8-2002

Tradeoff Analysis and Evaluation in the Management of Forests for Multiple Uses. The use of Euclidean distances as a Decision Support Tool

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TRADEOFF ANALYSIS AND EVALUATION IN THE MANAGEMENT OF FORESTS FOR MULTIPLE USES. THE USE OF EUCLIDEAN DISTANCES AS A DECISION SUPPORT TOOL

By

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Engineer. Universidad Politécnica de Madrid, 1997

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

(in Forest Resources)

The Graduate School

The University of Maine

August, 2002

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An Abstract of the Thesis Presented
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This research proposes the use of Euclidean distances as a decision support tool in forest ecosystem management in a framework of analysis that integrates linear programming, growth and yield simulation software and Geographic Information Systems. The developed methodology, which integrates economic, ecological and ecological values, helps decision makers better understand the implications of their decisions and the tradeoffs that occur when forest values compete. The study also tests the hypothesis that forest management directions that favor the greatest variety of conditions lead to a greater aggregate value than those directions that favor narrower goals.

The study area is composed of more than 36,000 acres of State-owned land in Western Maine. The dissertation is organized in six parts. The first two parts reviewed definitions of forest values and existing quantifiable methodologies that estimate these values. To provide management guidance for recreational opportunities, the third part

analyzed recreational supply and demand at the local and state level. This analysis led to the conclusion that the area should retain its remote and undeveloped character while providing primitive and semi-primitive recreational opportunities. Parts four and five created a modeling environment that allowed the simulation of 44 management scenarios varying from "high intensity management" to "no management," and integrated a variety of computer applications including ARC/INFO®, Forest Vegetation Simulator, and Spectrum. An evaluation of the capabilities and limits of the software used revealed that their integration represents a powerful tool in forest management. The last part presented a new methodology of analysis. The researcher created a nine-dimension space where each axis represents the percent decrease of each analyzed outcome relative to the maximum capacity of the forest to produce a benefit in the absence of any other competitive uses. The Euclidean distance in the defined nine-dimension space quantified how far each simulated scenario was from the theoretical optimum. This distance represented a comparative measurement across scenarios and was compared to the variety of benefits provided by each scenario in order to test the original hypothesis. The researcher concluded that Euclidean distance represents a simple, flexible and accurate quantitative indicator of economic, social and ecological values of any management plan given any number of feasible, desired goals.

DEDICATION

To my parents-

mi mamá: Milagros Ibáñez Rabadán,

y mi papá: Antonio Álvarez García.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. David B. Field for his support, time, trust, and for providing me with the opportunity to pursue a career in the United States. I am especially thankful for his mentoring and his friendship both professionally and personally. It has been a great honor to work with him. I would also like to thank the other members of my committee Dr. John Daigle, Dr. Steve Sader, Dr William Krohn and Dr. Kevin Boyle for their help and guidance.

Steve Swatling, Bigelow Preserve manager, also deserves special thanks as he provided me with all the inventory information for this study.

Many thanks to Bruce Meneghin, from the USDA Forest Service's Inventory and Monitoring Institute, for all the technical support with the computer program SPECTRUM.

Many faculty members and personnel, in a very generous way, shared their time and thoughts with me during all these years. I owe them all a great deal. Al Kimball deserves special recognition, as he is a man who cares and worries about students. It has been a great honor to have met him.

I was very fortunate to have the opportunity to develop many friendships during my research. Thanks to all my fellow graduate students, especially Silvia Cordero Sancho, Ram Kanagaratnam, and Dr. Laura Kenefec whose advice and help has been extremely valuable for me. Thanks to my friends James Leck, Sue Griffin, Dr. Carol Wood and Fred Nichols for making my life sweeter and easier.

I am deeply thankful to Michael Goergen for being such a good mentor and friend, and for changing my life in such a wonderful way!

Lastly, but most importantly, I would like to thank my all family, without their support I would never accomplish anything, including this degree. Thanks for their love and encouragement. Thanks to my mother, Mila, whose strength and soul made me who I am today. ¡Gracias mamá!. Thanks to my father, Antonio, my sister, Natalia, my sweet brother, Toño, and my grandmother, Pepita.

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1.1. CHAPTER ABSTRACT

This paper presents a literature review of the different forestry values defined by researchers for the last four decades. In the decision-making process, quantification analysis of natural resources values represents a measure of the impacts that result from changes in uses of goods and services. This information is essential in the development of management alternatives to achieve public and private needs and objectives. Here are presented the different reasons why value analysis is so crucial for the decision maker, why the forest values are important, and the context within which values should be interpreted. Our review of values in the literature is focused on both monetary and nonmonetary units of measurement. A complete classification of forest values is proposed. Within nonmarket values, one can categorize forest values according to use-related characteristics as: consumptive use value, non-consumptive use value, indirect use value, and existence value or nonuse value. I present a review of some case studies related to nontimber forest consumptive and nonconsumptive values.

1.2. THE IMPORTANCE OF FOREST VALUATION

In sustainable forest management, forest value analysis helps to identify appropriate management goals, to anticipate social reactions, and to deal with conflicts over public forest lands (Bengston, 1994). Forest managers and policy makers need a broader knowledge of the diverse, complex, and multidimensional values associated with forests to develop and successfully implement ecosystem management approaches that are socially and politically acceptable as well as

biologically sound (Bengston 1993). Social, political and ecological considerations should be integrated to develop sustainable forest management decisions to achieve specific goals. Each component is an essential part of the management process and cannot be isolated. The principal goal of this paper is to provide a detailed description of the different forest value concepts presented in the literature related to forestry.

Besides timber resources, forests provide many useful "nontimber" products and services. There is no doubt that both resources, timber and nontimber, have value. But, the fact that some nontimber resources have no well-defined market prices makes their values more difficult to determine and to compare with others. These resources are largely unmeasured, and even unknown in some cases. To achieve efficient resource allocation and to use forest resources in a sustainable way, while avoiding conflicts, the values of both timber and nontimber resources should be estimated. The common objective of all methodologies developed to measure amenity resource values is to provide a better understanding to policy makers about social preferences and goals regarding these resources.

According to Kaiser, Brown and Davis (1988), two issues should be noted before extramarket valuation can be fully integrated into resource analysis. First, all resource outputs must be directly comparable with each other. Extramarket values should share the same theoretical and philosophical foundation with market values. The same theoretical assumptions and hypothesis should be used for both extramarket and market values. Resource values must be commensurate in order to compare values of different resource outputs directly. This will allow us to make tradeoff analysis between resources based on value estimates. Second, it is important to know why and how resources benefits are valued, which can help the decision making process.

Sinden and Worrell (1979) described the following requirements that the information needed to make rational decision must satisfy: a) express benefits in terms comparable with costs, b) express values of all alternatives in comparable units, and c) express values for all individuals. The conventional unit for valuation that satisfies these requirements is money. However, any index or group of them that meet these requirements may be satisfactory for the planner or analyst. Sinden suggested that, in some cases, units of time may be as effective as units of money, and in other cases an index of relative value may be all that is needed. However, what determines whether something is a benefit or not? How do we interpret benefits to one person that represent costs to another? Schreyer and Driver (1990), in their study about "Benefits of Wildland Recreation Participation," stated that to measure benefits we must distinguish what the benefits are, how they are to be measured, and what the value of a particular benefit is to an individual. The fact that there are two primary ways in which benefits may be manifested in some natural resources complicates the measurement. For example, recreation benefits include both recreational experience and remembering these experiences later on.

Some authors (Kuenzel, *et al.* 1995) argued that current management strategies, based largely on biological information, are inadequate. Biological information is absolutely necessary in developing ecosystem management strategies, but seldom guarantees a socially acceptable management plan. Because land management involves human behavior, managers must integrate public values and preferences in implementing plans. The authors defined three frameworks for studying a given situation with respect to understanding human behavior:

- The social utility approach, based on economic theory, focuses on an object's usefulness for human purposes.

- The action theory approach, which emphasizes objects in society that facilitate coordinated activity, is oriented toward creating consensus.
- The epistemological tradition, focused on analyzing the relationship of behavioral and societal trends, arises from routine practices of everyday life. But the evaluation of the contribution of ecosystem functioning to human welfare is a complex task. "It is a task of weighting human social values and is the quintessential task of politics" (Westman 1977). It is very important for the public to have a clear idea of the benefits they obtain from nature, in order to communicate their true wants about the relative merits of conservation of the natural environment and development.

National forest managers and planners world-wide must make difficult choices that frequently involve conflicting uses. In most cases, natural resource management agencies, charged with managing the environment for social benefits, and typically with critically limited budgets, are facing increasing pressure to respond to the often conflicting demands of economic development and environmental protection (Miles *et al.* 1995; Dennis 1996). Not only must a social perspective be included in management plans, but also the social perspective is controversial in some cases. This underscores the importance of incorporating a study of social needs and values with biological information to produce management plans.

For the last three decades, researchers have carried out studies to find public preferences related to natural resources within the USA (Daniel 1973; Zube *et al.* 1975; Daniel and Boster 1976; Buhyoff *et al.* 1978; Anderson 1981; Benson and Ullrich 1981; Balling and Falk 1982; Zube *et al.* 1982; Brown and Daniel 1984; Hull, Buhyoff and Daniel 1984; Vining *et al* 1984; Hull and Buhyoff 1986; Kaplan and Herbert 1987; Daniel *et al.* 1989; Countryside Commission 1994; Bishop and

Karadagli 1996). During this time, a high level of environmental awareness has prompted efforts by land management organizations to understand the public's perception of environmental quality. Scenic beauty is one attribute of environmental quality that is of particular interest, both because the public has the ability to evaluate it and because it is readily available for public critique. Clearly, people pay large premiums for better views (Magill and Schwarz 1989). Therefore, scenery possesses monetary as well as non-monetary value, and society is able to express its preferences in the market system. Thus, the public uses scenic beauty to evaluate management policies and actions. As Hull and Buhyoff (1986) state, "scenic beauty advertises management policy".

However, the physical characteristics of a forest are not the only determinants of public reactions to scenic beauty and other opportunities for recreation. A variety of cultural and social influences shape the public's aesthetic reaction to nature (Anderson 1981; Álvarez *et al.* 1999). In addition, social and individual equity should be considered as an important element in the evaluation of outdoor recreation. In Harou's (1982) study about the evaluation of outdoor recreation benefits, he concludes that the total benefits for a low-income group were seven percent higher than would have been true had the income distribution effects not been taken into consideration. Planners should include an income distribution dimension in the evaluation of recreation benefits.

Allocation of public lands among alternative uses is a very difficult task. This task is even harder when some forest uses, such a timber production, can be evaluated by market prices, and other uses, such as air quality, cannot. Inadequate consideration of unpriced values can lead to management decisions whose effects on both natural and social systems could be irreversible. It is not possible to estimate the "intrinsic"

value of natural resources, just as it is impossible to put a monetary value on human rights. The main goal in valuing natural resources is to provide a guideline for comparing different decisions in the management of a natural area. There is no formula for the monetary estimation of intrinsic forest value, but some approaches can provide estimates of comparative human preferences, as well as actual expenditures related to natural areas. Many public studies have been carried out by the USDA Forest Service to evaluate the net values of wildlife, wilderness, and general recreation and to allow comparisons of values reported using different methodologies and different units of measurement (Beardsley 1970; Payne and DeGraaf 1975; Daniel and Boster 1976; More 1979; Boyce 1980; Irland 1980; Benson and Ullrich 1981; Althaus and Mills 1982; Brown 1982; Schuster and Jones 1983; Sorg and Loomis 1984; Schuster *et al.* 1984; Jones and Schuster 1985; Loomis and Hof 1985; Peterson and Sorg 1987; Schaffer and Davis 1988; Magill and Schwarz 1989; Cordel *et al* 1990; Driver and Peterson 1990; Driver 1990; Easley *et al.* 1990; Magill 1990; Rolston 1990; Arnold *et al.* 1991; Strauss and Lord 1991; Glass and Moore 1992; Payne, Bowker and Reed 1992; English *et al.* 1993; Daniels *et al.* 1994; Bolon, Hasen-Murray, and Haynes 1995; Cole 1996).

Both public lands and private landowners face ever increasing user demand for activities such as hunting, fishing, picnicking, camping, and bird watching. These and other uses compete with timber production for attention. What will be the most profitable combination of uses for the landowners and what values may accrue to them? Peterson and Sorg (1987) summarized three ways for deciding how to allocate resources in a free economy:

- Market equilibrium: people bargain with each other to exchange goods and services within a framework of established economic rights and rules.

- Political equilibrium: a non-violent means of collective decisions, resolving conflicts, and distributing wealth.
- Benefit-cost analysis (BCA): a technical simulation of market equilibrium that attempts to correct market flaws resulting from imperfect competition. "BCA attempts to evaluate the economic efficiency of various government proposals by estimating and summing all the costs and benefits, so that the net gain in aggregate wealth with or without a proposal can be measured."

Public agencies of western countries use this last-mentioned method (BCA) in their studies. It is important to distinguish between the methods used to allocate resources and the methods used for resource valuation. Resource allocation methods are designed to estimate the best distribution of land uses given specific social goals and interests, while resource valuation methods try to quantify the worth or value of natural resources to society and to derive social goals and interests from that value.

The information needed by decision-makers about beneficial and detrimental consequences of alternative courses of action depends on the context and objectives of the decision. Driver and Peterson (1990) stated, "...The goal is always to select the most valuable alternative, but the definition of 'value' varies with context, and so does the method to measure it". So the knowledge of the context as well as the goals pursued is essential to decision makers. Valuation is the first step in the policy decision process (Figure 1.1). Four elements are important in the valuation process: the value concept adopted; an analysis of the resource and its interactions with society (opportunities, consequences, market segment, etc.); decision objectives; and assigned value of some of the parameters involved in the decision-making process. The policy decision process also considers a variety of other information, which may include a participant's perception of other social goals as well as assorted forms of political

lobbying and pressures from vested interest groups. The economist's monetary, or other social scientists' nonmonetary, measures of value are therefore just one input to this decision process that ultimately will determine the destiny of the amenity resources under considerations (Stoll and Gregory 1988).

Driver and Peterson (1990) defined types of analyses related with decision-making problems. To identify those variables that are important to the decision objectives and that differ in magnitude among the decision alternatives, we need qualitative analysis. However, to measure the magnitude by which decision alternatives change these salient variables, we should use quantitative analysis. Finally, the valuation process measures strength of preferences for the decision alternative by assigning value to the alternatives themselves or by assigning value to the variables that measure the changed characteristics caused by the alternatives.

Multiresource analysis provides us the following three advantages: 1) a consistent framework to study the different options of resource management, 2) a state of the art of development opportunities, and 3) some indicators of market interactions (Kaiser *et al.* 1988). Resource decisions need to be made through comparison of relative value. However, not all natural resources values are expressed in comparable ways.

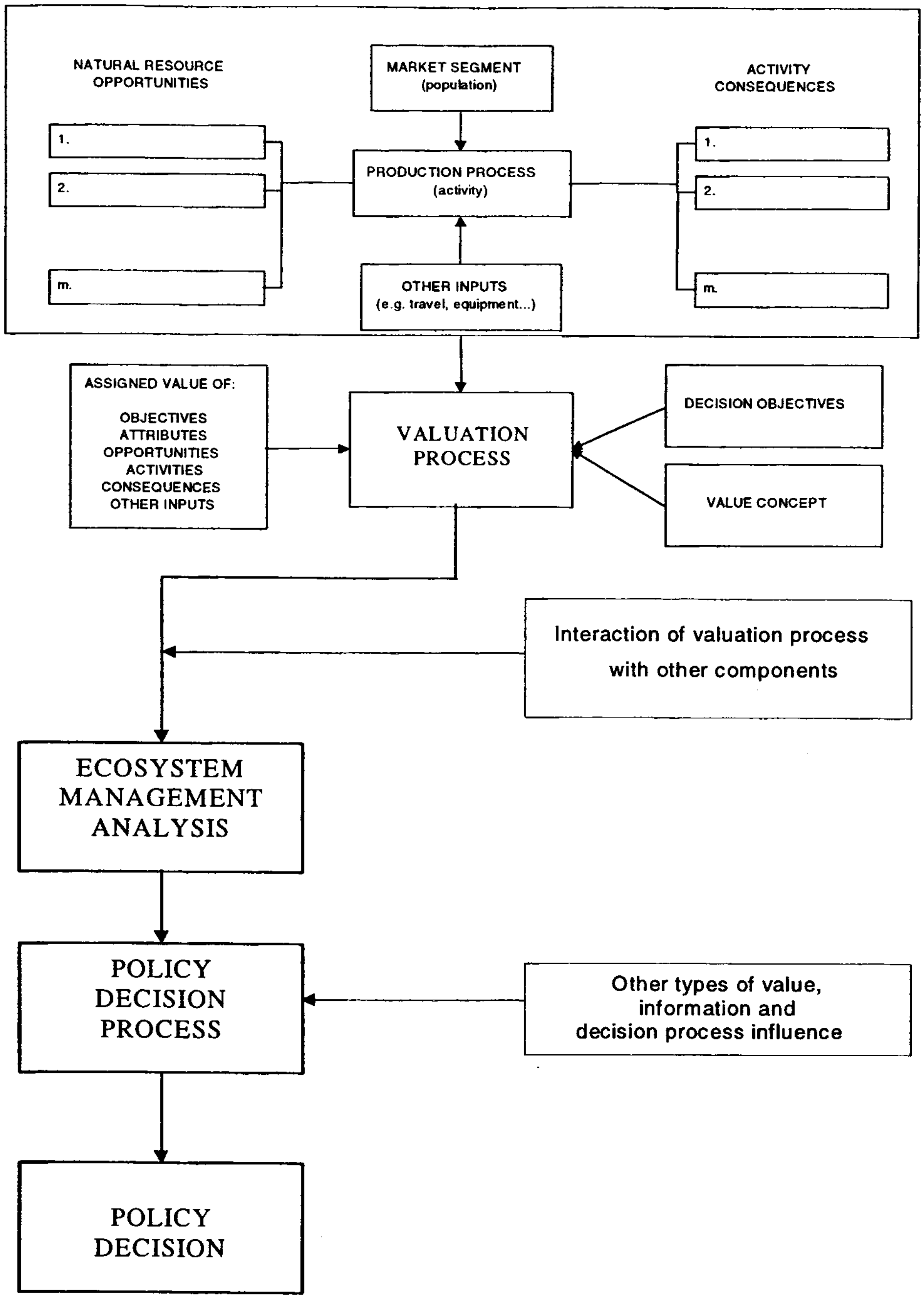

Figure 1.1: The process of policy decision making.
(Source: modified from Driver and Peterson, 1990).

