematical, computer, diagrammatic, or verbal, may be in some sense invalid. Model validity refers to a broad spectrum of performance standards and criteria. Examples are model credibility, realism, generality, precision, breadth, and depth (Marcot et al. 1983). The various criteria refer to such attributes of models as the number of parameters in a model and their interactions, the context within which a model was developed or should be used, and the underlying and simplifying assumptions of the model structure. A parameter that is estimated precisely, accurately, and without bias may still be used inappropriately, as in a model that generates wrong predictions.

Reliability of Theoretical Constructs -- Asking the Right Question. The context in which a theory is applied or a model is used may introduce yet another source of scientific uncertainty. Even given that a model has been validated -- that is, shown to be a useful tool and shown to generate acceptable predictions according to particular criteria -- it still may be applied to the wrong problem. For example, a life table model that assumes that there are equal sex ratios and that all adults breed each year may generate acceptable predictions for use with Dall sheep *(Ovis dalli),* but may generate grossly inaccurate predictions when used for species with variable or quite different social breeding organizations, such as pronghorn antelope *(Antilocapra americana).* This would introduce the uncertainty of how reliable the model is when used with some species or under some circumstances. Further, the hypothesis or problem that is set up to begin with may be ambiguous, misguided, or inherently unanswerable.

DECISION-MAKING RISK

Quite distinct from the various sources and forms of scientific uncertainty associated with data and their use is the risk that arises when making a decision based on incomplete or imprecise information. Even if such decisions are made rationally, they may lead to undesirable outcomes. Decision theory addresses how uncertainty of information used in decisions can be quantified and how risk can be explicitly represented in various ways.

LEGAL REGULATIONS REGARDING UNCERTAINTY

The Council on Environmental Quality (CEQ) has published (51 FR 15618, April 25, 1986) a new regulation regarding how to deal with incomplete or unavailable information when preparing an environmental impact statement (EIS). The new amendment directs agencies either to obtain essential information for including in the EIS, if costs are permissible, or to include a statement about the incomplete or unavailable information that meets certain specified requirements. The regulation also provides guidance on how to deal with scientific uncertainty:

> If the agency is unable to obtain the information because overall costs are exorbitant or because the means to obtain it are not known, the agency must (1) affirmatively disclose the fact that such information is unavailable; (2) explain the relevance of the unavailable information; (3) summarize the existing credible scientific evidence which is relevant to the agency's evaluation of significant adverse impacts on the human environment; and (4) evaluate the impacts based upon theoretical approaches or research methods generally accepted in the scientific community. ... Impacts which have a low probability of occurrence but catastrophic consequences if they do occur, should be evaluated if the analysis is supported by credible scientific evidence and is not based on pure conjecture, and is within the rule of reason.
>
> CEQ has advanced this regulation because it has concluded that the new requirements provide a wiser and more manageable approach to the evaluation of reasonably foreseeable significant adverse impacts in the face of incomplete or unavailable information in an EIS. The new procedure for analyzing such impacts in the face of incomplete or unavailable information will better inform the decision-maker and the public (Federal Register 1986:15620).

This regulation calls for recognizing and disclosing that vital information may be incomplete or unavailable, and for applying the best available information, methods, and theoretical approach to estimating impacts. The overall intent of the regulation, as with the decision theory approach, is to provide decision-makers and publics with the best available professional thinking on potential or likely impacts and to recognize uncertainty in the scientific information, so that risks may be more clearly understood and accounted for in the decision-making process. The implications of this regulation are particularly pertinent to viable population analysis, where definitive information on population or habitat trends as well as basic ecological information on species are often lacking. Where feasible, theoretical approaches to estimating trends and ecological relationships may have to be used.

