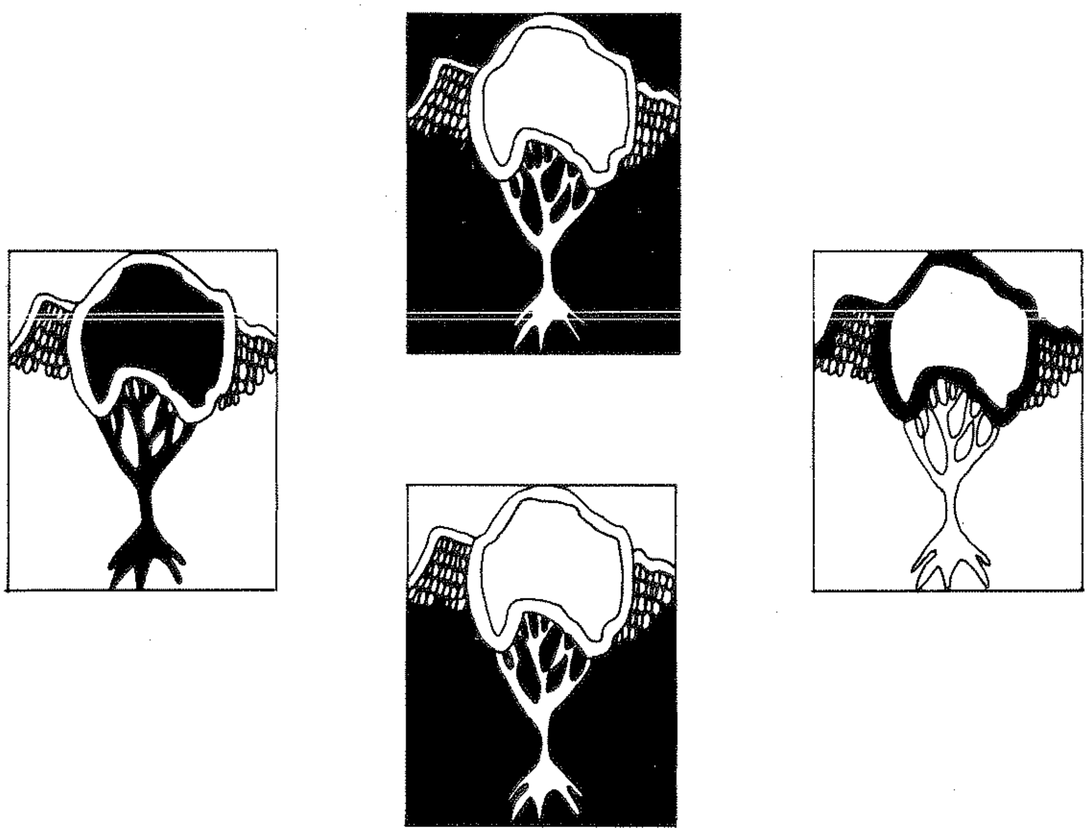
Uncertainty in Forestry Investment Decisions

Regarding Timber Growing



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P R E F A C E

The following papers were presented as a panel discussion of "Uncertainty in Forestry Investment Decisions Regarding Timber Growing". The panel was a special meeting of Working Group V, 5 (Investment Problems in Forestry), Section 31 (Forest Economics), at the 15th Congress of the International Union of Forestry Research Organizations held in Gainesville, Florida, March 19, 1971.

The purpose of the meeting was to assess the importance of considering uncertainty in economic analyses regarding timber growing, to judge the adequacy of available methods for handling uncertainty, and to suggest research needs. The papers and the resulting discussion emphasized the presence of uncertainty in forestry investment decisions and the importance of considering uncertainty in economic analyses, and suggested that although there is much we do not know about handling uncertainty we are not now doing as much as we could.

The authors hope that the publication of these papers will further stimulate interest in developing and applying concepts for handling uncertainty in forestry investment analysis.

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TABLE OF CONTENTS

UNCERTAINTY--SOME INTRODUCTORY REMARKS

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We are here to discuss uncertainty in forestry investment decisions regarding timber growing. Uncertainty is a fitting topic for us to consider this year because 1971 is the 50th anniversary of the publication of a book that has become one of the classics of economic literature. I refer to Frank H. Knight's "Risk, Uncertainty and Profit," published in 1921.

This book is remarkable for its insight into the role of uncertainty in the decision-making process. It is fitting on the 50th anniversary of the publication of this book that we allow Professor Knight's words to introduce our topic:

> "It is a world of change in which we live, and a world of uncertainty. We live only by knowing <u>something</u> about the future; while the problems of life, or of conduct at least, arise from the fact that we know so little . . . The essence of the situation is action according to <u>opinion</u>, of greater or less foundation and value, neither entire ignorance nor complete and perfect information, but partial knowledge. If we are to understand the workings of the economic system we must examine the meaning and significance of uncertainty; . . ." (p. 199).

> "At the bottom of the uncertainty problem in economics is the forward-looking character of the economic process itself. Goods are produced to satisfy wants; the production of goods requires time, and two elements of uncertainty are introduced, corresponding to different kinds of foresight which must be exercised. First, the end of the productive operations must be estimated from the beginning. It is notoriously impossible to tell accurately when entering upon productive activity what will be its results in physical terms, what (a) quantities and (b) qualities of goods will result from the expenditure of given resources. Second, the wants which the goods are to satisfy are also, of course, in the future to the same extent, and their prediction involves uncertainty in the same way. The producer, then, must <u>estimate</u> (1) the demand which he is striving to satisfy and (2) the future results of his operations in attempting to satisfy that demand" (p. 237).

"The problem of meeting uncertainty thus passes inevitably into the general problem of management, of economic control. The fundamental uncertainties of economic life are the errors in predicting the future and in making present adjustments to fit future conditions" (p. 259).

"We are thus brought naturally around to a discussion of the most thoroughgoing methods of dealing with uncertainty; i.e., by securing better knowledge of and control over the future" (p. 260).

These words by Professor Knight point to the importance of uncertainty in the decision-making process. They suggest the need to consider uncertainty in economic analyses, especially concerning decisions about investments in production processes. What impact has this view had over the past 50 years?