1.3. THE CONCEPT OF "VALUE"

The concept of "value" in natural resources is complex. Webster's Dictionary shows thirteen different definitions for the meaning of the word "value," compared with seventeen meanings in The Random House Dictionary of the English Language. In some cases, value is defined as an active verb, such as in "valuing alternative futures." The fact that subjective natural resource characteristic units are not standardized makes this task more difficult. The assignment of imputed market values facilitates tradeoff analysis among multiple resources (Wargo 1990).

Value is a direct function of a capacity to satisfy human desires. Sinden and Worrel (1979) stated: "Anything that is worthwhile having or doing is said to be of value to the persons involved ... Value is used as a measure or indicator of relative importance, and the comparative values of alternative things or actions provide guides for choices and decisions". Stoll and Gregory defined value as the "worth of some set of changed circumstances as judged by the sovereign individual" (1988).

Some authors (Sinden and Worrel 1979; Irland 1987, Bengston 1993; Kuenzel, *et al.* 1995) argued that value is not a fixed or inherent property; it depends on the circumstances under which is used. Value depends not only on the nature of the resource itself, but also on who evaluates it and the environment in which it is assessed: purpose, time, people, conditions (physical environment in which the evaluator finds herself or himself), and circumstances (the personal, physical, emotional, psychological, social, and political situation of the evaluator at the time of the valuation). Value is reflected in the functional relationship between objects and people.

Valuation is the process of estimating what a commodity or service is worth. Driver, *et al.* (1987) defined two main approaches to outcome valuation (defining a

benefit as any "improved condition"): (1) the utility-based approach, which requires a measurement of the monetary value of outcomes; and (2) the condition-based approach, which relies upon both monetary and nonmonetary units of measure, enhancing analytical and descriptive power in estimating magnitudes and distributions of gains and losses.

The complex process of an individual's valuation at a particular time is illustrated in Figure 1.2. Although this individual decision process is not necessarily always followed, it gives us an idea of the pattern. The influences involved in the process are basically the external world in general, the society surrounding the individual, and the environment. Furthermore, society creates institutional acting on both utility and supply, it promotes different attitudes and states a defined moral. The environment has surrounding biophysical characteristics, acting on both utility and supply.

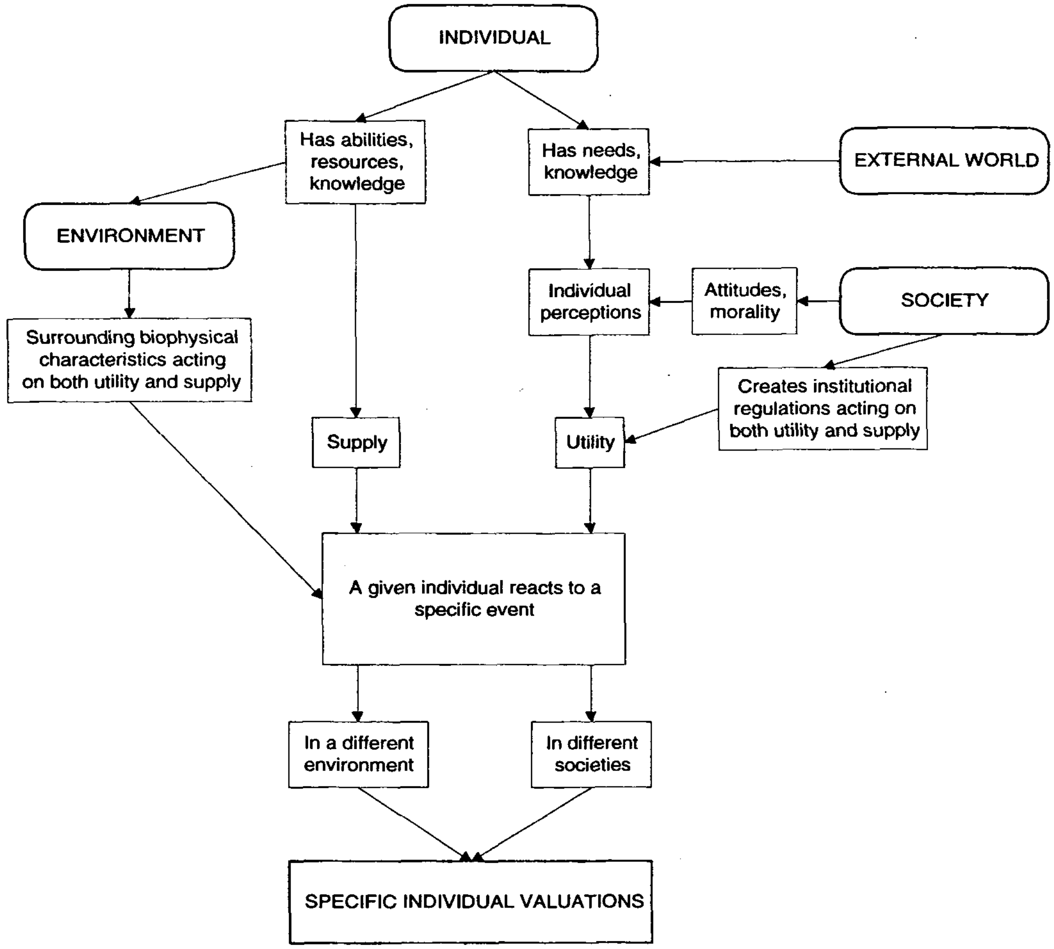

Figure 1.2: Individual valuation process at a given time.
(Source: Sinden and Worrel 1979).

Each individual has, at any given time, certain needs and desires, as well as his/her own knowledge of how to satisfy these needs and desires. In addition to this, he/she knows how to make use of knowledge, abilities, and skills. Individual needs are influenced by the society and the external world, and individual knowledge and abilities are influenced by the environment. In the individual's decision process, he/she evaluates each alternative in terms of both its utility to him/her and the opportunity cost of obtaining it. But because offers and demands are affected by the

environment and social groups, he/she might value differently depending on the circumstances (Sinden and Worrel 1979). According to Steinoff (1980)

> A value can be dealt with only in relation to other values. The mind of man, consciously or not, places all things in a preference order in a given situation. He then chooses a thing higher in the preference order over one lower in the order. This establishes the relative 'value' of each thing for him. These values change with each situation. Values of things may be related to a common denominator such a money, in which case they may be said to have a money value. Or they may be expressible only as a preference, which is evidenced in the behavior, as for example in the vote.

According to Shaw and Zube (1980), value can be expressed in different ways: economic terms (dollars), social and psychological terms (social trends, traditions, behavior, attitudes, preferences, satisfactions), and ecological terms (diversity, energy role, etc.). They state that these three basic groups represent total value. So, the total valuation of a natural resource should consider economic, ecological, and socio-psychological measures. Values are connected in some sort of system in the human mind (Figure 1.3). Perceptions, attitudes, and the value of the resource affect each other. Perception and attitudes result in motivation and, therefore, human behavior. Daigle *et al* (2002) showed the differences in attitudes, perceptions and values based on different three types of outdoor recreationists (hunters, wildlife viewers, and others). According to the authors, a recreationist gets involved on an activity when s/he believes that s/he can contribute to the activity, s/he has the means to do it, and when the activity produces a satisfactory output for the person. Fulton *et*

al. (1996) and Vaske and Donnelly (1999) defended that wildlife values affect behavioral intentions (or attitudes), which relates to behavior. However, according to Vaske, the correlation between intentions and actual behavior is not perfect, though both concepts are related. Later research (Hrubes *et al.* 2001) found that relationships within the value-attitude-behavior, defined by the previously mentioned authors, depends not only on resource value orientations, but also on fundamental life values.

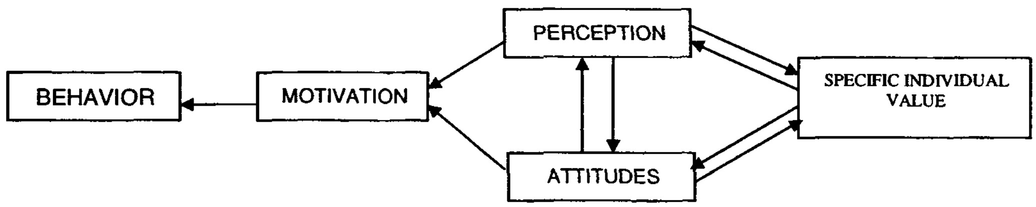

Figure 1.3: Relationship between different types of value expressions for the individual.
(Source: adapted from Steinhoff 1980).

1.4. DIFFERENT VALUE CONCEPTS USED IN THE LITERATURE

The literature of economics speaks of many different kinds of value: "fair market," "condemnation," "litigation," "assessed," "loan," "investment," "insurable," and so on. But, the definition of these values and their use is beyond the scope of this paper. The most important concept of value used in the environmental and resource economics literature is "**economic value**." This is defined as the market consideration of scarcity (supply), utility (demand), and future benefits. Stoll and Gregory (1988) defined it as "the worth of some set of changed circumstances as judged by the sovereign individual." Just *et al.* (1982) gave a simple definition: "the amount of money (or the goods that could be purchased with the money) that one is willing to give up in order to get a thing or that one requires in compensation for the loss of a

thing." For other authors, Freeman (1993), the economic concept of value is based on neoclassical welfare economics.

> The basic premises of welfare economics are that the purpose of economic activity is to increase the well-being of the individuals who make up the society, and that each individual is the best judge of how well off he/she is in a given situation. Each individual's welfare depends not only on that individual's consumption of private goods and services produced by the government, but also on the quantities and qualities each receives of nonmarket goods and service flows from the resource-environment system.

Morris (1956) distinguished among "operative value," "object value," and "conceived value." Operative value is the worth implied by the actual choices people make. Object value is the worth implied by the choices of a perfectly informed decision maker whose choices and objectives are constant. Conceived value is the worth assigned by the choices people believe they ought to make. Therefore, economic value measures operative value in terms of monetary exchange. Driver and Peterson (1990) affirmed that there is no difference between the three definitions for a person who is perfectly informed and whose choices are consistent with his or her objectives. In this case, the three of them are definitions of economic value.

Forest values can be divided into two main categories: "use values" and "non use values". Vicary (1986) defined use value as "the value of a property for a specific use or to a specific user, reflecting the extent to which the property contributes to the utility or profitability of the entity of which it is a part." In a broader sense, use value is defined as the economic value associated with the *in situ* use of a resource (Freeman 1993). The term "non-use value" is controversial. A typical approach is to

first define "total value" as the individual's willingness to pay to preserve or maintain a resource in its present state. Then, if total value exceeds use value the difference between them is the nonuse value. "Non-use value" sometimes is also called "existence value," "intrinsic value," or "preservation value." The disagreement is not only about definitions. Authors also argued over the classifications of various values. Freeman (1993), Bengston (1993), McKenney and Sarker (1994), Driver (1990), Rolston (1990), Peterson, Driver and Gregory (1988), Berry (1993), Miles *et al.* (1995), Peterson and Sorg (1987) are some of the authors who have expressed their own classifications and definitions of different nonmarket natural resource values. Figure 1.4 represents a classification of the forest values found in the literature

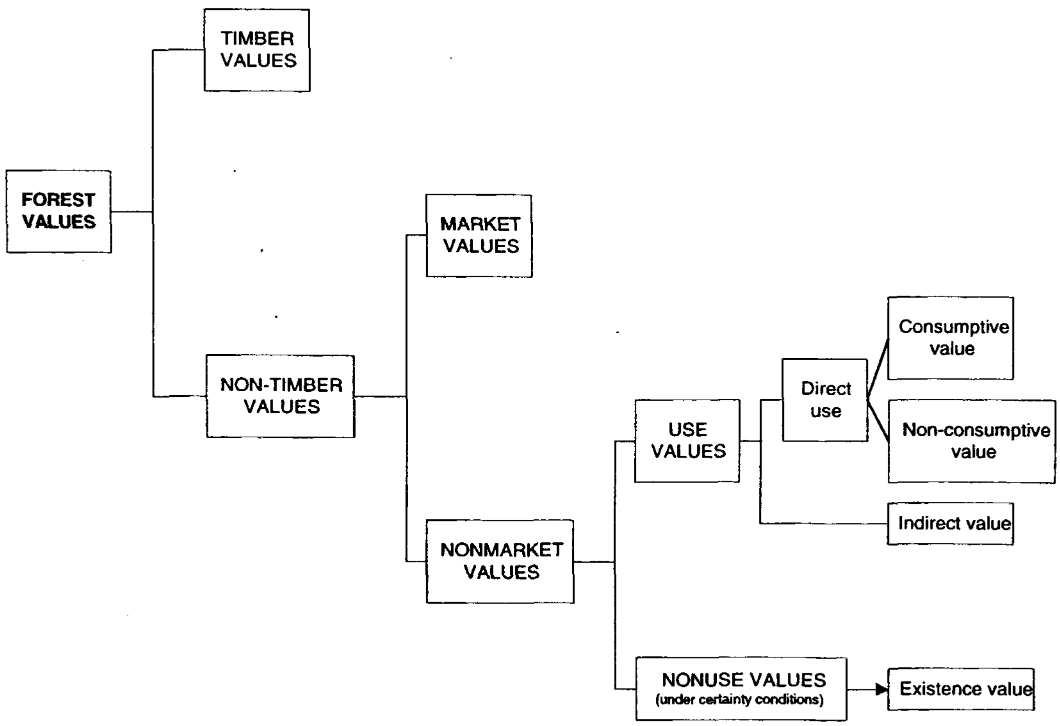

Figure 1.4: Forest values classification.

Forest values may be divided into two main categories: wood values and non-wood values. Wood values represent all forest products derived from timber production. Non-wood values are associated with goods and services produced by forest lands that enter an individual's preference (or utility) function and for which individuals are willing to sacrifice their scarce resources (McKenney and Sarker 1994). The non-wood value category is divided into market values and non-market values. Market values exist for forest goods and services for which there are priced market exchange mechanisms. Whereas, non-market values are those for which there are no market prices. Non-market values can be classified into use values and nonuse values.

Use values include those from recreational opportunities, reflecting the actual preferences a person has for participating in an activity like hiking, hunting, or fishing. Driver and Peterson (1990) stated that the demand for and value of these recreation activities depend basically upon the scenic beauty of the forest, especially those immediate experiences that focus on physical forest characteristics. Within this category there are consumptive values and non-consumptive values. Consumptive values are related to activities that use up forest resources in order for value to be realized (hunting, fishing). Non-consumptive values are related to activities that do not consume a product or material outcome of the natural resource. In the traditional classification activities such as skiing, hiking, camping, wildlife watching, or appreciating a view are included under the non-consumptive category. However, some of these activities "use up" the forest in the sense of erosion caused by overuse, destructive behavior, "solitude" values (personal experience between an individual and nature), or impact on wildlife. The "solitude" value of enjoying a natural area can be disturbed when the individual loses the sense of "personal experience" between

him or her and nature. Therefore, everyone else is responsible for the loss of someone's "solitude" value. In these sense, one could argue that activities that "consume" a condition could be considered as consumptive too.