ANALYSIS OF RISK

This section briefly reviews concepts and methods of risk analysis (Holloway 1979, Raiffa 1968, Levin and Kirkpatrick 1975). Risk analysis (Figure 2) involves (1) estimating probabilities of chance events, (2) estimating the values of outcomes (payoffs) of every possible sequence of management decisions, and (3) using the probabilities of chance events in calculating the overall expected payoff of management decisions available at the present time. Uncertainty in the estimates of probabilities and payoffs may affect how the results and conclusions of a risk analysis should be interpreted. Also, alternative decisions may be evaluated in light of the forgone payoffs from decisions not taken and in light of the range of future opportunities that are retained or lost. Once a risk analysis is complete, a decision has to be made as to the best course of action. The decision-makers' attitudes toward risk and the utility of outcomes will influence what they view as the best course of action. Finally, the value of gathering additional data or information may be estimated.

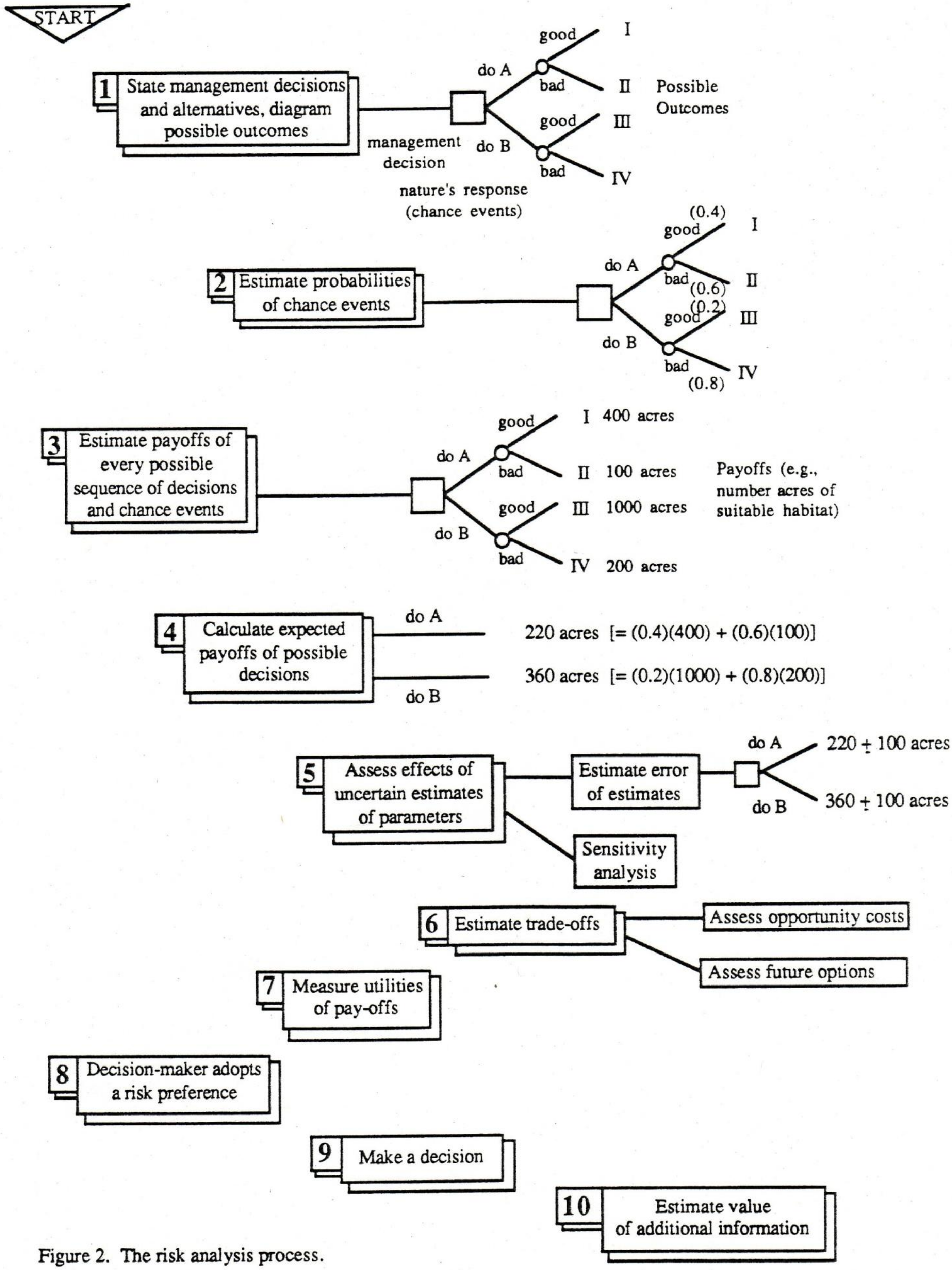

Figure 2. The risk analysis process.