In recent years advances have been made in introducing the concept of uncertainty in economic theory and analysis. An extensive literature on decision making under uncertainty has developed (for example: Shackle, 1955; Grayson, 1960; Carter, Meredith, and Shackle, 1962; Schlaifer, 1969; Halter and Dean, 1971). Nevertheless, since the publication of Professor Knight's widely quoted book most economists have continued to neglect uncertainty. For the most part uncertainty plays no fundamental role in either static or dynamic economic theory. The concept of uncertainty is relegated in most economics textbooks to an occasional mention or to a chapter toward the end of the book, if it is mentioned at all (there are exceptions; for example, Hirshleifer, 1970). Yet, as Karl Borch (1968) has suggested ". . . the methods of classical economic theory . . ., which served well in so many situations, may break down when we bring uncertainty into the model."

Economic theory still is built primarily around deterministic models based upon assumptions of complete knowledge and certainty. In contrast, real-life decision makers usually work with incomplete knowledge and a large element of uncertainty. Professor Knight's remarks imply the need for a revision of economic theory to make it correspond more closely to reality.

One would expect economists in forestry, especially those concerned with investments in timber production, to be more aware of uncertainty than economists in many other fields. After all, we work with long production periods, from 10 to 100 or more years, which introduces many elements of uncertainty into our analyses.

Every forest economist could readily list many factors included in economic analyses that are subject to uncertainty: goals and objectives of producers, desires and wants of consumers, basic economic data, physical inputs, costs, physical production response, market structure and prices, technological change, and so on. Yet we seldom encounter an explicit treatment of uncertainty in published economic analyses of timber production. Typically, we all recognize the existence of uncertainty but ignore it in our analyses. Why?

Perhaps some forest economists remain unconvinced as to the importance of uncertainty in economic analyses. Perhaps some are skeptical as to our present ability to adequately handle uncertainty in our analyses. Many may be uncertain about how best to handle uncertainty. Whatever the reason, a discussion of uncertainty and its place in forestry investment decisions is appropriate at this time.

Today we have an opportunity to explore ways to explicitly consider uncertainty in our economic appraisals of timber production activities. We are fortunate to have with us a panel of forest economists who are highly qualified to introduce our discussion. Their publications have contributed to our understanding of uncertainty and its importance in forestry decision making (Keltikangas, 1969; Schweitzer, 1968; Thompson, 1968). They will discuss: (1) the problem of uncertainty in forestry investment decisions; (2) alternative approaches for handling uncertainty; (3) uncertainty and future value scales; and (4) a case study in timber production under uncertainty, forest fertilization in the Pacific Northwest.

I hope that these presentations will help us assess the importance of considering uncertainty in economic analyses regarding timber growing, judge the adequacy of available methods of handling uncertainty, and suggest research needs in this field.

In listening to our panel today you may wish to keep in mind Professor G. L. S. Shackle's existential view of man as a decision maker in the here-and-now:

> "For us, conscious humans, there is nothing but the present . . . The past exists in memory, but memory is a mental act of the present . . . there is no attainable future, outside our own minds, with which we can have any contact whatever. All that is, is in the present, which exists <u>alone</u>" (Shackle, 1969).
>
> ". . . I contend that men cannot compare future events themselves but only their own present, subjective, imaginations of these events, and that it is the feelings that these imaginations give them that will decide their choice; . . ." (Shackle, 1955).
>
> "Everything we know about the future is an inference, the end of a reasoning process, whether the reasoning is sound or not . . . decision is wholly concerned with the future . . . Decision, then, is choice, but it is choice amongst <u>thoughts</u> . . . it is choice amongst the products of imagination." (Shackle, 1966).

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THE PROBLEM OF UNCERTAINTY IN
FORESTRY INVESTMENT DECISIONS

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My inability to attend this meeting and present this paper personally is an example of one of the uncertainties in forestry. I am especially disappointed in being unable to participate in the discussion. That is always the best part of such professional meetings. I also regret missing the discussion because my examination of the other papers indicates differences among the panelists that will lead to a lively discussion among them.

My assignment on this panel is problem identification. Problem identification is very important. A problem clearly identified is a problem at least half solved. I wish I could assure you that I could identify the problem of uncertainty in forestry decision making clearly enough that the remaining three panelists would only have half of the job remaining for them.

I was selected for this assignment because your panel chairman considered that a forestry consultant should certainly have been exposed to a wide variety of forestry investment decisions involving uncertainty. I must agree that this is so. In my short four years of experience on consulting I have assisted some of the most uncertain decision makers that you can imagine. Surprisingly enough, to me, helping the decision maker who recognizes the uncertainties is much easier than helping those to whom everything appears certain. It is frightening to make projections of future prices, for example, for some decision maker who expects your projection to be "right on".

My remarks will be based on observations on the real world of forestry decision making. My comments will also be influenced by my experience in the somewhat less-than-real world of forestry economics research. Before you reach the wrong conclusion, however, let me assure you that my training and experience in economic theory and investment theory have been extremely valuable to me in advising the real world decision makers. I am not against theory nor against sophisticated models for analysis.

Uncertainty is the spice of our lives. If we removed uncertainty; it truly would become a dull world of economic and silvicultural projections. Management to achieve desired forestry objectives would become an equally dull routine. We should approach the uncertainties in our work with relish rather than with a dismal attitude about how uncertainty has spoiled our beautiful theories and models.

Uncertainty seems to exist in two forms: that which is in the minds of analysts and decision makers, and that expected in the real world of future events. In both forms it creates problems for the analyst of forestry investments and for those who must make the investment decisions. I have found a particularly difficult type of uncertainty in the minds of forest managers. Here I refer to the uncertainty about the objectives being sought after. This kind of uncertainty is all too common among forest managers. It is revealed when they, or the owners who they serve oscillate from seeking profit maximization, to seeking control of wood supply, to seeking security from risk, to seeking pride of land ownership, and to other objectives. I am going to eliminate that kind of uncertainty from my discussion. I wish I could eliminate it from forest managers' minds in the real world.

The second kind of uncertainty is that in the world of future events. This kind is, of course, also in our minds. This was illustrated by Dr. Lundgren when he pointed out that only the past and current events are certain; it is the future which is uncertain. It is this second kind of uncertainty that has attracted the attention of theorists who wish to modify their theoretical models to account for uncertainty. Things about which forest managers are uncertain are: future prices, costs, and physical production response to management.