Some authors (Boyle and Bishop, 1987) distinguish a third value, indirect use value, within the use value category. People who do not come in direct contact with the natural resource may also obtain some satisfaction from indirect sources, such as television documentaries, readings or pictures. These authors also group consumptive and nonconsumptive values in a "direct use" category.

Nonuse values are associated with actions that do not involve any kind of participation in forest activities in the present time or any actual physical consumption of goods or services. Option value relates to the willingness to pay for an opportunity to have services or resources available in the future, whether they are used then or not. Option value is "an adjustment to resource values to reflect uncertainty" (Boyle and Bishop 1987). It is not a nonuse value. Two main factors contribute to uncertainty: the variety of future activities to choose among, and uncertain income levels and other economic issues. The term "option value" has been incorrectly used in the literature. In order to measure the possible use in the future, we should measure the "option price" (Bishop 1982). Option Price is the appropriate Hicksian measure under conditions of uncertainty. Therefore, the "option value" is defined as the difference between certainty and uncertainty measures.

$$OV = OP - E(cs) = \begin{cases} \leq 0 \\ \geq 0 \end{cases}$$

Where *OV* is the option value, *OP* is the option price, and *E(cs)* is the expected consumer surplus. Option value can be greater than, equal to or less than

zero. Under conditions of uncertainty the option value provides information about the difference between the estimated value (option price) and the expected consumer surplus. It also provide the degree to which we are underestimating ($OV < 0$) or overestimating ($OV > 0$) consumer surplus. Option value can be positive, negative, or equal to zero depending on the type of person (risk averse, risk lover or risk neutral) and the sources of uncertainty. Two main factors contribute to this uncertainty --the variety of future activities to choose among and uncertain income levels and other economic issues.

Existence value derives from the satisfaction people place on simply knowing that some forest resource exists (Driver and Peterson 1990). Some authors (McConnell 1983) argued that existence value is based on an altruistic attitude toward other people's use of a resource, independent of any use made of the resource by the person holding the existence value. Krutilla and Fisher (1975) stated that a bequest motivation, or preserving options for the future are two of several possible explanations for a pure existence value. Kopp (1992) affirmed that people could have what are essentially existence values out of an ethical or altruistic concern for the status of non-human species or proper rules of human conduct. From all these different perspectives about the definition of the existence value, without mentioning the philosophical approach, I suggest that the existence value represents a group of motivations in which all different positions have a place. Therefore, existence value combines many aspects of the concept that other authors have classified as different values:

- **Bequest value** refers to the value an individual places on being able to pass good things on to future generations.

- **Vicarious value** comes from the fact that someone obtains satisfaction simply from knowing that particular environmental amenities still exist. One knows about them via pictures, television documentaries, magazines, etc.
- **Altruism value** comes from the individual knowing that the resource is undisturbed, without any other pretensions.
- **Stewardship value**: Peterson and Sorg (1987) give two interpretations about this value. The first one defines this value as the willingness to pay because ecological diversity is part of the affairs of other individuals. The second interpretation is that "today's generation should make decisions concerning the use of natural resources as though the present generation does not have ownership of the resources, but is instead the steward of resources that belong to the future".
- **Intrinsic value** is the product of belief that value is an inherent property of the object, independent of usefulness to humans.
- **Cultural and symbolic value**. Forest is part of our own culture. Societies have developed in the forest and in its transformations through the decades, so forest is part of everyone's culture.
- **Life support** as a part of our terrestrial ecosystem and **genetic reservoir value**. A forest is an ecosystem, a home with a contained place for its member species, each with an evolutionary fitness (Rolston 1990).
- **Moral value**: we value an object morally when we regard it with love affection, reverence, and respect (Bengston 1993).
- **Natural history value**: the value derived from the fact that each forest is unique, each has its own biocharacteristics with its own richness (Rolston 1990).
- **Scientific study value** and knowledge reservoir. Forest is a reservoir of biodiversity. Much remains unknown about natural values.

- **Character-building value**: the forest teaches one to care about his or her physical condition. Some social groups have been developed from this characteristic, such as Boy and Girl Scouts, church camps, the National Outdoor Leadership School.
- **Religious experience value**: for some cultures a forest is a "church". They relate spiritual experiences with different actions in the forest. Mountaintop experiences, the wind in the trees, a quiet snowfall are experiences that show us the power of Mother Nature. The Penobscots run every year almost 100 miles by foot and canoe to reach the top of Katahdin (Maine) to restore spiritual strength.
- **Deep values**: this refers to those philosophical values that relate forest with the roots of human existence, where life rises.
- **Quality of life values**: air quality and water quality are good examples of the benefit and values than we obtain from the forest. There is no doubt that the forest is one source that improves our life quality.

1.5. NONTIMBER FOREST VALUES

Nontimber forest values have played an essential role in the progress and existence of some societies in history. Nowadays, researchers are focusing more and more on quantification analysis and methodologies to estimate the social demands and needs regarding these values. In a recent study conducted by Joseph Buongiorno and the USDA Forest Service (in press) on 610 maple-birch stands in Wisconsin, preliminary results showed that nontimber forest values (an average of $20 per acre per year) on national forest land were around ten times greater than timber benefits. In this same study, private owners' nontimber values ranged from $8 to $9.50 per acre per year, which represents four times the amount of timber benefits from county and

state forest, twice the value of timber benefits from private, nonindustrial private forest lands and slightly higher than timber revenues on industry lands. These numbers show the important need of research towards a better understanding and quantification of nontimber values, and the role they play in social well being and regional economies.

1.5.1. Non-timber forest consumptive values

Through the decades, nontimber products have gained more popularity in the market. In some developed countries, like the USA, the special forest products industry has gained increasing attention as timber harvest levels have declined, and has even been heralded by some people as a partial solution to timber industry employment problems. This is the case for western Washington and western Oregon (Schlosser 1997). In other countries, the economy of non-timber products is already strong enough to support a sustainable industry. The "dehesa" is a habitat formed by *Quercus suber* as the principal tree species. This habitat occupies the southwest region of the Iberian Peninsula (Spain and Portugal). Tree density is low enough to allow different grass species from the *gramineae* family and herbaceous plants from the *leguminoseae* family to live underneath the tree canopy. These herbaceous species in combination with acorns are used by local farmers to feed their pigs. But, what it is more important in the economy of the "dehesa" habitat is the use of the bark, which is cork. Spain and Portugal are the primary cork-producing countries in the world, and the profit obtained just from cork is bigger than the timber market value. So, in the dehesa habitat we can find three different and very important nontimber products for the economy: bark, grasses, and acorns.

In other countries (mainly developing ones), non-timber products are crucial to the local economy. A good example is the case study titled "The markets of Non-timber Forest Products in the Humid Forest Zone of Cameroon" (Ndoye *et al.* 1998). The study provides evidence of the size of the markets for products from four species (*Dacryodes edulis, Irvingia spp., Cola acuminata* and *Ricinodendron heudelotti*) in Cameroon, as well as the level of employment these markets generate. It also analyzes how these markets function and the traders who participate in them. The study highlights the role of non-timber forest products as a source of employment and income not only for gatherers but also for traders. It shows that, during the first half of 1995, more than 1,100 traders, most of them women, engaged in the distribution of some $1.75 million dollars worth of the four products analyzed. But, this value is insignificant compared with other forest non-timber markets.

The Pacific Northwest of the USA and Southwest of Canada may contain the widest diversity and abundance of special forest non-timber products in North America (Savage, 1995). This area includes Washington, Oregon, California, British Columbia, and parts of Idaho. There is an important existing market for floral greens (salal, ferns and beargrass), Christmas greens (noble fir boughs), wild edible mushrooms (morels, *Morchella* spp.; chanterelles, *Cantherellus cibarius*; boletes, *Boletus* spp.; and matsutake, *Armillaria ponderosa*), wild edible berries (huckleberries, elderberries, raspberries, etc.), quinine oak, cascara bark, wild ginger, and wild plants used for medicinal products (pacific yew, arnica, abies oil, etc). Schlosser and Blatner (1989) estimated that these forest products represent more than $128.5 million in domestic and export sales. Just the financial returns to mushroom processors generated $2.9 million in profits during 1992, with Asia and Europe being the main consumer countries (Schlosser and Blatner 1995). Savage (1995) affirmed

that millions of dollars of fresh Northwest mushrooms are flown to these regions every year. The unknown potential of other areas could be hidden by the use of timber as the only forest resource.

There is a potential for any species from any of the living things that exist on the earth to benefit humans. From the plant species we could make use of leaves, seeds/fruits, boughs, bark, resins, saps, roots, chemicals and genetic material. From fauna can be derived bones, teeth, meat, fats, milk, blood, oils, musk, antlers, furs, hides, horns, hooves, skin, shells, chemicals, body parts, organs, DNA, and animal products, nests, honey, wax, silk and even excrements (Lund 1998).

Sometimes we domesticate and commercialize some non-timber forest products, and eventually they become part of the agricultural sector without belonging anymore to the forest sector. This fact causes some disadvantages in the forest economy sector, because the profit that the products generate is no longer associated with this sector. Hunting and fishing are two of the nontimber consumptive benefits that are well known in western countries. The economic benefits obtained from them are very important in local economies of rural regions.

Finally, the importance of the minerals, soil and water supply must be mentioned. These products are essential to humans, and the three together are essential parts of any ecosystem. The role that forests play in watersheds is very important, especially in arid areas where desertification may occur if the natural ecosystem is disturbed. Not only is the water supply essential for human and nonhuman life, but also water quality and air quality are two benefits that forests can influence. The soil is an essential component of the forest. Its destruction by human action or by natural processes (sometimes increased by human activity) means the

destruction of the forest. Natural erosion occurs, but human pressure and human actions may cause the destruction of fragile ecosystems.

1.5.2. Non-timber forest non-consumptive values

Besides forest consumptive benefits, we can also obtain nonconsumptive benefits. Forests provide opportunities for human recreation, fishing (when in the practice of this sport we release the fish), and other activities related to wildlife (nongame animal activities, such a birdwatching) and wilderness (aesthetics, scenic viewing, philosophical, religious, and artistic inspiration). One of the most important nonconsumptive benefits for society is forest diversity. Biological diversity refers to "...the diversity of life in all forms and all its levels of organization, not just the diversity of plant, animal, and microorganism species. At its most elemental level, biological diversity encompasses the varied assemblages of organic molecules that comprise the genetic basis of life" (Hunter 1990). Some aspects of ecosystem diversity remain unknown to the scientific community. This fact makes management for forest diversity more valuable because we do not know which human benefits we may lose if we lose the richness of the ecosystem.

Even more, sometimes familiarity with an ecosystem convinces us that we understand it, but we probably are not capable of understanding the benefits that this ecosystem can contribute or will contribute to society in future generations. Consider the wetland example. The value of wetlands lies in their contribution to the diversity of a region's natural heritage. However, in the past, people ditched and drained wetlands for agricultural and development purposes, these places were often considered as mosquito infested areas. Similarly, forest products and services are not

always seen as useful for humans, though they are always there (unless the area is disturbed by human or natural causes).

Values placed on forest amenities depend on the society, cultural traditions, and the degree of technologic development. Snowmobiles allow new groups of users of nature to enjoy the scenery. Fifty years ago, such winter access to the forest would have been unbelievable. This type of transportation allows new ways of enjoying the nature, though it has some ecological disadvantages that also should be considered such as wildlife disturbances, and noise and air pollution.

All forest benefits, consumptive and nonconsumptive ones, are interrelated. All of them influence each other to a certain degree as the result of being part of the same ecosystem. Even timber resources and productivity are influenced by the management of nontimber forest benefits and services (Schuster *et al.* 1984). Research is need in this field so managers can understand the consequences and tradeoffs given different management alternatives. The fact that non-consumptive values are harder to estimate does not imply that their quantification is as important as consumptive values.

Chapter 2. REVIEW OF THE ECONOMIC METHODOLOGIES APPLIED IN FOREST ECOSYSTEM MANAGEMENT TO ESTIMATE NATURAL RESOURCES VALUES.

2.1. ABSTRACT CHAPTER

This paper provides a broad review of the different methods developed to estimate the partial or total value of natural resources, the advantages and disadvantages of their use, and some considerations related to the validity of the valuation methods. Most of the methods reviewed in the literature are based on economic theory, using monetary measures. Some of the economic methods described in this paper are: travel cost analysis, hedonic property values, avoidance expenditures, referendum voting approach, contingent valuation, and conjoint analysis. There have been very few attempts to estimate these values with non-monetary units. Sinden and Worrel (1979) compiled a broad spectrum of theoretical research foundations, some of them in early stages of development and not necessarily based on economic units, which suggested the development of new robust methodologies. Some of which are reflected in today's methods.

2.2. INTRODUCTION

As human populations increase, the need for economic development will increase the use and consumption of natural resources. In the case of forested lands, increased demands for timber and other industrial products can be predicted as human population growth increases. Needs for recreational uses and other forest services (clean water and air) will grow at the same time. Defining a balance among different

demands while managing our forest in a sustainable way requires a rigorous study of the outcomes and net benefits of management alternatives.

Nowadays, there is not a definitive method that provides a measure of the total value of natural resources. Several approaches have been developed, but none of them can be applied without restrictions. The common objective of all approaches is to provide a better understanding to environmental policy makers about social preferences related to both priced and unpriced, and amenity and non-amenity resources.

One of the problems of partial estimates of value is that measuring only the on-site consumptive use may presume to measure the total value. Peterson and Sorg (1987) proposed two ways of including nonconsumptive values in a decision making process. The first one is through political action --showing the consequences of actions and letting the political system reach its own conclusions. The second one is to devise ways to measure these nonconsumptive values scientifically and include them in a Benefit-Cost Analysis.

From the classifications of approaches to measuring environmental and resource values found in the literature, the one developed by Mitchell and Carson (1989) and reviewed by Freeman (1993) stands out for its clarity and simplicity (Table 2.1). This classification is based on two characteristics: the data source (what people say, or from what people do) and whether the method provides monetary values directly or whether the monetary value is obtained through some indirect technique based on a model of individual behavior and choice.

Estimation approach	What people do (revealed behavior)	What people say (stated preferences)
$ Directly	Competitive market price Simulated markets	Iterative bidding (CV) Open ended questions (CV)
$ Indirectly	Travel cost Hedonic property values Avoidance expenditures Referendum voting	Payment cards (CV) Dichotomous choice (CV) Contingent referendum(CV) Contingent activity (CV) Conjoint analysis

Table 2.1: Value estimation methods classified according to their characteristics.
(Source: adapted from Freeman 1993, p. 24.)

2.3. DIRECT METHODS

Direct methods, dealing with observations of how people actually choose to maximize their utility, use competitive markets and simulated markets set up specifically to obtain individual values. These methods provide monetary values based on the price of the good or service. One example of these methods is the residual value approach, used generally to value timber and minerals. It begins with the market sales prices for finished lumber, ore, minerals, or oil, and deducts all processing, transport, and extraction costs. In theory, this will measure the in-place value of the market resource. These values will be affected by the degree of competition for the right to use the product (Irland 1987). Another method attempts to estimate the benefits of reducing damage to ecosystem functioning by estimating the cost of repairing or replacing damaged functions (Westman 1977). In practice, we can rarely repair all the damage because some ecosystem disturbance processes are irreversible.

2.4. INDIRECT METHODS: REVEALED PREFERENCE MODELS

Indirect methods, based on actual choices, reflect utility maximization. Models include the travel cost method and its different variants (simple travel cost model, multiple site travel cost model, elliptic method, random utility model, and hedonic

travel cost model), hedonic property value model, avoidance expenditure model, and referendum voting approach.

2.4.1. The travel cost method (TCM) or Hotelling-Clawson-Knetsch method.

Clawson and Knetsch (1966) designed the earliest version of this method. Cocheba (1978) defined it as a method that "...employs demand estimates for recreational activities to impute a value to the set of resources in existence at the site where activities take place".