ESTIMATING PROBABILITIES OF CHANCE EVENTS

Risk assessment entails quantifying the possible payoffs of various courses of management decisions. One key element in the assessment is specifying the various responses that may result from each decision and estimating the probability of occurrence of each response. Probabilities may be estimated based on theoretical distributions, actual case history observations, or a subjective assessment of probabilities based on conditions.

Theoretical Probability Distributions. When the actual response to a management decision is unknown, the probability of responses may be estimated by using theoretical probability distributions. For example, a management decision may decrease the suitability of a particular habitat for a species. What may then be estimated is the probability that the site would be recolonized by the species. If empirical data are lacking to estimate the response of the species, a theoretical probability distribution, such as a Poisson distribution, may suffice to estimate the probability of recolonization over time.

Two important considerations when using a theoretical probability distribution are the appropriateness and reasonableness of the shape and the parameters of the distribution. For example, a uniform random distribution probably is not an appropriately shaped distribution for estimating the likelihoods of recolonization over time; the uniform distribution implies that recolonization is equally likely regardless of the duration of time, whereas recolonization probably is increasingly likely the longer the time period, all else being equal. A Poisson-shaped distribution may be a more reasonable approximation. Also, the type of distribution must match the problem. That is, whether the distribution should be discrete or continuous, and truncated or open-ended on one or both ends need to be determined. Distributions commonly used in decision problems include the uniform, binomial, Poisson, normal, exponential, and beta (Holloway 1979).

The parameters of a distribution also must be specified. Parameters include mean, mode, variance, and upper and lower boundaries. For example, the uniform random distribution simply requires specifying boundaries, whereas the binomial distribution requires specifying a mean and standard deviation. Parameters are best estimated from empirical information, when available.

Empirical Probability Distributions. When sufficient field information is available, probabilities of responses may be approximated by calculating the frequency of various observed responses. However, the context of the decision problem should be the same as that for which the empirical data were derived.

Subjective Probability Distributions -- the Bayesian Approach. A third method for estimating probabilities of chance events is a Bayesian revision of probabilities (Holloway 1979, Rubinstein 1975, Spetzler and Stael von Holstein 1975). This involves integrating empirical observations with information known prior to the observations. A probability distribution is calculated for the prior information and is revised by calculating a conditional probability based on both the prior information and the empirical observations. An advantage of the Bayesian approach is that it takes into account information known prior to estimating probabilities of chance events, rather than simply using observation frequencies or theoretical distributions. A disadvantage is that the probability distribution of the prior information is often difficult to establish, yet it may have a great influence on the final, revised probabilities. Often, prior probabilities are little more than educated guesses, and personal biases may inadvertently slant the calculations of revised probabilities.

ESTIMATING PAYOFFS

Each sequence of decisions and each combination of possible responses (chance events) has an associated final payoff. A payoff -is the final net value resulting from a sequence of management decisions and chance events. For example, a payoff may be the total acres of habitat that are provided over a sequence of management decisions and chance events of habitat response. A payoff may also be the net dollar value of timber taken from a particular stand or watershed. Payoffs may be calculated by adding all positive results (returns) at each step and subtracting all negative ones (costs). Alternatively, one could discount future returns and costs in order to weight more heavily those occurring at present or in the near future.

Calculating Expected Payoffs of Possible Decisions. The next step in a risk analysis is to calculate the expected value of payoffs associated with each decision. Expected value is calculated by multiplying the probability of each chance event by the payoff of that event and summing over all events. Consider an example of decisions affecting the reclamation of desirable habitat. If 3 possible decisions have associated probabilities of chance events (probabilities that the habitat will be reclaimed to a desirable quality) of 0.2, 0.3 and 0.5, and payoffs of 100, 150, and 120 acres of habitat, respectively, than the expected value of the payoff associated with each decision is 20 acres (0.2 x 100 acres), 75 acres (0.5 x 150 acres), and 60 acres (0.5 x 120 acres).