Much good thought and work have been devoted to the development of economic models to accommodate human behavior under uncertainty. Very little, if any of it has found its way into forest managers' tool kits. Forestry investment analysis procedures, without the uncertainty refinements, have become an important basis for forest management decisions, even on public forests. This has not been accomplished without considerable effort on the part of economists and financially oriented foresters. Invariably those real world decision makers who have accepted economic analysis have done so by utilizing it as an aid rather than the only way to reach a decision. They rightfully contend that a proper mixture of theory and judgment is needed. Much of what they refer to as judgment could best be described as procedure whereby they decide how much uncertainty they can accept with a chosen alternative. Forest managers do take uncertainty into account. No one has yet been able to make an empirical model of how they do it or a theoretical one of how they should do it.

I have found that the best practice in consulting is to inject as much economic analysis into the decision making framework as the decision maker can understand and/or will allow. There is little danger of injecting too much. Within this practice I have found it very helpful to demonstrate to the decision maker a range of expected results associated with a reasonable range of uncertainties about the future. I have, on some occasions, been able to present an array of the present net worth results related to various degrees of certainty of obtaining the conditions on which the analysis is based.

The most knowledgeable decision makers will tell you that although uncertainty cannot be ignored, neither can it be adequately handled by any sophisticated model for analyzing alternatives. My experience has lead me to accept this situation. What, then, can be done. I propose that uncertainty can and should be dealt with in other than the decision making activities. I propose that the actions taken to implement a decision can deal effectively with part of the uncertainty problem in forestry investments.

No matter how permanent a particular decision may appear to be, it is invariably not the last one on that subject. Invariably there are many more opportunities to reconsider and revise and make new decisions regarding the same or a similar set of investment alternatives on the same forest property. In almost all writings and teachings about forestry investment analysis the long-term nature of forestry is emphasized. It is emphasized as a disadvantage to the investment analysts and a burden to the forest owner. I would contend that this is not so. I consider the long-term nature of forestry to be an advantage because it provides a great length of time during which the manager can change his decision and revise his action program accordingly. Or he can use the time to take whatever action is necessary to make the past decision be correct.

Those decision makers and analysts who plead for special consideration due to the long-term nature of forestry have apparently done so from fear, fear that they would be allowed only one chance to make, or assist in making, a decision. My experience indicates that even the most important decisions regarding the most long-term aspects of forestry are repeatedly reviewed, reanalyzed and remade. Never are these permanent and binding for even ten years, let alone a rotation or forever.

If you accept my proposition about the advantage of having plenty of time to change courses of action, then you may wish to hear how I would propose to capture this advantage. After a decision is made that appears to be so permanent and long-term, one should stop and make a list of the most important factors that influenced the decision. Then contemplate which factors are outside of the manager's control and which ones are within his control. All decisions require an action program to achieve the results desired. The action program should be a well-planned and positive one. Such a positive approach should: 1) assure that the manageable factors are well-managed, and 2) provide for continuous examination of current trends in the uncontrollable factors in order to detect those leading toward undesirable results.

Let's examine a specific case. Suppose a manager has decided to precommercially thin based on the best information about growth response and about projected prices and costs. Suppose also that a present net worth or internal rate of return analysis was used to determine which of the various sites and stand conditions to thin. Suppose that a profit maximizing alternative was selected from those examined. Suppose also that credit was taken now for increased growth by planning for an increase in the current cut of mature timber elsewhere on the same forest property. Any such decision must be made in the midst of large uncertainties.

Let's classify the decision factors in this case uncontrollable or controllable. The controllable ones are: 1) the thinning activity itself, 2) the current harvest of extra yield; 3) the places to thin, 4) the thinning intensity, spacing, etc., 5) the silvicultural skill used in thinning, and 6) labor's efficiency during thinning. The uncontrollable factors are probably: 1) the price of final harvest products, 2) wage rates and machine rates, and 3) the weather.

If I were the forest manager assigned to carry out this decision, I would annually reexamine the decision and revise it if necessary to reflect any changes in my expectations regarding all of the factors. For example, I would check in the field to see if growth response was being achieved. If it was not, I would stop the thinning program and stop the current cutting of the extra final harvest.

I would check the costs to see if the experienced costs were the same as those projected. If not, I would try to find the reason and to take appropriate action in one or more of the manageable activities. I would check price trends and cost of labor trends to determine whether the decision to thin still appeared valid.

I would refuse to listen to any silly foresters who cry "overcutting" in regard to the extra current harvesting being done on the basis of the extra growth in immature stands. The reason I wouldn't listen is because the forest and each stand in it is a flexible and long-term production process and I can stop the extra harvesting at any time with very little effect on the long-term future production. Many more opportunities will occur to the forest manager during the life of each stand for influencing the production and the profit therefrom.

The uncertainties in timber growing pose problems to the manager. These problems must be dealt with in the decision making process and during the activities necessary to carry out those decisions. Because uncertainties are all in the future, and because some of them will respond to future management, decision making should be considered as a repetitive process and should be carefully coordinated with the management action programs which the decisions call for. My advice to those of you who wish to continue your research on the problems of uncertainty is to suggest that you expand your study to devise methods to reduce uncertainty during the entire productive process which only begins with the decision making. This will bring you a step closer to the real world of the decision maker and will make your new approaches of real value to the decision makers.

SOME APPROACHES FOR CONSIDERING UNCERTAINTY IN FORESTRY INVESTMENT DECISIONS

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The introductory remarks and the preceding paper presented the problem of uncertainty in making forestry investment decisions. Subsequent papers will discuss some difficulties encountered in empirical attempts to handle uncertainty. The purpose of this paper is to help bridge the gap between problem recognition and empirical consideration of uncertainty. This purpose will be accomplished by reviewing some of the formal approaches to decision making under uncertainty found in decision theory literature.

Decision theory, in a broad sense, is the body of knowledge concerned with decision making under uncertainty. General treatment of the theory is available in a number of texts (e.g., Luce and Raiffa, 1957; Chernoff and Moses, 1959). Applications of the theory to several disciplines, including business (Schlaifer 1959), oil exporation (Grayson, 1960), forest engineering (Dane, 1965), forest management (Marty, 1946; Thompson, 1968), and agriculture (Halter and Dean, 1971), are also available.