The TCM is a way to measure the economic value of a natural area to which people travel from a wide range of distances (Peterson *et al.* 1988). It estimates the value of the site characteristics by examining how users choose which site to visit. The method is based on the fact that "...even if there is no entry fee to a recreational site recreationists pay an implicit price when they visit. This implicit price is reflected in the cost related to traveling to the site. Included are vehicle-related and the time costs of the trip (both on the road and at the site)" (McKenney and Sarker 1994). It uses data on observed expenditures in actual markets to estimate the value of related goods not directly sold in markets. The unpriced good might be a characteristic of the priced good or a separate good that can be acquired only if the priced good is purchased (Brown and Walsh 1988). This method relies on actual travel costs experienced by visitors to infer their demand curve for the experience. To estimate the demand curve for the number of trips to the site, we need data from visitors from different locations and the number of trips they take. The estimated demand curve can provide rough initial estimates of consumer willingness to pay and, therefore, aggregate or total benefit measures for the recreation site (Irland 1987, McKenney and Sarker 1994). There are four variants of the travel cost method:

1. The simple travel cost model is designed to value an entire site by estimating the demand for trips to the site. The model is based on the recognition that the cost of traveling to a site is one important component of the entire cost of a visit, and there will be a wide variation in travel cost across any sample of visitors to that site. There are six assumptions that, according to Freeman (1993), are needed to use the simple model properly:

- People's reactions to changes in travel costs are similar to reactions to changes in entry fees.
- The main goal of each trip is only to visit a site. If there is more than one site, a part of the travel cost would be a joint cost that cannot be distributed among different purposes.
- Recreationists' travel expenditures are made to use a recreational site; people do not travel just for the experience of traveling.
- The amount of time spent by each visitor is equal. If this parameter depends on the visitor, the full price of a visit will be an endogenous variable.
- There is no utility or disutility derived from the time spent traveling to the site. If part of the trip is driving through the area, the travel cost is overestimated.
- The current wage rate is the relevant opportunity cost of time.
- There are no alternative recreational sites available; no substitutes.

Under these assumptions, the simple travel cost model estimates the willingness to pay to visit one site, where there are no alternative places to visit. The model assumes that people will make repeated trips to a site until the marginal value of the last trip is worth what they have to pay to get there. The value of a site is the difference between the marginal value of each trip and its marginal cost. The marginal cost of the trip is the actual travel cost per person, and the marginal value of a trip is

the travel cost of the most distant person who has made this trip their last. Therefore, the value of a site is the difference between the actual travel cost and the travel cost of the most distant person who has made this trip. In economic terms, the site value is the consumer surplus for trips (Robert and Markstrom 1988). It is important to distinguish between studies dealing with single-day trip data, and multiple-day trip data, because there could be significant differences between these types of data. Reiling, Boyle and Phillips (1989) found that multiple-day trip values are higher than single-day trip values. This model, besides the travel costs, requires data of the origin of travelers to specific sites to calculate a travel cost curve.

2. The multiple site or multi-site travel cost model values types of sites and studies interactions among systems of sites. This method is based on the Simple Travel Cost Method, but includes the travel cost to the relevant sites as independent variables. So, the model values different site sets. Multi-site models are estimated as systems of demand equations. The travel cost considered by the model corresponds to the closest site type, so it assumes that people go to the closest type of site. Here, besides the data concerning the origin of users, we also need the location of alternative sites people visit, which makes the value estimations more complicated.

3. The elliptic method estimates the expected amount of time of recreational travel through a region, given the limited amount of trip travel data often collected in visitor surveys (English and Thill 1996). These estimates are often used in economic impact analysis, aggregating them at the level of counties or group of designated counties.

4. The random utility model attempts to study the choice among sites as a function of the characteristics of the available sites. It is based on the fact that having different sites whose characteristics have changed in interesting ways, we can value changed characteristics. So, the model values site characteristics by examining subtle shifts in

the demand for trips to various sites. This method requires measuring the objective characteristics of each site.

5. The hedonic travel cost model values site characteristics by examining how users choose which site to visit. It is based on the assumption that the cost of visiting any site from a determined origin is directly related to the characteristics of that site. Each site is characterized by a set of attributes, so the goal is to estimate the marginal travel costs associated with each characteristic. When the levels of attributes change, the method can measure changes in net economic benefits accruing to consumers of nonmarket forest attributes. In the previous models, site demand depends on the characteristics of the site. Information on the site is used to value characteristics of the site. This model values site characteristics to estimate the implicit price of characteristics themselves. One cannot use the method to value a single site; there must be sites that have, and others that do not have, the desired characteristics. So, people must have choices of sites to visit (Robert and Markstrom 1988).

The USDA Forest Service has developed the Recreational Market Model (RMM), which allows estimation of consumer and producer surplus from data obtained from the Rocky Mountain Travel Cost Model (Arnold *et al.* 1991). This model is an example of how valuation studies allow analysts and policymakers to observe the effects that management policies would have on economic welfare before they are implemented.

2.4.2. Hedonic property values.

This approach provides a tool to obtain welfare measures from actual differences in prices of houses. When housing prices reflect environmental quality levels (different levels of contamination due to dominant wind direction, for example) then it can be possible to estimate the demand for public goods (such as clean air)

from the differences in price shown in private markets. "The hedonic price technique is a method for estimating the implicit prices of the characteristics that differentiate closely related products in a product class" (Freeman 1993). Hedonic price models quantify the contributions of the market and non-market components of a good to its equilibrium market price (McKenney and Sarker 1994).

2.4.3. Avoidance expenditures.

This method estimates the value of increasing an environmental quality by the decrease in expenditures due to the environmental improvement. For example, if water quality improves, tap filters are not needed, so the savings that this improvement causes reflect the value of increasing water quality. It does not measure consumer surplus; it just measures a low level of desired characteristics expressed by the consumer of these expenditures. This method, also known as "averting behavior," is only used in those cases where the use of other methods is difficult.

2.4.4. Referendum voting approach.

This indirect method is based on observed choices in a referendum setting. Public choice about taking or leaving a fixed quantity of a good shows only whether the value of the offered good to the voter is greater or lower than the offered price (Freeman 1993). There is not much literature regarding the use of this model because of the lack of real information about consumer answers in such scenarios.

2.5. INDIRECT METHODS: EXPRESSED PREFERENCE MODELS

Methods based on revealed behavior cannot measure nonuse values, while methods based on stated preferences can. They are summarized in Figure 2.1, and basically they group into two main categories: the contingent valuation methods and the conjoint analysis.

2.5.1. Contingent valuation.

Contingent or simulated markets are often used as proxies for actual markets, which allows analysts to approximate quantity demanded at different price levels. Contingent valuation uses surveys to create hypothetical markets so that people can express their willingness to pay for a supply of nonmarket goods. Economic theory states that willingness to pay for a nonmarket resource should approximate what one would pay to avoid the loss of the resource (Schroeder and Dwyer, 1988). But, in practice, there are some differences between the two perspectives. The contingent methods are based on the assumption that individuals are capable of expressing their preferences for changes in quality or quantity of public goods through interviews or surveys (Mitchell and Carson 1989). Kaiser *et al.* (1988) explained the main reasons why the method's structure may not meet this assumption:

- The consumer may not be able to express his/her real behavior in hypothetical circumstances. People's answers should reflect their actual behavior in a market. This task is difficult because market prices for the opportunity generally do not exist. In a real market situation, people can compare prices, shop around for the best buy, compare different decisions, and consider alternatives for a long time. A short time spent with an interviewer may not reflect real behavior, especially when those interviewed know that they are not actually paying these prices.
- The interviewer must make sure that the respondent understands the scale of the situation. That is, "Values for the general availability of an activity cannot be used to determine the value of the same activity for a specific site or the general availability of an opportunity over time".

Psychological studies of contingent valuation indicate that, under given contextual variations, respondents can be asked to express their willingness to pay, and the correspondence between intentions and actual behavior will have a strong correlation (Ajzen and Peterson 1988). It is essential that the measure of WTP is the average across the different estimates of these contextual variations. It is also very important to observe actual behavior in an equally varied set of circumstances. This approach involves a more thorough survey.

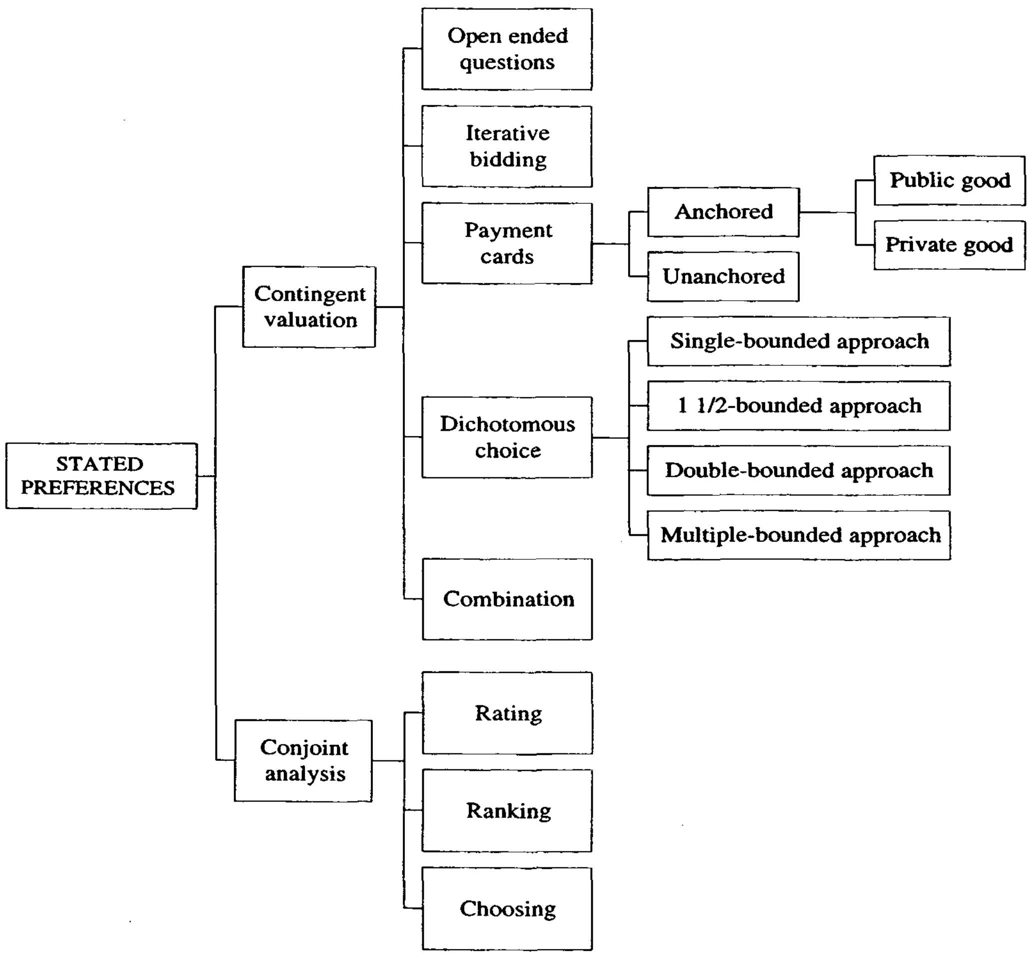

Figure 2.1: Value estimation methods based on stated preferences.

Contingent valuation interviews have three parts (McKenney and Sarker 1994):

- A presentation of the hypothetical market, which describes the (environmental) benefit to be valued, its actual status, its substitutes, and the method of payment (WTP) or compensation (WTA).
- Some valuation questions, to obtain the respondent's maximum willingness to pay for (WTP) or willingness to accept (WTA) the benefit.
- Some questions related to general information, like the respondent's age, income, and knowledge about the subject.

The accurate presentation of the hypothetical market and the correct identification of the value object are the keys to contingent method. A poorly framed contingent valuation question may lead different people to express attitudes toward different components of the question. Driver and Peterson (1990) suggested five steps to characterize this framework. Taking the example of valuing clean water, we must distinguish between:

- clean water,
- policies that affect water quality,
- studies about the efficiency of those policies,
- beliefs about personal responsibility for water quality, and
- a behavior, such as payment for a policy to affect water quality.

The direct methods, based on people's answers, involve asking people about the value of environmental goods and services, as well as changes produced in their attributes, creating hypothetical markets. From the eleven variants of this method, the most commonly used contingent valuation models are the iterative bidding model, open-ended questions model, payment card model, and dichotomous choice model.

1. Iterative bidding. The person is asked whether he or she would be willing to pay $Y to improve an environmental quality. If the answer is "yes," then the next question will involve a higher amount of money; if the answer is "no," the amount will be lower. The difference with the dichotomous choice approach is that the bidding games model repeats the procedure until the answer is "no", if the previous answers had been "yes," or until the answer is "yes," if previous answers are "no." The highest price response is interpreted as the maximum willingness to pay. Actually, this method has been replaced by the dichotomous choice method due to the influence of the starting point of the first bid proposed in people's answer. This method is now seldom used.

2. Open-ended questions. This method estimates total benefit (consumer's surplus and consumer's expenditure) by directly asking for the willingness to pay to obtain an increase in an environmental quality. The willingness to pay can be expressed in marginal units (when we talk about numbers of fish or recreational trip days, for example), or total quantity (when we talk about air and water quality, biodiversity, etc.). Also, direct questions are used to ask for the willingness to accept a decrease in environmental quality. This is the amount of money that people are willing to accept in order to obtain the same utility when there is a decrease in an environmental quality.

3. Payment card. There are two varieties of the method: the anchored approach and the unanchored approach.

3.1 The anchored approach provides the interviewee with an information card. This card contains information about average amounts of other expenses that society pays for other public or/and private goods and services. Then the person is asked to express his/her willingness to pay for the amenity improvement or change in quality. This

method can be used with public goods and private goods, but nowadays this application is rare.

3.2. The unanchored approach provides a card with different ranking amounts and the respondent must choose which ranking is the one that adjusts to his/her value estimation of the public good. So the public is expressing a range instead of a fixed number.

4. Dichotomous choice. The interviewee is asked one or several questions, depending on the variety of the method, to which the answer is "yes" or "no." There are four different approaches of the dichotomous choice method.

4.1. Single-bounded: Instead of converting data on "yes" or "no" responses to a referendum question into a monetary measure, this method employs some explicit utility (a theoretic model of choice). People are asked their willingness to pay a determined amount of money to obtain an environmental change. If the answer is "yes," their willingness to pay is at least the cited amount (could be bigger); if the answer is "no" then their willingness to pay is smaller than the asked amount. Respondents are divided according to several subsamples, and members of each group are asked to respond to different dollar amounts. Then we can test the hypothesis that the proportion of "yes" answers decreases when an environmental good price increases, so we can estimate the indirect utility function or bid function with a model of discrete choice.

4.2. 1½-bounded: Dichotomous choice questions may be influenced by the magnitude of the bid stimuli that survey interviewees are asked to consider. Single-bounded questions do not provide enough information to isolate the anchoring effect caused by the proffered bid (Boyle *et al.* 1997). Therefore, these authors have proposed a modification of the single-bounded dichotomous choice method in which the sample

is divided into two groups. The first group is asked an open-ended question; the second one is asked a single-bounded (yes/no) question. Then we can estimate the error due to the initial bid.

4.3. Double-bounded: the first bid question is followed by a second one, which depends on the answer to the first question. Let's say that the first bid amount is $20. If the answer to pay this amount for a determined environmental change is "yes," the next amount asked will be $30; if the answer is "no" to the first question, then the second question should ask for $10, for example. This method gives us more information than the single-bounded method, but the first bid influences the answer of the interviewee to both questions.

4.4. Multiple-bounded: each person has to answer "yes" or "no" to each of the several amounts presented to him/her for just one natural resource change. For example, a person might be asked: would you be willing to pay $1 to improve the quality of the water?, will you pay $2?, will you pay $6?, will you pay $15?, and so on. So we can determine the range where the interviewee stopped saying "yes" and started saying "no". This method is influenced by the order in which we ask the amounts. It has been found that there are a significant differences in the answers if we start asking the higher amounts first by comparison with asking first the lower ones.

5. Contingent activity. Hypothetical questions are asked about activities in this method to obtain data, which can be used as additional information in models based on actual behavior. So, this method is supplementary to others, and usually data obtained from it reflects the change in an environmental attribute. It can be used in methods like the travel cost method.

2.5.2. Conjoint analysis

Conjoint analysis estimates interviewees' acceptance of multiple commodities by asking them to rate, rank, or choose between different theoretical situations, each of which represents a level of an environmental service. This methodology is relays on a survey for evaluating consumer acceptance of multiple- attribute commodities (Roe *et al.* 1996). Within the conjoint analysis method there are three different models: the rating approach, the ranking approach and the choosing approach. In the rating approach, people rate each theoretical situation or commodities with a given scale (usually from 1 to 10). In the ranking approach, people are asked to state their preferences by establishing a rank order of a given set of theoretical situations or commodities. In the choosing approach, people are asked to choose one of the theoretical situations. Each commodity reflects a level of an environmental service (water quality, air quality, visibility are some examples) as well as other attributes of choice (entry fee, number of visitors per day, facilities of the area, etc.), and each attribute has different levels. Therefore, when there is a change in the level of one or more attributes we will have a different commodity to value. The value of the environmental services can be derived from rankings, ratings, or choices. The interviewee should evaluate at least two commodity descriptions, and one of them must be the *status quo* commodity or actual condition. Rating provides more information than the other two, giving a quantitative measure of people's stated preferences, though the other two may be easier to respond for the interviewee. Data will imply weights for each of the attributes. Roe *et al.* (1996) suggested that effective conjoint surveys must use contingent-behavior questions, so instead of asking, "Which commodity do you prefer?" we should ask, "Would you pay…"

All of the methods explained above have an economic perspective. The value of a good is based on its price in a real or hypothetical market context. Monetary indices focus on human-use value (whether consumptive or nonconsumptive), rather than other values of the good *per se* (intrinsic value). There are many other classifications of valuation methods from an economic point of view in the literature. The one proposed by Sinden and Worrell in 1979, based on characteristics of the benefits, provides a wide reference frame for locating amenity valuation methods. Figure 2.2 shows a compilation of all the methods presented by the authors. Some of these methods can be applied to the valuation of amenity resources, but others have never been used in this area. Consequently, there are no data available on which to comment. Some of the methodologies require market data to estimate values, in which case they cannot be used to estimate some amenity resources values.