Then, for each set of alternative decisions, the best single decision is the one that has the highest associated expected value of payoff. Using the above example, the best decision would be the one involving a probability of 0.3 and a payoff of 150 acres, because this decision had the highest expected value of payoff (75 acres) given the probability of habitat response. In this manner, the best sequence of decisions may be identified as those that provide the highest expected payoffs (Raiffa 1968). However, the decision-maker's attitude toward risk could modify the courses of action chosen from those that simply have the highest expected values (Holloway 1979).

Assessing Effects of Uncertain Estimates of Parameters. A risk analysis is a quantitative assessment of the expected payoffs of various decisions. However, values of payoffs, costs, and probabilities of chance events are seldom known with certainty. Rather, they are estimated from incomplete information, from theory, or from best guesses. The sensitivity of the results of a risk analysis to uncertainty or variations in payoffs, costs, and probabilities can be assessed in two ways. First, the error of each estimated value in the decision model can be calculated by statistical methods. Second, sensitivity analysis can be applied to the risk assessment to determine how much the expected payoffs resulting from each decision would change, given a variation of the parameters of the model. Sensitivity analysis is an easy way to determine when uncertainty or variability in any of the parameters may influence decisions.

Opportunity Costs and Future Options. The variety of outcomes from different possible decisions implies that some outcomes may be traded off when a particular attitude toward risk is taken and when a decision is made. Two types of tradeoffs may be estimated: opportunity costs and future options. An opportunity cost is the highest value of payoff from a decision that was not made and that is not incurred from the decision that was made. For example, from the perspective of wildlife conservation, by selecting to develop a campsite in a remote valley, an opportunity cost may be the nesting pair of peregrine falcons *(Falco peregrines)* that would be displaced by the development.

The second type of tradeoff may be assessed as the range of future opportunities that may or may not be available as a result of a particular decision. For example, there may be a future opportunity to artificially introduce peregrine falcons back into the valley should the development be reduced or removed, or there may be no opportunity for such an action if other decisions encourage further development. In analyzing environmental impacts from potential decisions, it is often of interest to distinguish between reversible and irreversible impacts; these may translate to recoverable and irrecoverable or irretrievable future opportunities. Resource planners often assess the retention of future options for resource use, such as the retention of valuable mineral resources in pristine and unexploited conditions in National Monuments and National Parks. However, in this case it is unclear how one can retain such options indefinitely yet still take advantage of their use and thereby eliminate future options.

MEASURING UTILITIES

Associated with each payoff is its intrinsic worth or utility. Utility refers essentially to the pleasure or displeasure one would derive from certain payoffs (Levin and Kirkpatrick 1975), especially as payoffs are compared among alternative decisions. Different decision-makers may apply different worths to the same payoff, depending on their beliefs, biases, and desires. Utility is measured in decision theory by testing how willing the decision-maker is to risk the loss of various payoffs in order to gain other payoffs, given the probabilities of both occurring. The responses of the decision-maker constitute his or her utility curves for the particular set of decisions being evaluated. Drawing utility curves helps explain and disclose the attitudes of the decision-maker and the values applied to payoffs.

For example, measuring the utility associated with potentially losing a breeding pair of falcons to a parkland development may entail asking how willing the decision-maker would be to risk the loss of the pair in order to gain the economic or recreational benefits of the site, if the probability of losing the pair was estimated at, say 90 percent, and the probability of gaining a $50,000 per year profit from the development was also estimated at 90 percent. Assessing the utility of an alternative decision may prompt asking how willing the decision-maker would be to risk the loss of the pair at a 70 percent probability in order to gain only a $20,000 per year profit from a lesser development of the site estimated at a 90 percent probability.