In this paper, a particular kind of decision problem will be considered. Specifically, those kinds of problems for which the decision maker, after defining his alternative actions and the possible consequences of each, cannot identify a unique, optimal action. While no unique, optimal action can be identified, many decision makers do have considerable experience in the particular decision environment surrounding their problem. To a large extent, much of the literature concerned with decision making under uncertainty forms or suggests a methodology for formulating problems and thinking about decision making to insure that the decision maker's decisions are consistent with his experience, knowledge, and judgment.

A major impetus for the development of a theory of decision making under uncertainty is that uncertainty can never be removed from decision making. Accepting this, it is suggested that procedures leading to actions which are consistent with the decision maker's experience, knowledge, and judgment should be employed.

An example will help clarify the kind of decision this paper is concerned with. Suppose the set of Actions (A_1, A_2, A_3) represent all possible alternatives available to the decision maker. The possible outcomes associated with these Actions correspond to the possible future environments or States of Nature (S_1, S_2, S_3). The occurrence of the States of Nature is beyond the decision maker's control, but the preference among Acts is dependent upon which State actually occurs. The decision among Acts must be made before the true State is known.

The following decision matrix illustrates the concept of alternative Actions and States of Nature as well as the Consequences -- expressed in terms of numerical loss -- associated with each Act-State pair.

States of Nature	Actions		
	A_1	A_2	A_3
S_1	12	7	0
S_2	8	5	10
S_3	2	5	15

For example, if the decision maker chose Action A_3 and S_2 turned out to be the true State of Nature, the loss would be 10. The above decision problem exists simply because none of the Actions has the least loss for each State of Nature. That is, the decision maker cannot choose one Act with any assurance that is preferable to either of the others.

If the above problem contained only one State of Nature, or if the decision maker were willing to exclude all but one State, the problem would be one of decision making under certainty. In which case, the choice among actions would be obvious. Also, if the decision maker were able to associate an objectively determined probability of occurrence with each State of Nature, the problem would be one of decision making under risk. In this case, the generally accepted decision rule is to choose the Action with the most favorable expected value1/ against the probability distribution.

However, this paper is concerned with decision making under uncertainty where the decision maker must choose from the available Actions knowing only that one of the possible States of Nature will occur.

As indicated, methodology is available to aid the decision maker, faced with uncertainty, to make decisions which are at least consistent with his experience, knowledge, and judgment.

1/Expected value is defined as the weighted average of all possible consequences for an Action; the weights are the probabilities of the various consequences occurring.

Procedures for Decision Making Under Uncertainty

Decision theory assumes that the decision maker can specify the Acts, States of Nature, and Consequences, but in many cases, this is a most formidable assumption. The theory is concerned with how to proceed, given a decision making problem under uncertainty. In this respect, the theory first recognizes two broad categories of decision making under uncertainty. The categories are distinguished by the amount of knowledge the decision maker possesses about the relative occurrence of the States of Nature, specifically, whether the decision maker is completely or partially ignorant about the States' occurrence.

Complete Ignorance

Under complete ignorance, the decision maker supposedly has no knowledge whatsoever about the occurrence of the States of Nature. Nevertheless, for these situations some decision making procedures or criteria are available. It may be helpful in reviewing these criteria to refer back to the previous example problem. In the literature, the criteria have been given names which attempt to describe their approach to decision making under uncertainty.

Minimax: Perhaps the most basic criterion for decision making under uncertainty is termed minimax. This is also the criterion an avowed pessimist might choose. To each Action, the decision maker associates that Act's worst possible consequence. The decision maker then chooses the Action whose worst is best. In other words, assume the worst will happen and make the best of it; i.e., minimize the maximum possible loss. For our example problem, the minimax criterion chooses Action A_2.

Minimin: The minimin criterion represents the opposite extreme from minimax. This criterion would be adopted by an extremely optimistic decision maker. He would assume that the best will happen and then choose the Action with the most favorable best-consequence. In our example, the minimin criterion would lead to the choice of Action A_3.

Hurwicz Index: The Hurwicz index criterion represents a compromise between the pessimism and optimism of the preceding approaches. To apply the criterion, the decision maker associates an index, α which, in effect, is an index of pessimism, such that $0 \leq \alpha \leq 1$, to the worst consequence (W) of each Action, and the value $(1-\alpha)$ to the best consequence (B) of each Action. The criterion chooses the Action for which the quantity $\alpha W + (1-\alpha)B$ is most favorable. In addition to the problem of specifying an index (other than 1 or 0, which correspond to minimax and minimin, respectively), the very notion of attaching an index seems to violate the basic assumption of complete ignorance about which consequence will occur.

Minimax Regret: As an alternative to minimax, Savage (1951:55-67) proposed the minimax regret criterion for decision making under uncertainty. The reasoning behind this criterion is that it is the differences in results, not absolute amounts, which are important. This criterion generally appeals to economists because of its similarity to opportunity cost.

To apply the criterion, the minimum Consequence for each State of Nature is subtracted from every Consequence for that State. The new results are called regrets -- hence the criterion name. Our example problem would now be formulated as follows:

States of Nature	Actions		
	A_1	A_2	A_3
	--------Regrets----------		
S_1	12	7	0
S_2	3	0	5
S_3	0	3	13

Minimax regret leads to a choice of Action A_2, the same as minimax, but this is not a universal condition.

Laplace or Principle of Insufficient Reason: This criterion for decision making under uncertainty assumes, since the decision maker is ignorant about the occurrence of the States of Nature, he should act as though they are equally likely to occur. That is, choose the Action with the most favorable average result. For our example, the average results are: $A_1 = 22/3$, $A_2 = 17/3$, $A_3 = 25/3$. The decision maker should choose A_2. Obviously, the decision maker has no more knowledge that the States will occur with equal frequency than that they will occur with unequal frequency. It is interesting to note that when a person makes a decision or recommendation based upon average results, from, for example, a research experiment, he is implicitly following a Laplace approach to decision making under uncertainty.

Most texts on decision making under uncertainty contain more detailed explanations of the above criteria and then conclude that none of the criteria are completely acceptable. However, when the decision maker has no knowledge about the occurrence of the States of Nature there is really no alternative to the above approaches.

Partial Ignorance

It seems intuitively reasonable that a decision maker, who has considerable experience and recognized expertise in the area in which he is making decisions, will have at least some knowledge about the States' occurrence. Many forestry decisions, which are dependent upon some future State, are made under conditions of uncertainty. However, most people might agree that foresters with experience in the area under consideration are better able to make these decisions than are non-foresters. This implies that the forester is able to bring reasoned judgment and experience to bear on the decision. He is still making decisions under uncertainty, but with partial rather than complete ignorance about the States' occurrence.