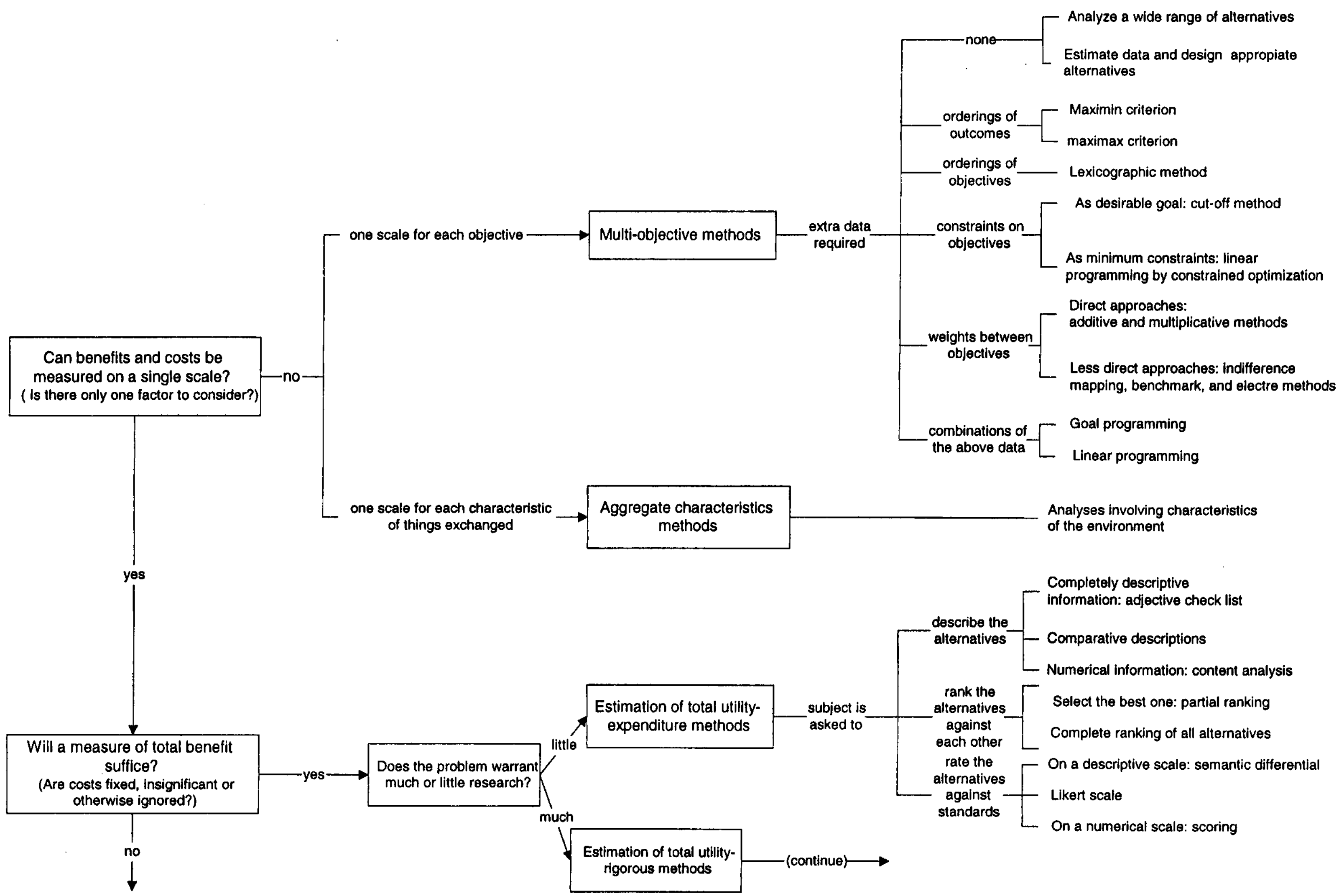

Figure 2.2: Methods of general valuation classified by characteristics of benefits. (Source: adapted from Sinden and Worrell 1979)

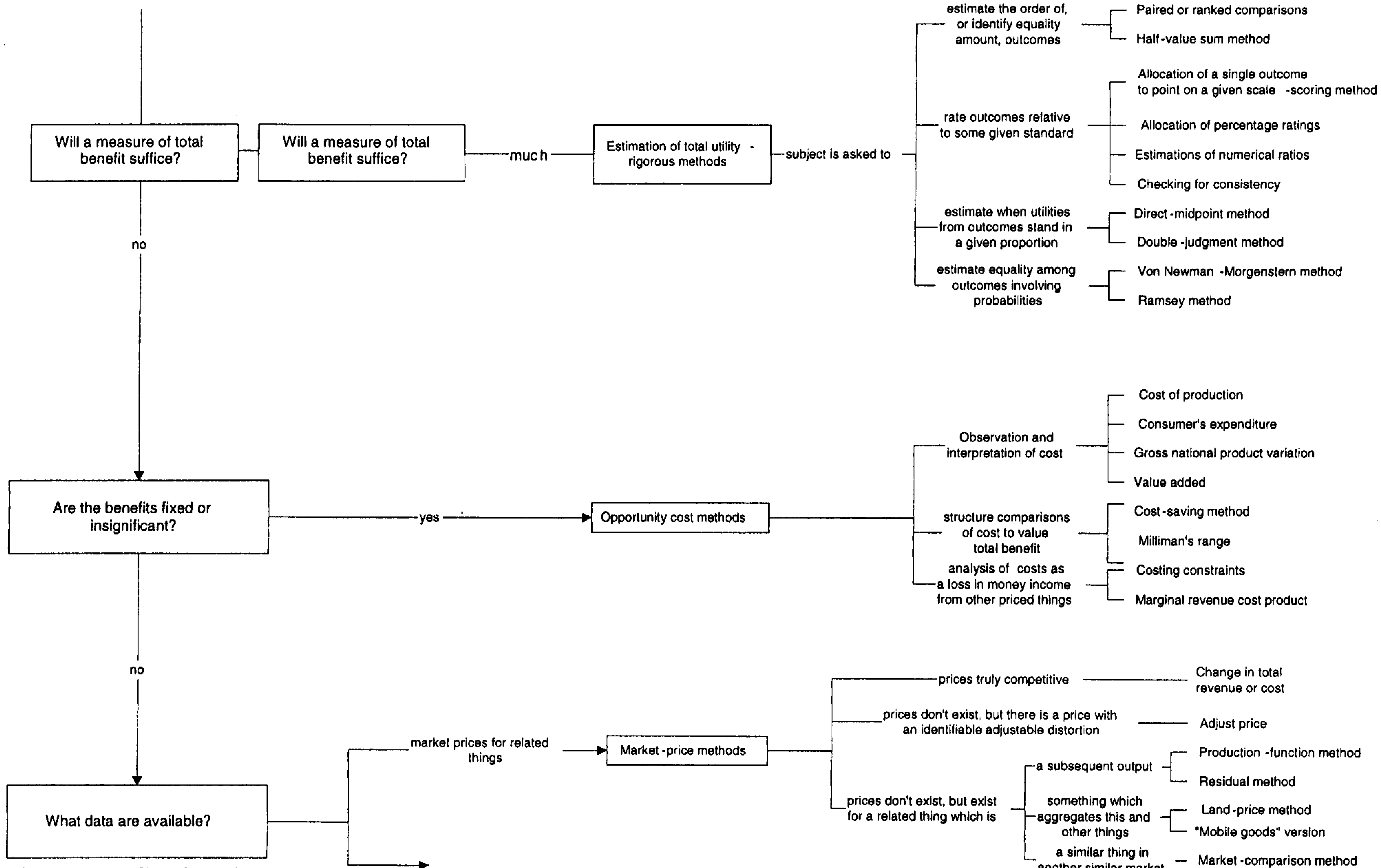

Figure 2.2.: Continued.

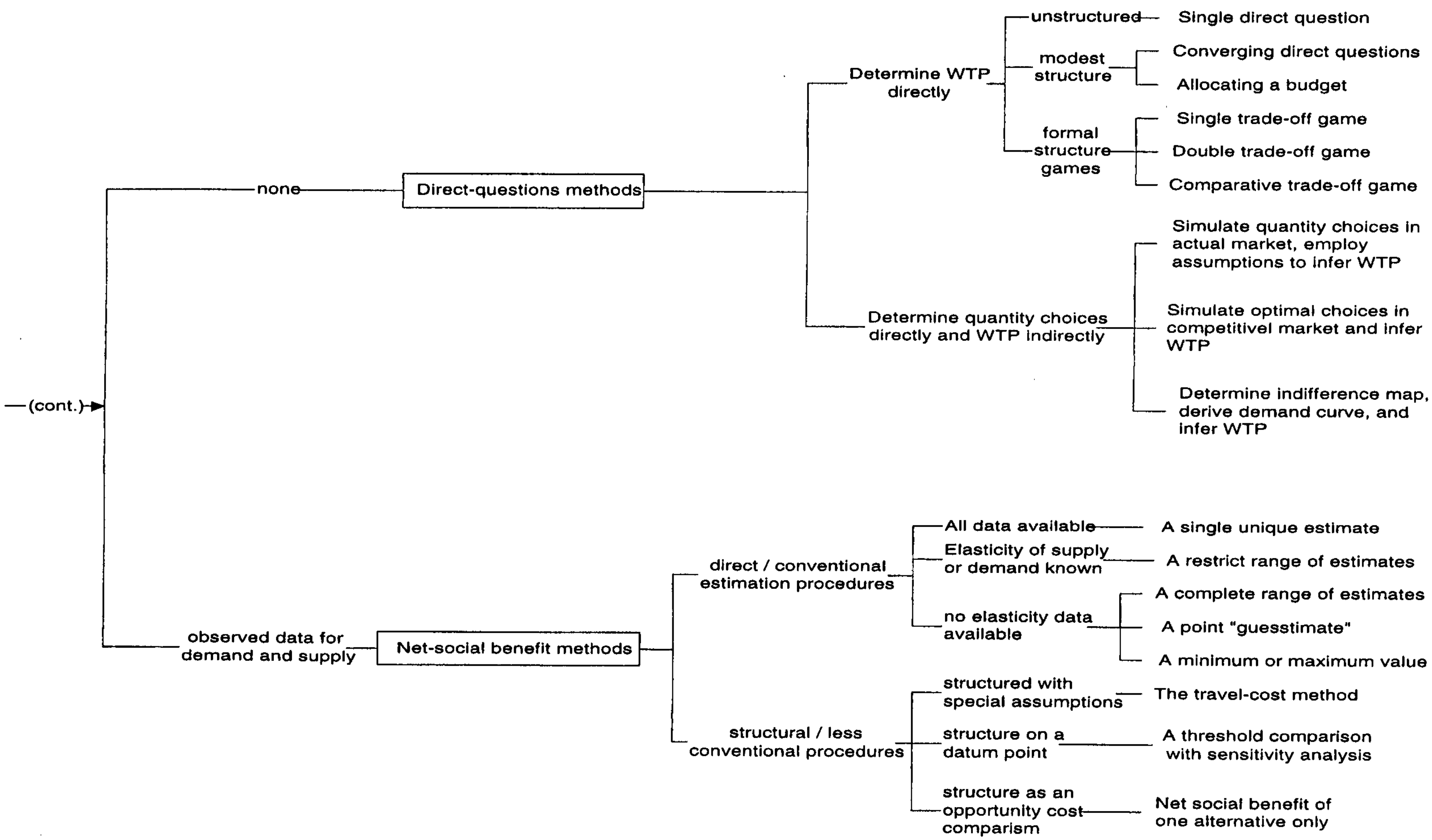

Figure 2.2.: Continued.

2.6. ADVANTAGES AND DISADVANTAGES OF THE METHODS

2.6.1. Travel cost method

The travel cost method relies on actual consumer behavior, but it does not provide information on how people feel about those resources that they would never consume or experience. It only calculates the recreational on-site use (use value) of the public good, without considering either the off-site use benefits (which, in some cases, are higher than on-site ones) or nonuse values. It also presents problems with valuation of travel time (in the zonal travel cost method), problems with the treatment of on-site time, and the incorporation of substitutes and site-quality information (Ward and Loomis 1986). The simple travel cost model does not consider whether a person has other reasons for taking a trip, or how much of the travel cost should be ascribed just to the site. One proposed solution is that, because it has been observed that people coming from further origins are more likely to visit multiple sites, all people coming further than 300 miles won't be considered in the study (Mendelson and Peterson 1988). The major disadvantage of the multiple-site travel cost method is that, instead of measuring a single distance from each individual origin, a multiplicity of distances must be measured.

2.6.2. Hedonic travel cost method

The hedonic travel cost method has several advantages. Instead of valuing a particular species of animal or a particular recreational aspect, this method is used to value a set of attributes that characterize both the biotic (vegetation type and size and wildlife) and abiotic (roads, campgrounds, and other facilities) attributes of a forest ecosystem. In addition to this, types of ecosystem attributes that are valued by this method are also attributes related with management decisions. Because value estimates

can be directly compared with management costs, management planning and decision making become easier (Holmes *et at.* 1995).

Hedonic property models are rarely used to estimate welfare demand due to the difficulty of estimating demand curves from the information obtained with this method. Even if the demand curve is estimated, the estimation error can be unknown since market attributes chosen to define instrumental variable equations are not fixed. But, it is possible to obtain some important information about marginal willingness to pay, or implicit prices, so as to know how the house price varies when there is an environmental change. The hedonic method assumes that estimated implicit prices are based on everything else being equal, which is very unrealistic in most cases. It is difficult to find two properties that differ only in the amenity quality level being studied. In addition to this, as Smith and Huang (1995) showed in their publication, "hedonic models are more likely to reflect aesthetics, materials and soiling effects" and, to some degree, perceived health effects (air quality, water quality), but the latter may well be incomplete. Estimated implicit prices should be used for public policy where management activities can improve a public good. The use of estimations in the private sector has an educational purpose for providing an idea about how the property price may increase if there is an improvement of a public amenity (Michael *et al.* 1996).

2.6.3. Contingent valuation methods

Contingent valuation methods dealing with what people say instead of what they do (real behavior) are not accepted by all scientists due to the fact that data used in these methods come from people's answers to hypothetical questions, rather than from observations of actual behavior. However, there are authors who argue that some of the

models based on what people say provide even more information than those based on what people really do.

> The hypothetical nature of referendum surveys makes it possible to gain more information than would be available by observing individual choice in most real-world markets or discrete choice settings. In real-world choice settings, it is typically the case that all individuals face the same set of prices for the set of alternatives from which they must choose.[...] Differences in responses must then be due to differences in individuals characteristics. But in a hypothetical referendum it is possible to present respondents in different randomly chosen subsamples with different referendum prices (Freeman 1993).

Some of the major problems in the use of hypothetical markets are due to the way questions are framed (Navrud 1990, Boyle *et al.* 1996). When someone is asked to express their willingness to pay for an environmental improvement that they consider to be rightfully theirs, his/her answer might be lower than if the same person is placed in the appropriate framework and questioning format of the environmental issue. We need to be aware that the questioning format influences welfare estimates. Moreover, contextual factors often significantly affect assigned values (Brown and Walsh, 1988).

Experiments to elicit assigned values must be carefully designed to represent the context to which results are to be generalized. If contingent valuation data are used in benefit-cost analysts along with actual market data, then a great effort is needed to demonstrate that comparability. Therefore, contextual factors as well as the design and realization of the interview play a very important role in contingent valuation. Results

obtained can be inconsistent with rational choice (embedding issue), such that respondents do not distinguish between small and larger scale environmental programs in terms of the WTP values. We can also obtain implausible CV responses, where the aggregated sample mean yields enormous dollar values for the good or program in question. Contingent valuation studies often fail to remind respondents of their budget constraints. We can obtain inadequate results due to respondents making uninformed decisions. Also the respondent must accept the information provided as fact if meaningful and reliable WTP estimates are to be achieved. There are also problems that arise when individual respondents feel environmentally supportive of any program and, as such, the WTP estimates for a specific program may be unreliable and indicate only a more general approval of the program ("warm glow" effect). The opposite effect can happen as well. People may disagree about paying for what they consider a "public" right. A good example could be found in a socialistic country, where it is assumed by the society that the government should take care of all environmental issues without questioning or asking more money from the society. People do not have to pay to reduce air pollution; industries are the ones that should reduce their emissions, and the government should establish laws to regulate pollution emissions.