ASSESSING ATTITUDES TOWARD RISK

Once the possible payoffs of various decisions are estimated from a risk analysis, it is up to the decision-maker to choose a course of action. The course that is chosen may be influenced by how much risk the decision-maker is willing to accept. If the payoffs are known with certainty or near-certainty, then little risk is involved and bolder courses of action can be taken than when the payoffs are more uncertain. Decision-making under uncertain conditions involves specifying an attitude toward risk, such as risk aversion (playing it safe, even if it means lower returns), risk neutrality (hedging bets), risk seeking (going for the high stakes but with higher likelihoods of losing), and risk ignoring (making subjective decisions regardless of the likelihoods of payoffs and their utilities).

The shape of the utility curves reveals the decision-maker's attitude toward risk with regard to the particular decision of interest. For example, a decision-maker may be willing to gamble only a small loss for a particular gain, or, put another way, may be willing to gamble a loss only if the probability of losing is relatively low. In this case, he or she is risk-averse, and the decision made would likely be conservative in nature. A problem with measuring attitudes toward risk by using utility curves is that decision-makers may respond to hypothetical situations and tradeoffs differently than they would to real ones, especially when administrative or political pressures and personal mores are actually brought to bear.

ESTIMATING THE VALUE OF ADDITIONAL INFORMATION

A final aspect of decision theory and risk analysis entails measuring the value of gathering additional data. In this regard, additional information usually has value only if it results in a change in some action taken by a decision-maker, although it may also have value if it helps confirm courses of action already decided upon. Expected values of both perfect (complete) and imperfect (sample) information can be estimated, the former giving an upward limit of information value.

Attitudes toward risk influence the expected value of additional information. The expected value of perfect (or sample) information for risk-neutral individuals is simply calculated as the expected value of the payoff if perfect (or sample) information could be obtained minus the expected value of the best alternative without this additional information. For individuals who are not risk-neutral, the value of information is calculated as the cost that makes the information alternative equivalent to the best alternative without the information. This cost is estimated best by a trial-and-error procedure (Holloway 1979). Calculations of expected value of additional information may aid in determining when to allocate funds and time to gather more data to help refine the estimates of probabilities of chance events, model parameters, or expected payoffs.

RISK ANALYSIS AND ASSESSING POPULATION VIABILITY

This section discusses the application of decision theory and risk analysis in assessing and managing for population viability. The use of risk analysis in assessing species-environment relationships and population viability is a relatively new phenomenon (e.g., Salwasser et al. 1984, Orians et al. 1986). In this section I discuss the relationship between uncertain scientific information and risks of extinction, a definition of viability from a risk analysis viewpoint, the role of adaptive management and monitoring, and examples of using a decision theory approach on habitat and species management.

UNCERTAIN INFORMATION AND RISKS OF EXTINCTION

The central reasons for applying risk analysis to assessing population viability are to help predict population trends and probabilities of extinction under a variety of alternative management strategies and to assess the role that uncertain scientific information plays in such predictions and in shaping management decisions. Predicting population trends and estimating probabilities of extinction are much more difficult with uncertain or incomplete information than if habitat conditions and the biological and ecological characteristics of the species are well known. If such attributes are too uncertain, then probabilities of extinction simply cannot be estimated, and management decisions cannot be aided by a risk assessment. This implies that management decisions based on highly imprecise information may carry a high degree of risk if the decision-makers' preferences lean toward risk-seeking. If the decision-maker is risk-averse, then he or she will make conservative decisions with respect to species' viability, and the chances of extinction will be lower.

Tenets of applying risk analysis to public health and safety (Starr 1985) may be equally extended to health and viability of wildlife populations. That is, risk assessment provides a crude comparison of the relative consequences of specific risks to viability, such as from demographic or genetic factors, with all the other risks that a population must deal with, just as it does with risks to public health and safety. Such a comparative risk assessment would help managers, politicians, and publics to understand and allocate society's limited resources for improving the health and viability of populations. However, the successful use of risk analysis for assessing population viability and for influencing major management decisions regarding habitat and animal management may be contingent upon public acceptance of the general concepts of risk analysis. This acceptance involves the definition of the concept of viability of populations.