Within partial ignorance, decision theory recognizes two classes of problems. First, is the so-called no-data problem, in which information other than the decision maker's judgment and experience is not available. The second is the class where it is possible to obtain empirical evidence to support or modify the decision maker's judgment and experience.

No-Data Problems. As indicated, decision making problems under uncertainty where experimentation to obtain knowledge about the decision or its environment is not possible or not feasible, are termed no-data problems. When the decision maker cannot obtain objective data on the occurrence of the States of Nature, he may resort to subjective probabilities which reflect his judgment and opinions. Perhaps the chief proponent of this approach is Savage (1954) who has proposed a "theory of personalistic probability". According to Winkler (1967:1105):

> "In the personalistic theory of probability, probability measures the confident that a particular individual has in the truth of a particular proposition ... The personalistic view differs from other approaches by not attempting to specify what assessments are "correct". All self consistent, or coherent, assessments are admissible as long as the individual feels that they correspond with his judgments."

Winkler (1968) has also recently summarized the "state of the art" for applying subjective or personalistic probability. For the no-data problem, if the decision maker can associate a subjective probability distribution to the occurrence of the States of Nature, he then proceeds as if he were making the decision under risk. That is, he chooses the Action with the most favorable expected value.

Experimentation Possible:

Even though a decision is made under uncertainty, it may be possible to perform experimentation, i.e., collect data, which is relevant to the decision-making process. Such a process combines an *a priori* probability distribution (the subjective distribution from the no-data problem) with empirical data to develop an a posteriori probability distribution.[2/]

The empirical data only serves to condition or modify the subjective probability distribution. If the data were direct observations on the occurrence of the States of Nature, then the problem would be changed from a decision making problem under uncertainty with partial ignorance to decision making under risk.

When experimentation is possible, the decision making criterion is: observe the experimental evidence, then choose the Action with the most favorable expected result against the posterior distribution.

Examples, complete with calculations, of decision making under uncertainty with partial ignorance, of possible forestry applications in both no-data and experimental situations are available, (Dane, 1965), (Thompson, 1968), and (Halter and Dean, 1971).

Discussion

Uncertainty is an inherent factor in the forestry decision making environment. This paper has reviewed some of the formal approaches to decision making under uncertainty assuming both complete ignorance and partial ignorance about the States' occurrence.

While the complete ignorance assumption may in some cases be appropriate[3/], major forestry investment decisions under uncertainty are generally made by persons with considerable experience and/or demonstrated expertise in making similar or related decisions. That is, the assumption of partial ignorance seems quite appropriate for many forestry investment decisions under uncertainty.

[2/] The posterior distribution is, in essence, a conditional probability distribution which can be calculated by Bayes' Theorem:

where:

$$P(Si \mid Zk) = \frac{P(Si)\ P(Zk \mid Si)}{P(Zk)}$$

where:

$P(Si \mid Zk)$ is the conditional (posterior) probability that Si will be the State of Nature, given the experimental result Zk.

$P(Zk \mid Si)$ is the probability Zk has been the experimental result when Si was the true State of Nature.

$P(Si)$ is the personal (prior) probability of Si being the true State of Nature.

$P(Zk)$ is the probability of Zk being the experimental result.

[3/] For example, if no other criterion can be shown to be clearly superior to minimax, it is very hard to argue against minimax for that particular problem.

Actually, the formal procedure for decision making under uncertainty with partial ignorance about the States' occurrence, seems remarkably compatible with many major forestry investment decisions. Assuming the decision maker can properly define his problem that is, specify the States, Actions, and Consequences, he then uses his experience and judgment to establish subjective (personal) estimates regarding the relative occurrence of the States of Nature.

The decision maker should then gather any available, additional evidence which bears upon the States' occurrence. The subjective estimates and empirical evidence are then combined to form posterior probability distributions for the States of Nature. When additional evidence is not available, the decision maker proceeds with only the subjective (personal) distribution.

While it appears to be an intuitively logical approach to decision making under uncertainty, the forestry investment literature contains no empirical applications of using posterior probability distributions. On the other hand, there are numerous examples of decisions being made based upon subjective (personal) probability distributions. Most studies which have used "expert opinion" as a basis for decision making are applying subjective (personal) probability distributions. Forestry examples of this approach include: Bentley and Kaiser (1967), Davis (1965), Teeguarden (1969), Thompson et al. (1968), Thompson and Haynes (1971), and Shores (1970).

A possible criticism of some of the above references is that expert opinion has been obtained without recognizing that a personal probability distribution was implied. For example, point estimates, perhaps the mean, have been substituted for the distribution. Thus, much information potentially available, and valuable, to the decision maker is not utilized. For example, consider the problem of predicting future yields from a pre-commercial thinning operation. A range of possible occurrences would in many cases be more valuable than a single estimate in terms of the low and high extremes, as well as a most likely value, Schweitzer (1968) has developed a computer program which will associate a probability distirubution to the range.

It seems inconceivable that uncertainty can ever be removed from forestry investment decisions. Therefore, since there is a body of knowledge which deals with systematic consideration, if not elimination, of uncertainty, this knowledge should be applied to help remove forestry investment decisions. However, as indicated previously and as we shall see in a subsequent paper recognition that a potentially helpful theory is available and taking advantage of the theory in practice are two distinct steps toward better forestry decision making. Defining the problem within a decision theory framework, that is, specifying the States, Acts, and Consequences, may be one of the most difficult aspects of applying the theory to forestry investment decisions.

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UNCERTAINTY AND FUTURE VALUE SCALES

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The investment decision this panel is concerned with can be loosely defined as a choice between two or more possible actions, at least one of which is aimed to affect timber growth. Each action will have its consequences, material or immaterial, and the choice is made by comparing these consequences with the goals of the decision maker and by selecting the alternative which seems best to meet the set goals.

Uncertainty, which is the main topic in this panel, is associated with that decision in two ways. The alternative actions and therefore also their consequences are not realized but imagined ones (Shackle, 1961). An action is expected to have some consequences, and the expectations are more or less uncertain, i.e. we know that each action may have more than one series of consequences depending on the future state of nature which will occur but we do not know which state it will be. The preceding paper by Dr. Thompson has discussed the problems caused by this first type of uncertainty.