Furthermore, psychological "loss aversion" should be considered. This involves the fact that, in practice, willingness to pay and willingness to accept have different values (the WTA value is usually bigger than the WTP value), though in theory they should have the same value. "People often seem to define their identities in terms of their rights, privileges, and possessions, so that the prospect of surrendering something after it has been possessed for a time is like losing a piece of the self, and provokes a strong

defensive reaction" (Schroeder and Dwyer 1988). Another explanation for this disparity is that willingness to pay is constrained by the consumer's budget, while willingness to accept has no similar constraint.

Another disadvantage of willingness to pay and willingness to sell questions in contingent valuation is that people may interpret these questions as requiring monetary amounts to express their changed utility. So people assign cardinal measures on utility instead of making measures along indifference curves (Mendelson and Peterson 1988). The contingent valuation method has the potential for estimating total willingness to pay for all the affected individuals. That is, it estimates not only the use value, as the travel cost method does, but also the nonuse values. No other economic method has been developed to do this.

It has been stated (Boyle *et al.* 1985; Mitchell and Carson 1989) that the starting point of the iterative bidding model, as well as the dichotomous choice models, does affect an interviewee's answer. This means that the amount of money of the first bid to improve environmental quality (determined by the interviewer) influences the respondent's final bids. Further studies reaffirm that "bid levels are not neutral stimuli and that bids should not be randomly assigned to respondents" (Boyle *et al.* 1997). The alternative to ask just their willingness to pay for this improvement brings problems, as well, due to the unfamiliarity. People are used to dealing with markets where they can compare prices and quality. Surveys using this form of question receive high rates of nonresponse to the valuation question and/or high proportions of very high or low stated values (Freeman 1993). However, Boyle *et al* (1996) stated that there is a difference between open-ended questions --"How much are you willing to pay to hunt a moose?"--

and dichotomous choice --"Would you pay $X to hunt moose?". Either open-ended answers underestimate values or dichotomous-choice overestimates them. Another problem is that the direct expression of values offers a potential for strategic bias: "Strategic bias results from conscious attempts by individuals to influence either their payment obligation or the level of provision of the environmental good through their stated valuations" (Freeman 1993). Bias must be inferred from our partial understanding of respondent behavior, or from the way we introduce the scenario in the survey. Mitchell and Carson (1989) described seven bias types that result from respondents being influenced by the interview situation, and/or scenario of the survey. In two types classified as "compliance bias", the respondent's WTP answer differs from his real WTP amount in an attempt to: a) comply with the expectations of the sponsor (sponsor bias), and b) please or be admired by the interviewer (interviewer bias). The other five types called "implied value cues" are: c) the influence of the elicitation method or payment vehicle (it may be increased by the tendency of "yea" saying starting point bias -already described), d) when a range of WTP amounts is given, it can influence the respondent WTP amount (range bias), e) the description of the good presents information about its relationship to other public or private commodities that influence a respondent's WTP amount (relational bias), f) the fact of being interviewed may indicate to the respondent that the amenity has value (importance bias), g) the order in which valuation questions for different goods or different levels of a good are presented may indicate to a respondent how those levels should be valued (position bias). Besides, there are potential sampling biases in contingent valuation surveys: h) when the population chosen does not represent those to whom the benefits and costs of the provision of the good will accrue

(population choice bias), i) when the sampling frame does not provide to every member of the population chosen a known and positive probability of being included in the sample (sampling frame bias), j) when the statistical estimations from WTP answers differ from population parameters on any observed characteristics related to willingness to pay (this may be due to nonresponse) (sample nonresponse bias), k) the probability of getting valid WTP amounts among sample elements with a specific set of observed characteristics is related to their value for the good (sample selection bias).

Success of the contingent valuation approach varies with the quality of the study. The lack of enough resources to conduct methodologically adequate contingent valuation surveys, and the lack of interviewer experience or training in carrying out sample surveys make this method prone to error (Mitchell and Carson 1989).

Freeman stated several advantages of the dichotomous choice model, as a hypothetical method based on "what people say". First of all, it places respondents in a familiar context where he/she answers yes or no. The individual just decides if he/she will purchase the benefit according to a fixed price, as in most markets. The format "take it or leave it" is less stressful to the respondent. Second, levels of not being involved in the study or nonresponse to the questions are lower since the questions *per se* are easier than asking "What would you be willing to pay?" In addition to this, strategic bias is minimized.

2.6.4. Conjoint analysis.

In conjoint analysis, the ranking and choosing approaches seem to be easier than the rating approach. The presentation of a given range amount of money instead of a fixed number is more understandable, especially for people unfamiliar with these

methods. Moreover, it is even less complicated for the individual to choose between different alternatives. However, the rating approach provides a quantitative measure of people's preferences. Conjoint analysis is not the solution to contingent valuation problems. Conjoint questions seem to have the same advantages and disadvantages as contingent valuation ones. However, the fact that in conjoint surveys the interviewee has to rate two commodities, the *status quo* and the proposed alternative commodity, to construct the dependent variable based on rating differences, removes the centering noise effect from the data --one person may rate the *status quo* commodity as 2, while another may rate it as 6 (Roe *et al.* 1996).

In general, Daniel and Swanson (1988) stated two major problems with the use of indirect methods to validate a contingent valuation measure. First, because indirect estimates cannot be regarded as measures of the true willingness to pay amount, they cannot be used as absolute criteria for the validity of a contingent valuation measure. Second, indirect methods are restricted to a subset of amenities, and cannot be applied to all public goods as contingent valuation methods can.

It seems that contingent valuation can estimate direct use values (consumptive, nonconsumptive and indirect use values) in a precise way based on public opinion, while more research is needed to determine whether contingent valuation can provide accurate estimates of nonuse values or so called existence values (Boyle and Bishop 1987).

Mitchel and Carson (1989) concluded in their articles that the results of contingent valuation methods and other nonmarket assessments must be interpreted and applied with considerable caution. Daniel and Swanson (1988) added to these comments that what is

less clear is how decisions about public amenity resources should be made in the meantime.

Despite all contingent valuation problems, a panel of six economists selected by the National Oceanic and Atmospheric Administration concluded that contingent valuation provides "useful information" if administered in conformance with specified guidelines (Arrow *et al.* 1993).

2.7. VALIDITY OF VALUATION METHODS

According to Harris *et al.* (1988), the validity of a measure "...refers to the extent to which it actually measures the theoretical construct it is purported to measure". There are three types of criteria that should be tested to establish the validity of psychometric measures: content validity, criterion validity, and construct validity (Novick 1985).

Content validity deals with how much a measure reflects the domain of a construct. In nonmarket valuation methods, the construct is the value of a good derived from market-like structures. Therefore, the domains are: the market structure created by the valuation method, the way that market and elicited values are presented, and the definition of the attributes and qualities of the good (Harris *et al.* 1988).

Criterion validity measures how much a measure of a construct is related to other measures (actual markets prices, for example). Construct validity estimates how much a measurement strategy measures an abstract construct (e.g. the value placed on clean air). This is perhaps the most important one since it indicates the usefulness of the measurement strategy.

The best way to validate any estimated measure is to compare it with the real value. But, this information is not available, otherwise there is no reason to estimate this value in the first place. Freeman (1993) proposes two options for assessing validity. The first one involves seeing if all known sources of bias have been removed or avoided through a precise design of the survey instrument and scenario. The second option proposes an empirical analysis of the answers to estimate whether they are consistent with economic theory, or to compare them with estimations obtained from other methods.

The construct validity of the simple travel cost method focuses on the fact that travel costs represent the price of the site. This implies many considerations described previously, which are in most cases unrealistic. For example, in most cases the purpose of traveling not only involves obtaining a good (in this case a recreational experience), we also travel because we enjoy the experience of traveling. The construct validity of the hedonic price method implies the definition of four important factors: a correct hedonic price function, accurately estimated demand and supply curves, the reality that amenity resources are not market goods, and assumptions about the nature of human decision making. Finally, the contingent valuation construct validity rests in the fact that people's information processing and decision-making processes limit the accuracy of the method's results (Harris *et al.* 1988).

Chapter 3. OUTDOOR RECREATIONAL DEMAND AND SUPPLY ANALYSIS IN THE STATE OF MAINE. MANAGEMENT RECOMMENDATIONS FOR THE BIGELOW PRESERVE.

3.1. CHAPTER ABSTRACT

This chapter provides management guidance for recreational opportunities at the Bigelow Preserve, with the goal of contributing to a highly diverse Recreation Opportunity Spectrum (ROS) at the regional and state level. A large-scale analysis of the outdoor recreational supply provided in the State of Maine helped identify management needs at the local level for the Preserve. The research focused on the ROS provided by the Bigelow Preserve (site level of analysis) and on the current and potential recreational activities suitable for the area. The author compared results to studies on future recreational demand. This analysis revealed that, although 74 percent of multiple-use public acreage has been classified as undeveloped, the number of public sites presents a relatively balanced distribution: 40 percent of the sites are developed, 22 percent semi-developed, and 38 percent undeveloped at the state level. At the regional level of Western Maine, the percentage of developed sites decreases to 36 percent and semi-developed sites to 18 percent, while the percentage of undeveloped sites increases to 46 percent. I concluded that the Bigelow Preserve should retain its remote and undeveloped character while providing primitive and semi-primitive recreational opportunities. While the Preserve has a social carrying capacity that allows for a potential increase in the number of users per year, further analysis should focus on physical carrying capacity for all areas with access. Due to predicted future demand trends, managers should promote activities such as canoeing, kayaking, hunting, fishing, and cross-country skiing within both

primitive and semi-primitive environments of the Preserve. These findings form the basis of management recreational goals in later chapters.

3.2. INTRODUCTION

Forest managers and decision makers need accurate information on how and to what extent forests benefit different sectors of society. Tradeoff analysis among different management plans can provide a decision-making framework to facilitate strategic planning. Recreation represents a very important component in the process of developing plans for public lands. However, when dealing with recreational analysis, we need to consider the different scales at which management decisions will impact recreational and other forest uses, as well as how outdoor-recreation demand and supply trends influence our decisions.

In today's society, competition for different uses of our forest resources causes disagreements and controversies about how these resources should be managed. Although outdoor recreation can be integrated with other uses of the forest such as timber and non-timber production, and wildlife habitat protection, it can also compete with them. Outdoor recreation is a concept that embraces the different ways of outdoor enjoyment or experiences. Recreational uses may conflict with each other and, in some cases, are incompatible within the same area. This conflict arises when certain recreational benefits depend on specific activities and resource settings that are not compatible or interfere with other uses. For example, the noise of a boat engine or the noise caused by logging operations might ruin the opportunity of someone looking for solitude.

Conflict originates with the factors that define recreational settings. Manning (1999) defined three broad categories of these factors: environmental, social and managerial. Each of these three categories varies along a scale (Table 3.1). Environmental conditions perceived by the observer vary with different stages of "natural" appearance. Silvicultural practices and other management actions have different ways of appearing more or less natural to people. A natural setting does not necessarily imply no management actions, just no visual perception of the management actions by the regular user. Visitor density can be controlled through several mechanisms, such as parking spaces, entry fees, permits, etc. The number of campsites, campsite types, facilities, trail maintenance and other management conditions (recreational or non-recreational) determine the degree of development.

Natural	← Environmental conditions →	Unnatural
Low-density	← Social conditions →	High-density
Undeveloped	← Managerial conditions →	Developed

Table 3.1: Framework for environmental, social and managerial conditions.
(Source: adapted from Manning 1999: 191).

The combination of environmental, social, and managerial conditions that give value to a place define the recreation opportunity setting (Clark and Stankey, 1979), which not only limits the type of recreational activity (camping, hiking, fishing, snowmobiling, skiing, and others) but also influences the user's degree of experience satisfaction. The different combinations of environmental, social, and managerial conditions define a diversity of recreational opportunities (Manning, 1999). However, though the recreational settings influence all recreational experiences, the visitors are the ones who produce the recreation experiences (Driver and Brown, 1984). Managers can

only provide the most suitable scenario for that experience to happen, but cannot ensure that it will.

The Recreational Opportunity Spectrum (ROS), developed and implemented by the USDA Forest Service, is a classification framework to quantify the potential for multiple recreation opportunities, and to integrate recreation into forest management planning (Douglass, 1993). ROS is based on the different environmental, social and managerial conditions that occur in the forests and relates to the degree of perceptive human influence. This management tool, which allows managers and policymakers to allocate and manage opportunities for recreation, recognizes that "experiences derived from recreation are related to the settings in which they occur" (Manning, 1999).

The demand for different recreational uses and opportunities raises the question of who should benefit from a particular natural area, and by how much. Managers seek the optimal balance according to social demand. The proposed solution to conflicting recreational uses has been to adopt a "diverse approach." By offering a range of recreational opportunities, one can meet more outdoor preferences, ensuring that minorities' preferences will have a place in management plans. The difficulty lies in the scale at which we should apply this diverse approach in order to ensure quality of recreational experience. Not every area should provide all possible recreational opportunities. Benefits from managing for a diverse approach derive from the system as a whole, not necessarily from each unit of the system. Managers and planners should evaluate the outdoor recreational supply and demand at the national, state, and local level. Places with unique characteristics, which make them more attractive, should have management plans that favor the conservation of such characteristics.

Clark and Stankey (1979) explained that the achievement of a diverse ROS is an indicator of outdoors quality. Manning (1999) defined quality from two perspectives. At the individual level, quality represents the degree to which recreational opportunity achieves people's needs. At the societal level, quality represents the provision of diverse recreational opportunities.

Furthermore, diversity "insures the flexibility necessary to mitigate changes or disturbances in the recreational system stemming from such factors as social change ... or technological change" (Clark and Stankey, 1979). New resources appear as societies find new uses of the forest. Human evolution and changes in society lead to previously undiscovered uses of our forests. Zimmerman (1951) argued that "knowledge is the mother of other resources." Resources result from the interaction between the environment and humans. New ways of enjoying the outdoors appear as technology moves forward. Thanks to technological advance, today we can enjoy areas covered by snow in a very different way than five decades ago through the use of snowmobiles. In the future, new forms of outdoors enjoyment will appear and a diversification of recreational opportunities will help to accommodate new needs.

Human behavior and preferences vary greatly among individuals. Some people enjoy the outdoors when they share this experience with others and, in the same way they socialize in other environments, they enjoy socializing in natural areas. However, other people's ideas of enjoying outdoor recreational activities imply solitary experiences where they establish a particular relationship between themselves and nature without the influence of other humans. People's tastes change over time and among the groups with whom they share experiences. The same individual who goes hunting with an all-male

group will behave differently than when he is taking his family fishing. Furthermore, these two groups will have different auxiliary activities and make different demands on the resource and recreation facilities. In other words, there is something in the nature of a recreational group that structures the group member's behavior (Burch 1964).

Conflicting activities are the result of conflicting experiences. Recreational experiences demanding more natural appearance and undeveloped areas with very few users are more restrictive than areas less natural and more developed with a greater number of potential users. For example, a motorboater seeking a fast-speed experience in a lake is less likely to be bothered by a canoeist than the same canoeist seeking solitude is bothered by the motorboater. Numerous studies (Lucas 1964a,b; Brewer and Fulton 1973; Knopf *et al.* 1973; Knopp and Tyger 1973; Stankey 1973; Driver and Basset 1975; McCay and Moller 1976; Lime 1977; Gramann and Burdge 1981; Adelman *et al.* 1982; Jackson and Wong 1982; Moore and McClaran 1991; Watson *et al.* 1991a; Watson, et al. 1991b; Ivy *et al.* 1992; Watson *et al.* 1994; Blahna *et al.* 1995; Ramthun 1995; Vaske *et al.* 1995; Jacobi *et al.* 1996) suggest that the greatest conflicts happen among the following groups:

- canoeists, motorboaters, and anglers;
- hikers, motorcyclists, horseback riders, bikers, and stock users;
- hunters and non-hunters; and
- cross-country skiers and snowmobilers.

3.3. STUDY AREA

3.3.1. Management environment[1]

In June 1976, a public referendum enacted the law titled "An Act to Establish a Public Preserve in the Bigelow Mountain Areas", which created the Bigelow Preserve. The Preserve was created as a response in opposition to an "Aspen of the East" proposal to develop the Bigelow Range into a ski resort. The Department of Conservation and the Department of Inland Fisheries and Wildlife are the agencies authorized to develop the management plans for the Preserve. However, the Bureau of Parks and Lands[2] is the public agency that has overall management responsibility for the Preserve. The Bureau of Forestry and the Department of Inland Fisheries and Wildlife are also involved in the management process. In addition, the volunteers of the Maine Appalachian Trail Club (MATC) maintain and manage the Appalachian Trail (AT) and an essential system of side trails and campsites in the Preserve.