Federal regulations mandate the maintenance of viable populations on lands administered by the USDA Forest Service (National Forest Management Act of 1976; see Salwasser et al., this syllabus). Recently, viability has been described as a probabilistic event (Shaffer 1981, Shaffer and Samson 1985, Samson et al. 1985). That is, the continued existence of a population is rarely if ever a 100 percent certainty. Rather, the likelihoods of a population persisting in a particular area may be estimated by calculating the probabilities of various factors that may cause its extinction. Two major factors are systematic pressures, such as habitat loss and habitat fragmentation, and stochastic events, such as environmental catastrophes and random variations in birth and death rates (Shaffer and Samson 1985, Samson et al. 1985).

Population viability (the probability of persistence of a population) is the complement of the probability of population extinction. Estimating such probabilities is a key step in a risk analysis. Shaffer (1983) and Marcot et al. (Spotted Owl Case Study, this syllabus) have estimated extinction probabilities of grizzly bear *(Ursus arctos horribilis)* and northern spotted owl *(Strix occidentalis caurina)* populations, respectively, based on stochastic events of demographic variability, that is, natural variations of birth and death rates. They found that probabilities of extinction are higher when smaller populations and longer periods of time are considered in the analyses. A comparison of the magnitude of such extinction probabilities among various management alternatives and various potential causes of local extinction is helping to shape decisions on planning for animals and habitats of both species.

ATTITUDES TOWARD RISK -- HOW IS VIABILITY DEFINED?

Population viability may be defined in terms of the likelihoods that various systematic and stochastic factors would cause extinction over a specified area and over a specified period of time. The key elements required to analyze population viability are estimates of likelihoods of extinction and definitions of the specified area and period of time. Techniques for analyzing extinction probabilities are discussed elsewhere (case studies, this syllabus). However, defining area and time period are critical prerequisites to applying a risk analysis of population viability.

Specifying the area over which the viability of a population will be considered is not trivial. Areas may include historic or present distributional ranges and may include a variety of public stewards and corporate and private ownerships. Areas also may straddle political boundaries across states or nations, especially with species that migrate (e.g., whooping crane, *Grus americana)* or that are widely distributed but occur at relatively low densities (e.g., goshawk, *Accipiter gentilis).*

Specifying the duration of time over which population viability would be assessed is also not trivial and may be differently defined by professionals, publics, and decision-makers with different interests in mind. In addition, deciding that.a population should remain viable for a particular planning horizon may not be the best way to frame the question because of lag times of effects. Management activities affecting animals and their environment may not be felt until well after the end of the planning period.

Who determines which species warrant viability concerns, and what appropriate probabilities of persistence, planning areas, and durations of time should be accepted? Ideally, the answer lies in the triad of publics, biologists, and decision-makers. Publics and biologists help identify species for which viability may be a social or biological concern; Federal regulations also play a role in this step. Publics express their concerns over the social, economic, and ethical interest in maintaining species' viability. Biologists assess the risks of extinction under given or proposed planning strategies, and may offer strategies to help increase probabilities of persistence. Decision-makers weigh the consequences of decisions in light of biological and other outcomes. In this process, risk analysis takes on an important role to help inform publics and decision-makers as to the degrees of risks and uncertainties that may be associated with existing or proposed management strategies regarding population viability.

ADAPTIVE MANAGEMENT -- REDIRECTING MANAGEMENT BASED ON EXPERIENCE

The adaptive management paradigm (Rolling 1984) calls for the results of management actions to be monitored and evaluated according to the original management objectives. Management actions are altered if it is discovered that results do not match expectations. In a risk assessment framework, adaptive management is (1) the validation of the results of the risk analysis and of its assumptions and uncertainties, and (2) the creation of new management objectives should the existing ones prove in some sense to be invalid. However, caution is in order when applying the adaptive management strategy on assessing the efficacy of population viability plans for two reasons. First, even constant monitoring of a population may fail to reveal lag effects of potential extinction; much of the risk to population viability consists of accumulated probabilities of extinction over time. Second, monitoring will never replace the loss of critical habitat or severe disruption of a species' environment; adaptive management and monitoring are not substitutes for bad decisions that imperil a population or that contradict legal mandates.