In this paper I try to present some ideas of the second type of uncertainty, i.e., uncertainty of the goals in relation to which the consequences are to be evaluated and of the value scales which link the consequences to the goals.

Every decision maker is supposed to have one or more goals which he seeks to reach through his activities. These goals may be a set level of consumption, certain degrees of security, of social prestige, of aesthetic pleasure, etc. There is no need to assume commensurability of the goals (see e.g. Johnsen, 1968). Yet it is reasonable to maintain that for each goal there must be some sort of a yardstick by which the degree of goal fulfillment or the relative value of different consequences can be measured or estimated. This yardstick I call a value scale.

Let me illustrate this by an example. Assume that there are two alternative forest improvement plans and we know - with certainty or not, it is irrelevant in this case - what amounts of timber there will be to cut during each future period if one plan is undertaken or the other. How should we compare these series of cuttings?

Uncertainty of goals means in this case that we do not exactly know which cuttings are substitutes and which are not. If the decision maker's goal is to increase cuttings for the first ten years, a plan which promises increases just after thirty years will not be accepted no matter how big the later increase. In that case the cuttings of the first decade and those of the fourth are not substitues for each other. If we do not know this, we may recommend wrong solutions to the decision maker.

The usual way out of the problem is to presuppose that we have first cleared up the exact goals of the decision maker. Very often this is, however, easier to say than to do. Individuals do not always have clearly in mind what they really want, and - more important - their goals are changing through time (see e.g. Dorfman, 1966). And this is even more true when we are giving advice not to individuals but to groups of people or to the society at large. I will, however, pass over this side of the problem and restrict myself to the other.

Uncertainty of value scales means, in our example, that we do not exactly know the rates of substitutability of those cuttings which are contributing to the same goal and, therefore, are substitutes for each other. If the decision maker's goal is to increase timber cuttings during the first ten years and there are two alternative plans promising increased cuttings in the fifth and in the eight year respectively, how are these plans to be evaluated? How much timber must there be in the latter cutting just to compensate a certain amount in the earlier one? To assume that this substitution (or value) rate is always known with certainty and to use one exact number for it would be a simplification of reality.

The value of the timber depends on what use the decision maker thinks he will have for it and what ultimate consequences that use will lead to. These ideas, on the other hand, are affected by the expectations he has on the state of nature that will prevail.

To simplify our example a bit, let us assume that our decision maker is planning no other use for the timber than to sell it. Then we are able to speak of money incomes as the consequences to be evaluated. In the transformation of cubic meters into dollars we utilize timber price estimates which may be relatively uncertain, but this uncertainty is not that of the decision maker's inner value scales.

Money is seldom the ultimate goal of action but a means to satisfy some more basic needs. Thus, the value that the decision maker puts on the relative weight of those needs can be said to depend on the very subjective ideads (mental images) the decision maker has as to the state of world (i.e. his environment) and his position in it, to his needs, and to his other resources available to satisfy those needs.

The more unclear the images are, the more uncertain the decision maker probably is on his value scales. Instead of having exact ideas of the substitution ratios between different incomes he may have more or less broad "indifference zones" (see e.g. Flora, 1966; Keltikangas, 1969).

The findings in psychological studies (see Edwards, 1954) indicate that a person's ability to express his preferences and their consistency markedly diminish as soon as he is asked to compare items which are very different in kind (as automobiles and insurance policies) or far from his everyday experiences (Cochrane and Bell, 1956; Weintraub, 1964).

We can expect similar tendencies if we try to determine a person's preference ratios between differently dated money incomes, or, what is the same, the discount rates by which he discounts future incomes. Instead of exact rates there probably are discount rate zones whose breadth increases with the length of the discounting period. As far as I know, there has been very little empirical study of this problem (see Flora, 1966).

In addition to the "broadness" of discount rates, this uncertainty has another clear effect. A person's ideas of the future states of world are projections of his past experiences, and his ability to imagine future changes in the world is therefore restricted by those experiences. The farther into the future he tries to look, the more unbounded his imagination will be. The diminishing boundedness means increasing uncertainty about the "right" image and in some point there must come a limit beyond which the person is unwilling or unable to form any definite expectations at all. Anything seems equally possible (Shackle, 1961). This point forms the decision makers time horizon. It is also the outer limit for his value scale.

There are, of course, differences depending on the situation and on the point of view we have in mind. As goverment official or district forester in a forest industry, we face the problem in quite another way than as a consultant for individual forest owners. Both the government and the company have much stronger inertia in their activities and in their existence than the individual. Thus, they probably have longer horizons and also less wide discount rate zones.

In every case, however, we must try to take this uncertainty into consideration. What possible methods, then, are there available? I am afraid this is a question to which I have no ready well-founded answer. Therefore I will leave it to the other members of this panel for deliberation. I only want to suggest a couple of viewpoints I think are essential.

It is most important that we, as advisers of the decision makers, realize the existence of this uncertainty and make it clear for ourselves what its effect may be. And keep this in mind even if we do not have any satisfactory method to take it into consideration explicitly.

The other point is that we must differentiate between a decision and its final realized result. What we at best can measure are present value scales for future incomes, i.e. how the decision makers at present feel about future incomes. These are not the same as their feelings at the future date when the chosen plan matures.

For example, societies are increasingly concerned with the quality of environment and governments no longer consider timber production as the sole goal of forestry. It is, however, rather probable that there will still be great changes in the public opinions about the recreational values of differently treated forests. Thus, if we now recommend cutting programs on the basis of the present social value scales, it might be very satisfying and unanimously acceptable solution now and yet be strongly criticized and an obvious failure when the future is at hand. And as many experiences tell us, we will then be accused of the "wrong" advice.

Can we avoid this situation? Are there any means by which we could "sell" the decision maker a value scale which we think he might accept in some future date but about which even we are uncertain?

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FOREST FERTILIZATION IN THE PACIFIC NORTHWEST:

A CASE STUDY

IN TIMBER PRODUCTION UNDER UNCERTAINTY

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Uncertainty is a problem in producing timber. Because future yields costs, prices, or technology are not precisely known, scarce investment dollars are frequently allocated in a manner that, with the advantage of hindsight, is later found to be less than optimal. The difference between what was done on the basis of incomplete or incorrect information and what might have been done had the future been less uncertain is a real cost.