The Bigelow Preserve was established to set aside land to be retained in its natural state for the use and enjoyment of the public, while protecting some important and fragile habitats from being destroyed (Bureau of Public Lands 1989). The Bigelow Act requires that recreational management will favor non-motorized, low intensity uses. The current (1989) management plan focuses mainly on semi-remote recreational opportunities, providing uses such as hiking, camping, hunting, fishing, boating, and "primitive" cross-country skiing where skiers have to open their own trails. Snowmobiling is the only

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[1] Information compiled from the 1989 Bigelow Preserve Management Plan.

[2] The Bureau of Public Lands and The Bureau of Parks and Recreation merged into the Bureau of Parks and Lands in 1995.

recreational motor-vehicle use. The rest of the motor vehicles, including those for timber harvesting purposes, are restricted to roads designed for their use.

The Preserve administration must also meet the requirements for multiple-use management set forth in 12 M.R.S.A. §585 and consistent with the Integrated Resource Policies adopted December 1985 by the Bureau of Public Lands. The 1989 management plan accounts for the following uses: wildlife, aesthetics, recreation, protection of fragile habitats and species, and timber production. All land use activities within the Preserve far exceed the standards of the Land Use Regulation Commission (LURC).

Timber harvesting practices must be approved by the Bureau of Forestry and be consistent with the area's scenic beauty and natural features. No structures such as buildings, ski lifts, or power transmission facilities are allowed, except for open trail shelters, temporary facilities for timber harvesting purposes, or small structures consistent with the undeveloped character of the Preserve.

3.3.2. Recreational environment

The Preserve is divided into two recreational zones: the Backcountry zone and the General Recreation zone. The Backcountry zone occupies two thirds of the area, and includes all the major hiking trails, all high altitude areas, most of the fishing opportunities and 44 percent of the campsites. The recreational opportunities provided in this area are:

Hiking trails. In the entire Preserve there are 33.2 miles (53.4 km.) of hiking trails. About 18.7 miles (30 km.) of Appalachian Trail (AT) crosses the Preserve from South to East. The AT is not managed by the Bureau of Parks and Lands, but by volunteers of the

Maine Appalachian Trail Club (MATC). It is surrounded by a 100-foot (33 meters) buffer zone where no timber cuts are allowed. Most of the hiking use is concentrated on the AT, which follows along the trunk line of the Bigelow Range, and the Firewardens' Trail. Besides, there are three more major trails: the Safford Brook Trail, the Horns Pond Trail, and the Range Trail. The MATC coordinates volunteers who maintain the 33.2 miles of trails at no cost to the public.

Campsites. The current management plan of the Preserve (Bureau of Public Lands, 1989) considers camping as a secondary activity to hiking, fishing and hunting. Within the Backcountry zone, there are two of a total of nine primitive campsites --four no-fire campsites spread along the trunk line and two of the five campsites or lean-to's in the Preserve. Unauthorized camping occurs in random places due to full existing sites or lack of time to arrive at destination. There are also sites along Flagstaff Lake and Huston Brook Pond.

Snowmobile Trails. According to the Bigelow Act, the only authorized recreational motor vehicles traveling off existing roads are snowmobiles. There are 23.5 miles (37.5 km.) of winter trails, which are maintained by the local snowmobile club and the Town of Eustis though a matching grant program with the Bureau of Parks and Lands. Snowmobilers also use some of the logging roads, and randomly develop trails to access Flagstaff Lake. These trails are in areas zoned Backcountry and General Recreation.

Cross-country Ski. There are no designated cross-country ski trails in the Preserve, but all unplowed roads are open to skiing. This opportunity represents a quite primitive cross-country ski use where the skiers have to be experienced and be able to open their own trails in the snow and, in the case of an overnight stay, be able to deal with cool

temperatures. A proposal of the Ski Touring Center in Carrabasset Valley to expand and maintain new cross-country trails in the Preserve is still a debated issue. To create a cross-country ski trail system will create a competitive situation between two types of users: those who search for primitive cross-country skiing, where trails are not groomed and there are no signs of development, and those who prefer a "security blanket", where trails are groomed and there are nearby places outside the Preserve where they can find meals prepared and a warm place to stay.

Boating. There is no motor-boat access and no launching ramps in the Preserve. Outside of the area, Flagstaff Lake has two boat launches at the West and East sides. The use of non-motorized boats from the Bigelow shore is allowed and possible. In the Eastern side, the road allows access to the shore where canoes, kayaks and small rowing boats can be carried to the water.

The General Recreational zone includes those areas with vehicle access. Some trailheads and campsites are in this zone. Currently, there are no developed recreational facilities such as showers, water and power hook-ups, or ball fields.

3.4. ANALYSIS OF RECREATIONAL USE LEVELS AND OPPORTUNITIES IN THE BIGELOW PRESERVE

Managers[3] of the Preserve estimate that the present recreational use has doubled in the last 12 years. Today, their estimations reveal that there are between 20,000 and 22,000 recreational users per year. Around 10,000 are estimated to be hikers (including

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[3] Personal communication from Steve Swatling, Bigelow Preserve's Manager, August 2001.

skiers), 8,000 snowmobilers, 2,000 hunters and anglers, and another 2,000 are campers that do not hike and people driving around the area.

The majority of the hikers, around 9,500, visit the Preserve between May and September. Assuming a uniform user distribution during this period there are around 62 visitors per day, which represents two users per trail mile per day. Twelve years ago, use levels of the Preserve were significantly lower, between 0.62-0.83 users per trail mile per day. Winter use represents "primitive" (without groomed trails) cross-country skiing and hiking activities. There are two types of winter users in the Preserve, those who spend at least all day hiking and cross-country skiing along ski trails that they open themselves, and might camp overnight (managers estimate that the level of use is around 100 users per year), and day users who spend a few hours skiing (between 300 and 400 users per year). Users of camps with vehicle access and drivers that enjoy wildlife from their cars and short stops represent a total of 2,000 visitors per year. The same number accounts for hunters and fishermen.

Shechter and Lucas (1978) developed a simulation model, the Wilderness Use Simulation Model, which assessed the carrying capacity of wilderness lands. Taking into account the author's use levels that ensure solitude, trail use with an average spacing between parties (group of people traveling together) of one-half mile, the maximum number of parties per day (or social carrying capacity) will be given by multiplying the total number of trail miles by the considered spacing between parties (half mile). Hence, the Preserve can provide a social carrying capacity level of 63.2 parties per day. Using the group size distribution (Table 3.2) of Shechter and Lucas' study in the Desolation

Wilderness (CA), the maximum social carrying capacity level can also be expressed by 222 visitors per day, which is above the present use level (62 visitors per day).

However, Shechter and Lucas' estimated social capacity level for a wilderness area in the late 1970's can only be interpreted as a reference point to compare current use. Many social and economic factors, as well as social recreational preferences, have changed since then, and these estimations do not account for the influence of other recreational uses on hiker use. In addition, the assumption of number of users equally distributed between May and September is not accurate. But, even if we double the number of users in July and August, the number of users per day (124) would still be half of Shechter and Lucas' estimation of maximum social carrying capacity.

We conclude that, theoretically, the campsites in the Preserve are sufficiently isolated, and that the current use of trails has not reached the maximum social carrying capacity level. This information should be verified with an on-site study to monitor campsite conditions and the actual numbers of users at each site, and to evaluate the degree of user satisfaction with respect to their solitude experience through a visitor survey.

Number of persons per party	**Percent of total**
1	8
2	39
3	14
4	15
5	9
6	5
7	2
8	2
9	1
10	1
11-15	2
16-25	1
Missing	1

Table 3.2: Group size distribution for the Desolation Wilderness (CA).
Source: Schechter and Lucas (1978).

Physical carrying capacity also influences the design of future management plans to protect ecological goals. One of the management goals of the Preserve is to protect some important fragile habitats. The combination of alpine and subalpine vegetation with a high elevation pond represents a fragile zone with high ecological value. Bigelow's mission of protecting important and fragile habitats must be a priority goal when establishing levels of physical carrying capacity in recreational plans. More information is needed to determine the Bigelow Preserve's physical carrying capacity and, indeed, whether the Preserve can admit more visitors per day without ecologically impacting the area.

In an attempt to estimate the recreational opportunities currently provided in the Preserve, we defined a ROS (Appendix A) modified from the Forest Service's ROS (Douglass, 1999) to fit the current managerial and biophysical characteristics of the area. Only four of the six categories defined in the Forest Service's ROS were adopted. The "primitive" recreational opportunity ensures a high probability of experiencing solitude, freedom, closeness to nature, tranquility, self-reliance, challenge and risk with a natural appearing environment and low interaction between users. This recreational opportunity requires a minimum size of 5,000 acres and distance from all roads of at leas 2 miles. The "semi-primitive non-motorized" opportunity provides a fairly high probability of achieving the same experiences as the primitive category, but does not ensure it. There are fewer restrictions in size (larger than 2,500 acres) and degree of remoteness (at least half mile from all roads) than for the primitive category, and some setting modifications are acceptable. The "semi-primitive motorized" opportunity provides a moderate

probability of experiencing solitude, closeness to nature, and tranquility, as well as a high degree of self-reliance, challenge and risk in using motorized equipment. It has fewer restrictions in degree of remoteness (within half mile of primitive roads or trails used by motor vehicles) than the previous category and a low concentration of users, but often evidence of others on trails. The "roaded natural" opportunity provides the chance to affiliate with other users in developed sites but with some chance for privacy. Self-reliance on outdoor skills is not necessary and there is little challenge and risk. This category has no size requirements, the modifications of the natural settings are acceptable, and access and travel is motorized. Due to the undeveloped nature of the Preserve, I did not include the "roaded modified" and "rural" categories. Figure 3.1 shows the current supply for each category. The number of acres corresponding to the "roaded natural" class is so small that it translates into 0% in Figure 3.1. The land percentages are nearly the same for the primitive (24%) and semi-primitive motorized (23%) classes, and semi-primitive non-motorized accounts for more than half of the total area (53%). Map 3.1 shows the spatial distribution of defined ROS area in the Preserve.

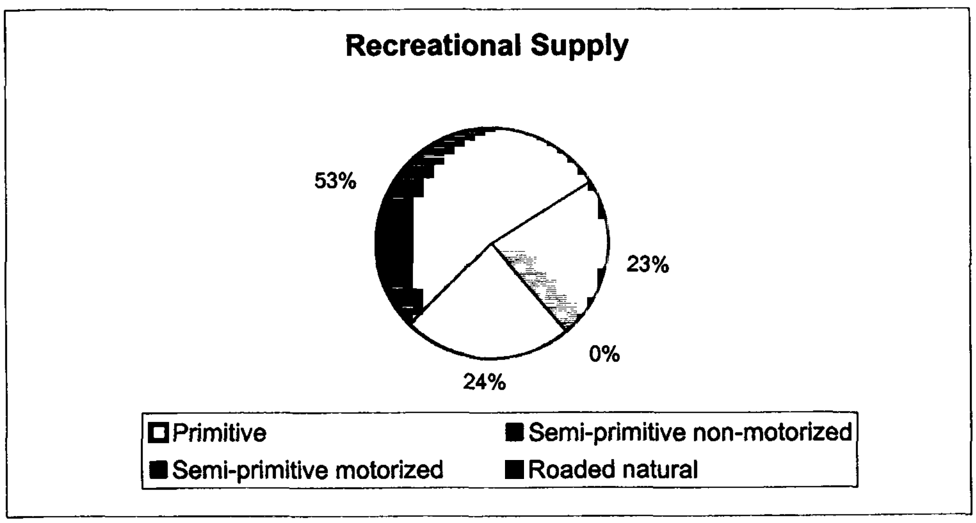
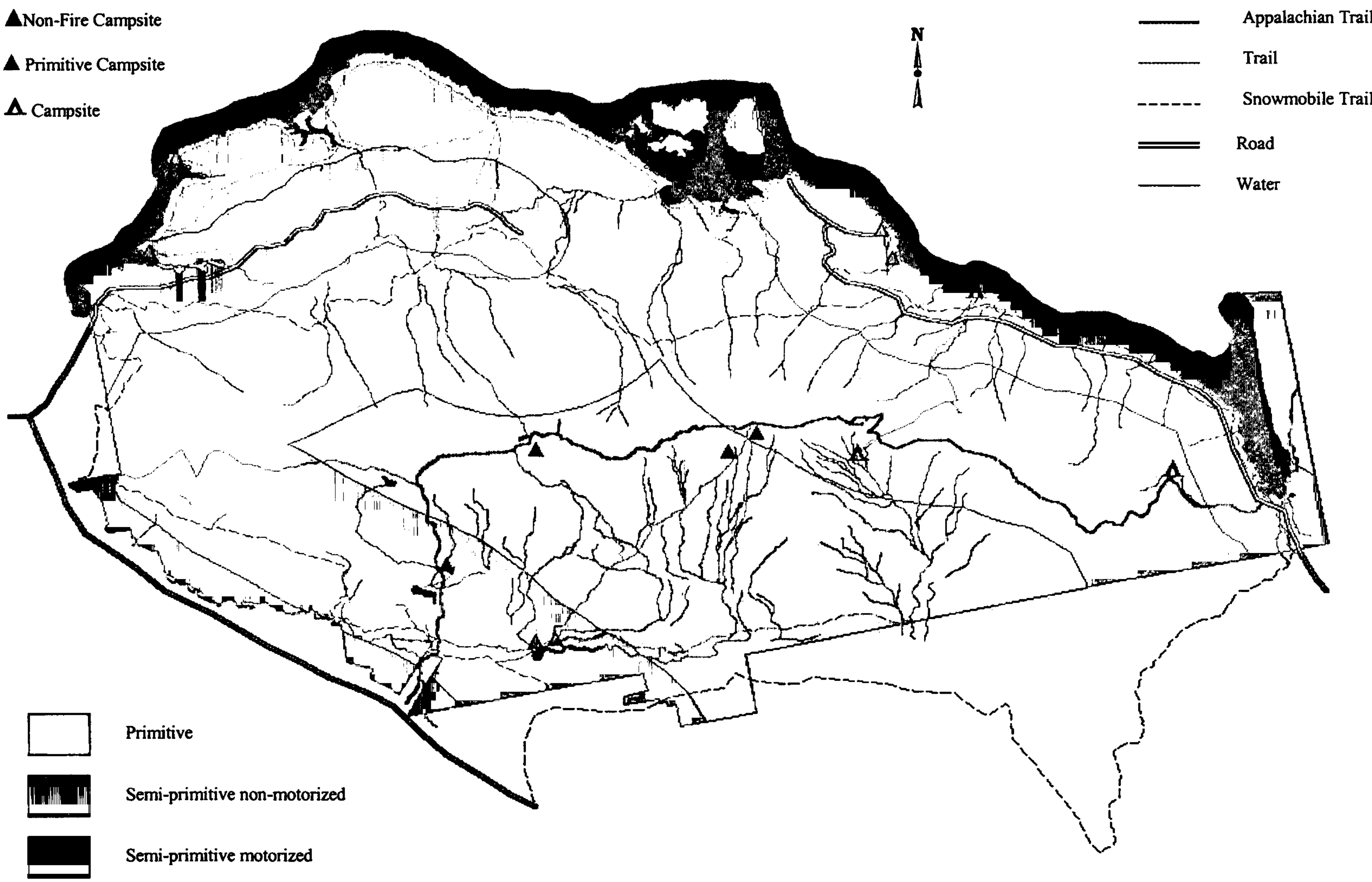


Figure 3.1: Recreational opportunities provided by the Bigelow Preserve (in percentage of total acres).



Map 3.1: Potential zones for primitive, semi-primitive non-motorized and semi-primitive motorized recreational use in the Bigelow preserve.

3.5. ANALYSIS OF RECREATIONAL OPPORTUNITIES SUPPLY IN THE STATE OF MAINE.

The State of Maine provides two major, general, geography based outdoor recreational opportunities: developed areas (majority existing in the southern and central coast regions of the state), and remote areas (in the western, eastern and northern regions). However, there are some developed facilities in inland Maine and some remote opportunities on the coast. Non-residents are largely attracted to the first region, while remote areas are more used by residents (Bureau of Parks and Recreation, 1993).

Our study focuses on recreational opportunities supplied by public multiple-use managements units, like the Bigelow Preserve. However, we should also consider the opportunities that the rest of the forest lands (privately owned parcels, State historic sites, and federal and state parks) offer to the public. The Appalachian Trail (AT) provides 300 miles of hiking trails across 32,000 acres of land. Acadia National Park (ANP) constitutes 47,633 acres of highly managed public land, providing a wide range of developed facilities, as well as remote and non-remote recreational opportunities. Although ANP provides a few less developed opportunities, the majority of the land is managed to accommodate over three million visitors every year. The high number of visitors is not comparable with any other public lands in the State of Maine. As in other developed recreational areas, the natural appearance has been modified by the construction of structures and facilities that accommodate users' needs (toilets, changing rooms, road network, bridges, information centers, stores, etc.)