Rolling (1984) noted that management acts may fail to give desired results because of (1) our ignorance of natural processes, (2) changing objectives over time, (3) the occurrence of unexpected events, (4) our inability to actually conduct planned management activities, and (5) changes or adaptations of biological systems. Some of these factors (1,3,4) may be assessed with risk analysis techniques, especially by using "what if' analyses such as error analysis or sensitivity testing. However, risk analysis generally is of little help when the basic structure of the management or the biological system is inconstant (factors 2 and 5).

EXAMPLES OF RISK ANALYSIS IN RESOURCE MANAGEMENT

Most resource managers, from the field silviculturist to the fish and game commissioner, use some of the elements of risk analysis in their everyday work, although they may not recognize the elements as such. The field silviculturist applies a wealth of experience as well as mental models of stand growth and yield to tacitly assess probabilities of payoffs and to decide what the best strategy would be to plant, thin, harvest, and manage a forest stand for wood production. The fish and game commissioner adopts a particular risk attitude and mentally weighs the uncertainty of information on population size and trends, opportunity costs, and future options when setting hunting and fishing seasons.

However, few formal risk analyses have been conducted in resource management, especially with regard to assessing and planning for population viability. Decision theory has been applied to .developing plans for managing endangered species (Maguire 1986b), growing Christmas trees

(Bentley and Kaiser 1967), evaluating effectiveness of herbicides (USDA Forest Service 1980), managing shoreline environments (Nnaji and Fisher 1983), and assessing wildlife-silviculture relationships (Marcot, in prep.).

Maguire (1986a, 1986b) has nicely demonstrated risk analyses of endangered species. Her analysis of introducing grizzly bears (Maguire, this syllabus) is probably the most thorough risk assessment regarding population biology attempted to date. It includes assessments of probabilities of payoffs when introducing bears of various combinations of age, sex, and season of introduction; resulting probabilities of reproductive success (reproductive value) of the introduced bears; estimates of the probabilities of success and failure of each possible decision; and estimates of the preference curves (attitudes toward risk) of managers and administrators involved in the decisions.

In summary, a risk analysis of population viability may entail the following information and sequence of events (Salwasser et al. 1984; see chapter on *Viable Population Planning,* this syllabus). First, what must be outlined in a table or decision tree are the possible set of decisions, their sequence, and the possible set of responses by the species and the outcomes of environmental conditions. The set of alternative decisions may be devised through a cooperative venture among interested publics and administrative personnel. Responses by the species may be estimated by using species-environment models, such as habitat suitability index models.

Second, probabilities of species' responses or environmental conditions (chance events) must be estimated. Such estimates may be made by using summaries of empirical observations, theoretical models, theoretical probability distributions, or some combination. The assumptions and uncertainties associated with the models and data summaries should be articulated.

Third, results of each possible decision and natural response (chance event) should be represented as a payoff. Payoffs may be represented in various ways, such as a population size or trend. Impacts on other resources may be represented in this summary, such as net income, total acres of habitat, or monetary value of agricultural or timber lands.

Fourth, the expected value of payoffs for each possible decision is calculated. This includes expected values of probabilities of persistence of populations as well as values of other resources. Opportunity costs and future options maybe estimated at this stage, as may the value of additional information that could be gathered on the species.

Fifth, the decision-maker weighs the various expected payoffs with the degrees of uncertainty of the data and models and other social, political, and administrative directives and exigencies and adopts a risk attitude for the decision at hand. This risk attitude guides what will be chosen as the best decision or sequence of decisions that will affect population viability. The decisions, risk attitude, and information used to formulate the decisions should be clearly articulated and disclosed.

Sixth, if acceptable in the social, political, biological, and administrative contexts, the management decision is implemented through a management plan. The population and/or its habitat is monitored over time to validate the assumptions and objectives of the plan. The results of monitoring are summarized and the efficacy of the plan is periodically evaluated. The plan is redrawn if the evaluation shows that results are significantly different than expected, if administrative objectives have changed, if unexpected events occur that alter expected payoffs, or if implementation proves to be infeasible or impossible. A revised risk analysis may than be called for.

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