It is my purpose in this paper to illustrate some of the uncertainties that face forest land managers in the Pacific Northwest of the United States. As a focal point, I have chosen to examine the uncertainties encountered in increasing timber production through forest fertilization. To rationalize such investments, I emphasize facets of the decision making environment that foster investments when detailed information on even the physical yields that will result is incomplete. Finally, I discuss some operational techniques that have been developed through trial and error to insure the best possible responses to fertilization at the lowest possible costs.

Forest Fertilization: An Annual $2 Million Investment in the Pacific Northwest

In the last 5 years, forest fertilization programs have been steadily increasing in the Pacific Northwest. Approximately 100,000 acres a year are now being treated (Anderson, 1969). A single private corporation has carried out about 90 percent of the fertilization in the past. Several other private firms and public agencies also have been fertilizing on a more limited scale.

The bulk of the fertilizing has consisted of applying nitrogen in the form of urea pellets to young Douglas-fir stands. Helicoptors are used to apply the urea, commonly at rates of 330 to 440 pounds (150 to 200 pounds of nitrogen) per acre. Total costs of fertilizer treatments probably average $20 per acre and $2 million a year for the Pacific Northwest.

The Data Base for Economic Evaluations Is Incomplete

In the Douglas-fir region, an often-heard recommendation is to fertilize a stand first when the crowns begin to touch and every 5 or 10 years thereafter. However, it is not obvious that enough long-term experimental evidence is available to justify such a prescription. The very oldest (statistically) reliable experimental plots in the Northwest have been followed for about 12 years, and a very few records of treatments to individual trees and plots go back another few years. While it is true that results can, to some unknown extent, be inferred from experiences with agricultural crops or from basic physiological studies, it is also true that there is very little empirical evidence in the region to demonstrate the cumulative effects of periodic applications of fertilizers to timber stands. A cursory examination suggests that extrapolating physical responses through a succession of applications over 25 or even 50 years might well contain substantial errors.

On the other hand, the bulk of the experimental evidence that has been accumulated seems promising. The literature suggests that extensive fertilization in Sweden, Australia, and New Zealand, and several years of more limited applications in the Pacific Northwest, have usually induced physical responses adequate to repay the costs of treatment (although published detailed economic analyses of either applied or research applications are notably scarce). Results have been especially heralded when fertilizing has been combined with thinning programs. It is worth noting again, however, that only a very few firms in the Pacific Northwest have been fertilizing on other than an experimental basis. Whether others do not follow because they have a greater aversion to risk or suffer shortages of investment capital or have other reasons has not been documented.

After recognizing that much is unknown about fertilization, one should recall that the same can be said about other more traditional forest management practices. For example, in the Pacific Northwest there have been repeated attempts to convert areas supporting brush fields to timber production by planting after spraying, burning, and/or mechanical site preparation. Occassionally this has been done three or four times over the years at considerable cost but without success. An adequate data base has not been available to support these activities, but incomplete information, in itself, has not prevented their adoption.

Institutional Factors Reduce the Importance of Response Uncertainties

Regardless of what is being done or has been done, we still have an unresolved question of investment economics: given a shortage of basic information, why is $2 million being spent each year for forest fertilization by, presumably, profit-maximizing firms?

It is unsatisfactory and probably wrong to simply attribute these investments to the optimistic nature of forest management decisionn makers. And it is practically impossible to list or even to know all of the assumptions and impressions and biases on which the decision makers have based their investments. However, we can examine what has happened and identify those factors that make the gamble--the willingness to fertilize in the absence of complete data--appear worthwhile.

Timber Production Is Often But One Element in a Firm's Operations

Viewed from the vantage point of corporate headquarters, one reason for investing in timber production is to protect the future of the firm. Generally, it is desirable to produce wood in the volumes and at the times that will insure the greatest possible company earnings. This implies coordinating timber management with land acquisitions and sales, plant expansions, and expected market demands. Long-term, company-wide strategic considerations include benefits and costs other than those relevant just to individual stand analyses.

Rather than on a rate-of-return basis, company forests have been traditionally rationalized (Fedkiw, 1960) as protection for a firm against

--future runaway market prices,

--future extended mill closures because of a general shortage of wood offered for sale, and

--future intermittent mill closures due to poor weather, labor shortages, or other temporary conditions.

Once a strategic decision has been made to own timber lands and to increase wood production, a strong emphasis will be felt at the operational level to adopt growth-stimulating practices that show promise; the uncertainties surrounding that promise might seem less significant.

Economic Analyses Often Should Be Applied To Management Units, Not to Individual Stands

In the Pacific Northwest the exercise of balancing today's fertilization costs against the discounted values of additional yeilds expected in the future is frequently overshadowed by the impact of this treatment on calculated allowable cuts.

Consider the approach to evaluating forest fertilization and other intensive management practices used by the State of Washington (Washington State Department of Natural Resources, 1970). Mixed old-growth and young-growth forests are managed to produce the greatest net revenues possible, within some rather broad environmental guidelines. The bulk of the forests are managed on a sustained yield basis. The allowable or permissible cut for any year can be roughly approximated by using the Hanzlik formula:

$$\text{Allowable cut} = \frac{\text{Volume of mature timber}}{\text{Length of rotation}} + \text{Mean annual increment}$$

When immature stands are fertilized, both the future yields from those stands and the mean annual increment for the entire management unit are assumed to be increased and the allowable cut is raised. In the woods this is accomplished by accelerating liquidation of the old-growth reserve without waiting for the treated stands to actually exhibit a physical response (Flora, 1966; Fries and Hagner, 1970; Ervasti, et al., 1970).

In addition to lands owned by the State of Washington, those commercial forest lands administered by the U. S. Forest Service and Bureau of Land Management (as well as the Crown Lands in Canada) are managed, by law, for sustained yield. I believe that comparable long-term management is also practiced by a number of the private corporations in the region. Given the legal or voluntary limitations on harvesting that accompany such management and the extensive old-growth reserves for timber found in the Pacific Northwest, fertilization can be extremely attractive. Stimulating growth in immature stands immediately leads to an increased cash flow income from harvesting other marketable timber.

Unfortunately, it is not possible to enjoy these company-wide benefits and ignore the incompleteness of physical response information. The problems of selecting specific sites to fertilize and application techniques which have the greatest chances of success still remain.

Operating Techniques Minimize Uncertainties

Areas that are similar to the most responsive experimental plots, which are found near Puget Sound in Washington, are given priority for fertilization Unfortunately, the process of identifying the most critical similarities is still uncertain: the more than 3,000 test plots in coniferous stands in the Pacific Northwest have not yet provided a reliable basis for ranking candidate stands, even in terms of physical responses (Strand and Miller, 1969).1/

Expected responses based on plot work must be discounted to allow for difficulties encountered in operational fertilization. One organization has noted that irregularities of application alone require that expectation of increased yields should be reduced by an average of 13 percent. Twenty possible causes of these irregularities have been categorized as human error (by both planners and helicoptor pilots), equipment failures, fertilizer characteristics, and errors related to characteristics of the area to be fertilized, such as size and shape.2/

Swedish studies have led to the adoption of a similar safety margin for profitability calculations when experimental results are extrapolated to field applications by fixed-wing aircraft (Hanger, 1966). In this case, the margin recognizes that the forest is broken by streams, rock outcrops, swamps, and roads. Applying an average reduction is an expedient means of getting on with the job, even when no one is certain just why experimental results are not being realized in practical applications.3/

The timing of fertilization applications--during the cooler and wetter months to reduce volatilization losses--can create scheduling problems. Heavy fertilizer trucks needed to supply the helicopters with urea are often slowed by poor road conditions. This results in work stoppages and excessive demurrage or standby charges for railroad cars and trucks.

The solution has been to temporarily store fertilizer on or near the heliports. One system now used in the Northwest is to truck 80-pound plastic bags of urea to the heliport and store them there.4/ Because the fertilizer bags can be stock piled at the heliports well in advance of need, the uncertainty of road conditions is less of a constratint on fertilizer applications.

1/ If ranking were possible, small or scattered desirable stands often could not be fertilized. The regionwide reliance on helicopters requires treating large contiguous blocks of land in a uniform manner. Rules-of-thumb based on several years of field experience spell out such details as the economically feasible sizes and shapes of treatment areas.

2/ "Theoretical Source of Application Error in Forest Fetilization," by Robert T. Berlland, a paper presented to the Operational Forest Fertilization Workshop, Camas, Washington, 1970.

3/ The traditional analytical approach to allowing for undefined combinations of uncertainties has been to inflate the discount rate used in evaluating investments (Flora, 1964; Robichek and Myers, 1966). Probabilistic techniques are now used to explicitly recognize the crudeness of much of the data used for planning (e.g., Teeguarden, 1969; Schweitzer, 1968). An overview of the application of such techniques is given by Brown (1970).

4/ Based on "Forest Fertilization in Northwest U. S. A. and Western Canada" by Robert F. Strand, a paper presented to the 15th World Congress of the International Union of Forestry Research Organizations, Gainesville, Florida, 1971.

Because a breakdown of any of the machinery required to move fertilizer could temporarily disrupt an entire system of application, contracts often cover all phases of a fertilizer application. Although the direct casts to the landowner might well be higher than if he were to operate his own trucks and tractor, he is able to both avoid investments in such equipment and transfer the risks of mechanical failures and the accompanying excessive costs to someone else. In effect, he pays an insurance premium.

Environmental Conditions Are a Source of Uncertainty

Still other safety margins are required because fertilization adds chemicals to the environment. Uncertainty regarding the ecological consequences has prevented any operational fertilization on Federal lands. The Bureau of Land Management, for example, in its most recent (tentative) management plan, states: "Preliminary economic analysis indicated feasibility but the decision was reached to withhold this practice from allowable cut planning until further testing can be completed regarding possible water pollution and fisheries damage side-effects" (Bureau of Land Management, 1970).

Firms that are fertilizing are also quite sensitive to the environmental aspects of their activities. To minimize the possibility of polluting water, and to minimize the possibility of being accused of polluting water, a number of safety margins similar to the following are included in field operation instructions:

--streamside buffer strips of timber are left unfertilized,

--no fertilizer is released over open water,

--none is applied on snow where it might be washed into streams,

--none is applied near domestic water supplies, and

--streams running through treated areas are monitored for their nutrient content.

These activities, and deliberate lack of activities, represent either out-of-pocket costs or opportunity costs. But they are recognized as necessary costs of fertilizing, just as screening clearcutting from public roads is now being recognized as a necessary cost of harvesting timber. Otherwise, it is conceivable that public opinion might result in more stringent restrictions on timber management planning.

Conclusions

I have shown that uncertainties characterize our knowledge of physical responses to forest fertilization, the application of fertilizer on an operational scale, and the political environment that sets the ultimate limits on applications.

Political considerations impose substantial costs in terms of required safety margins or outright prohibitions. On Federal lands, operational fertilization is ruled out, at least for the present.

Development costs are always incurred in creating expertise in applying a new treatment, as in the case of fertilization. Mechanical durability the importance of weather conditions, the transferability of research plot results to the field--all must be established by trial and error. Even for established practices, such as harvesting, a changing technology and changing esthetic requirements imply new techniques must be tried. And experimenting is expensive.

It is in coping with a shortage of physical response information that we might reasonably feel most confident. Presently available probabilistic and simulation techniques show promise as means for quantifying the economic risks inherent in investing when responses are uncertain; they also have the potential for determining how much might economically be spent on the interest of becoming less ignorant.

The widespread advent of automated data storage and retrieval systems has enable forest land managers to have ready access to a much larger proportion of a firm's total fund of data than was true a few years ago. In the same vein, any level of knowledge can lead to analyses that both consider more relevant factors and provide more detailed and informative answers. For example, the adoption of computers permitted first the development of (deterministic) linear programming and later such variants as "stochastic linear programming," "linear programming under uncertainty," and "chance constrained linear programming: (Byrne, et al., 1968), whihh are designed for use with imperfect data such as that which is common to decision making in forestry.

In a broad sense, all of the problems of uncertainty that plague investments in fertilization are due to a lack of complete information. At any given point in time, however, the quantity of information that is readily available can only be supplemented at some cost, if at all. For the present, in the Pacific Northwest fertilization will continue to be justified on the basis of the fragmentary experimental and experience data that are available and by the advantages gained through the allowable cut effect.

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