Baxter State Park, a wilderness area of 202,064 acres, provides opportunities for hiking, mountain climbing, and camping. There are 180 miles of hiking trails, more than

twenty outlying sites, and ten campgrounds with facilities including lean-tos, tenting space, bunkhouses, fireplaces, and picnic tables. The fifty-five miles of narrow roads prohibit travel with large trailers. Canoes are available for rent. The park presents remote and semi-remote areas suitable for primitive, semi-primitive non-motorized, semi-primitive motorized, and roaded natural recreational opportunities (according to the ROS defined by the USDA Forest Service—Douglass 1999). Although the park's size allows a potentially large number of users to visit the area, the number of parking spaces available restricts its access. There is no correlation between the number of acres and the number of users allowed per day. There are areas restricted to public access and the five percent of the Park that provides developed use (cabins, campgrounds) is concentrated in specific sites. Therefore, Baxter State Park provides a fixed amount of recreational supply not correlated to its size.

The private sector supplies the majority of the facilities (see Table 3.3 and Figure 13.2) for: snowmobiling (97% of trail miles), camping (92% of sites), horseback riding (85% of trail miles), ATV riding, boating (81% of dock capacity), cross-country skiing (67% of trail miles), and freshwater swimming (60% of beach feet). These numbers are not surprising if we consider that 96 percent of Maine's forest lands are privately owned. However, public lands account for two thirds of the supply for hiking (63%) and picnicking (62%). Information for other uses is not readily available (Bureau of Parks and Recreation, 1993).

In 1993, 1,163,992 acres were available for outdoor recreation, with about half of them (523,200 acres) today managed by the Bureau of Parks and Lands (Bureau of Parks and Recreation, 1993). These public lands, classified into state parks, public reserved

lands, and state historic sites, scattered across the State of Maine (see Map 3.2) represent 2.6 percent of the state's 20,393,928 total acres, and provide a wide range of recreational opportunities.

	Federal	State	Private	County	Total Supply
ATV riding (miles)	0	25	146	1	172
Camping (sites)	278	1669	24602	247	26796
Boating (dock capacity)	0	22	1696	379	2097
Cross-country ski (miles)	127	89	907	178	1301
Hiking (miles)	556	231	484	39	1310
Horseback riding (miles)	43	37	498	6	584
Picnic (tables)	299	2856	2927	1509	7591
Snowmobile (miles)	140	186	10588	16	10930
Swimming (feet of beach)	1120	10675	59641	28228	99664

Table 3.3: Supply of recreational activities by jurisdiction.
Source: Bureau of Parks and Recreation (1993).

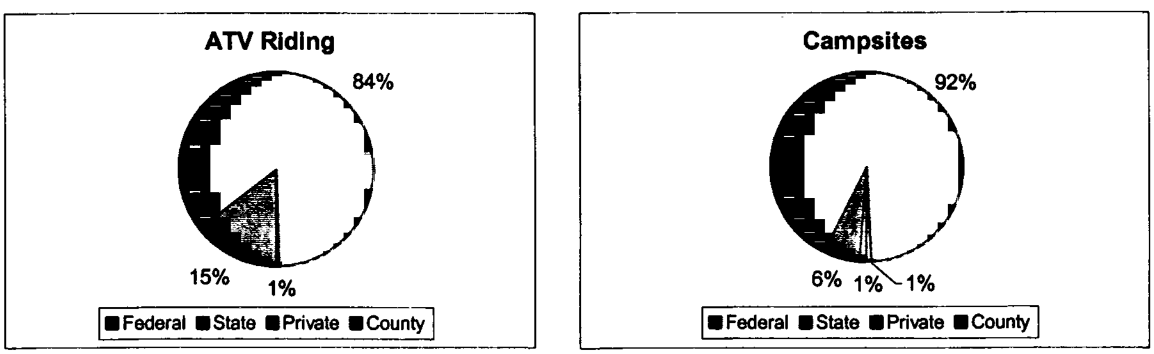


Figure 3.2: Distribution of ATV riding, camping, boating capacity, cross-country skiing, hiking, horseback riding, picnicking, snowmobiling, and swimming activities by jurisdiction
(Source: Bureau of Parks and Recreation, 1993).

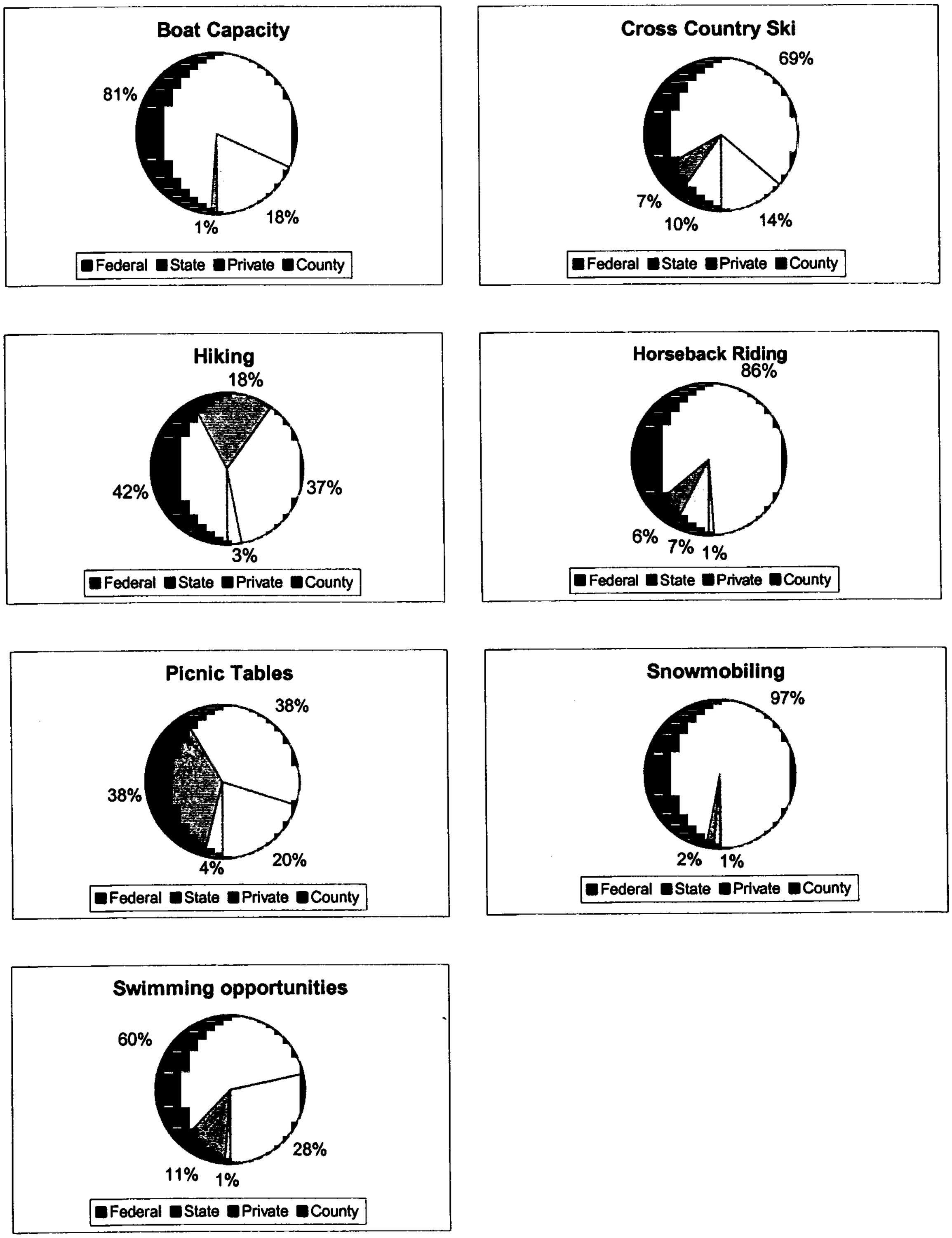
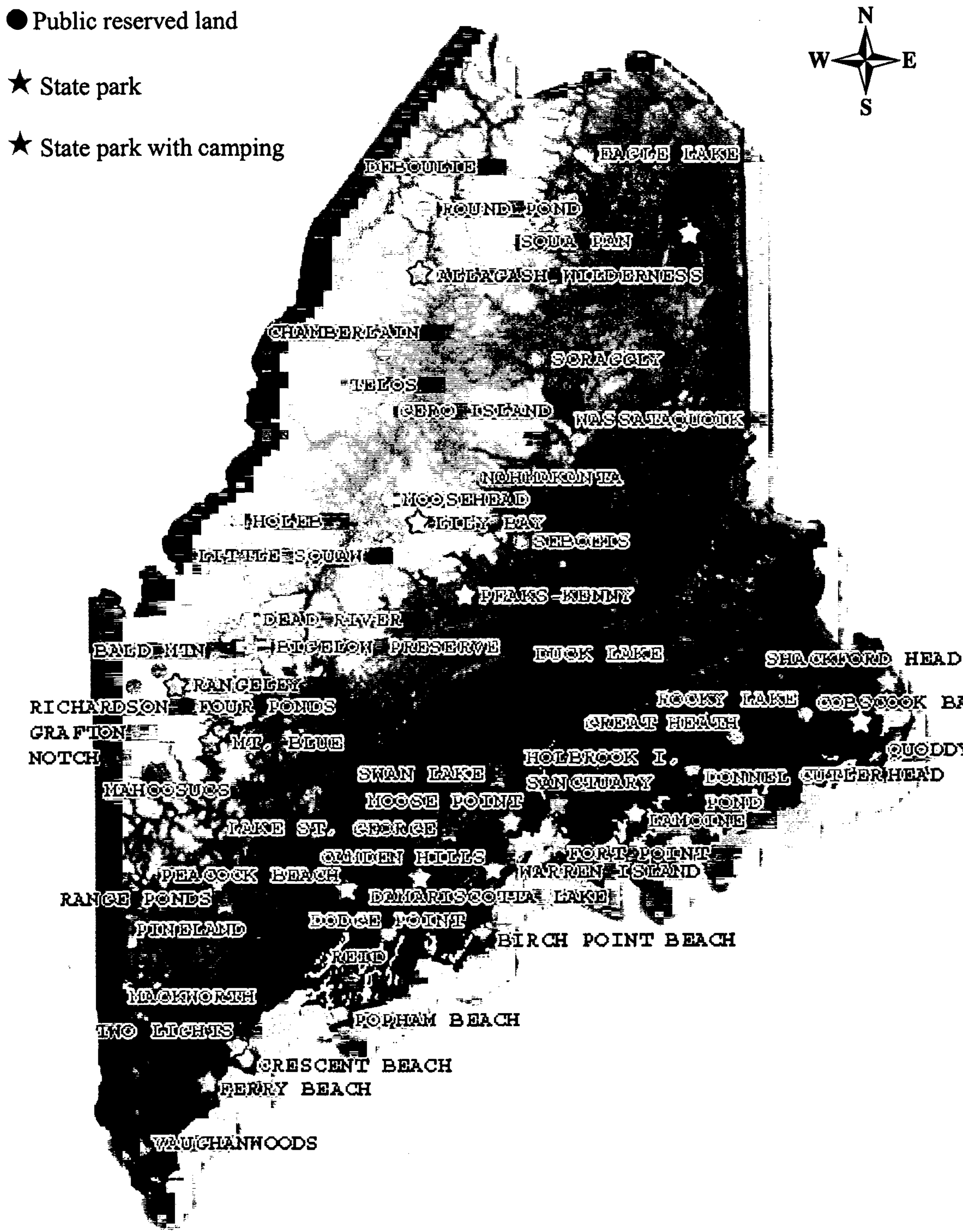


Figure 3.2.: Continued.



Map 3.2: Location of Maine public lands excluding Acadia National Park and Baxter State Park.
(Source: Bureau of Parks and Lands, 2001).

In an attempt to analyze how multiple-use public lands (state parks and public reserved lands) contribute to the total recreational supply in the State of Maine, I defined a regional classification for the limited data obtained from the Bureau of Parks and Lands' website (2001). The classification focuses on the general character of the area (developed, semi-developed and undeveloped) according to the recreational nature of the place, its remoteness, the degree of development, and the recreational facilities. The classification is directly related to the predominant recreational opportunity that the area offers. At this level, there is no analysis of the ROS within the area (as I carried out for the Bigelow Preserve).

Within each public unit, I analyze the recreational activities. These activities are the recreational actions (hiking, picnicking, skiing, hunting, etc) that individuals experience in a given place under a set of environmental, social and managerial conditions. The same activity can happen in different recreational opportunity environments. For example, camping is a recreational activity that might occur in a developed campground zone or in a primitive camping zone. However, there are some activities, such as ATV riding, that require a specific recreational opportunity zone such as semiprimitive motorized or roaded natural.

The proposed regional classification of outdoor recreational character would allow us to quantify and estimate the recreational supply currently offered to the public at a large scale. Within this broad recreational analysis context, a piece of land or unit is classified as "developed" if there are facilities such as shelters, toilets, showers, ballfields, playgrounds, lifeguards, lighthouses, or other constructions that provide a majority of developed recreational opportunities. The "semi-developed" category

includes those areas that the Bureau describes as "semi-remote" or presents facilities such as picnic areas, grills, and boat access. The "undeveloped" category includes areas described as "remote" by the Bureau, or that do not present any facilities other than primitive campsites, trails, and/or water access for canoes and kayaks according to the information provided by the Bureau of Parks and Lands' website (2001). Each area classified under one of these general categories can provide more than one recreational opportunity. For example, the Bigelow Preserve character falls into the "undeveloped" category according to the Bureau's description of the area at its web site. However, the Preserve provides three (primitive, semi-primitive nonmotorized, semi-primitive motorized) of the six recreational opportunities defined in the Forest Service ROS. Results obtained from using this broad classification should be interpreted as a coarse estimation of the total supply at the state level. A deeper analysis, considering land size constraints, distance from roads, visually sensitive zones, and number of encounters with other parties, would provide a more accurate definition of all recreational opportunities within each recreational area. The lack of data for each site limits us to considering just the character of each site to estimate current recreational supply. I are assuming that the undeveloped and semi-developed characters tend to provide primitive and semi-primitive recreational opportunities, while a developed character leans towards providing recreational opportunities where the evidence of humans and the managerial setting is more noticeable than in the other classifications. However, there could be cases where, even if the main character of the zone is developed, some primitive recreational opportunities exist, and vice versa.

According to the defined classification, the number of public sites presents a relatively uniform distribution: 40 percent of the sites are developed, 22 percent are semi-developed, and 38 percent are undeveloped at the state level (Figure 3.3-A). At the local level, the Maine Lakes & Mountains region (Map 3.2), the percentage of developed sites decreases to 36 percent and semi-developed sites to 18 percent, while the percentage of undeveloped sites increases to 46 percent (Figure 3.3-B).

However, an analysis of the number of public acres shows a pattern different from the distribution of the number of public sites belonging to each category: 74 percent of Maine state parks, with the exception of Baxter, and public reserved lands' acres provide undeveloped opportunities, 20 percent semi-developed opportunities, and 6 percent developed opportunities (Figure 3.4-A). This means that 74 percent of multiple-use management public acres are remote or do not present any facilities other than primitive campsites, maintained hiking trails, and/or water access for canoes and kayaks. These results are slightly altered if we include Acadia National Park and Baxter State Park. Assuming that Baxter provides both undeveloped and semi-developed opportunities, and dismissing the small percentage of land that provides developed facilities (cabins), 61 percent of the acres offer undeveloped opportunities, 28 percent semi-developed, and 11 percent developed (Figure 3.4-C).

Moreover, I found that multiple-use public lands present a linear relationship between the size of the units and their general character at the large-scale level. Development is associated with smaller areas, while lack of development is associated with larger areas (Figure 3.5). The average size for developed-classified lands is 969 acres, for semi-developed 6364 acres (6.5 times larger than the previous average), and for

undeveloped 13417 acres (13.8 times bigger than developed average). This relationship—size versus degree of development—can also be observed by analyzing graphs A, B and C in Figure 3.4. Undeveloped multiple-use public lands represent 74 percent of the lands and 38 percent of the sites, while developed multiple-use public lands represent 6 percent of the lands and 40 percent of the sites. This reveals that our original recreational opportunities classification based on the facilities provided in the area also had a size component associated with it, though this information was not originally included. More undeveloped areas are larger than developed ones. These results support the idea that solitude, remoteness, and tranquility experiences require larger areas where encounters with other users are less likely and, therefore, we should impose size restrictions when managing for primitive recreational opportunities.

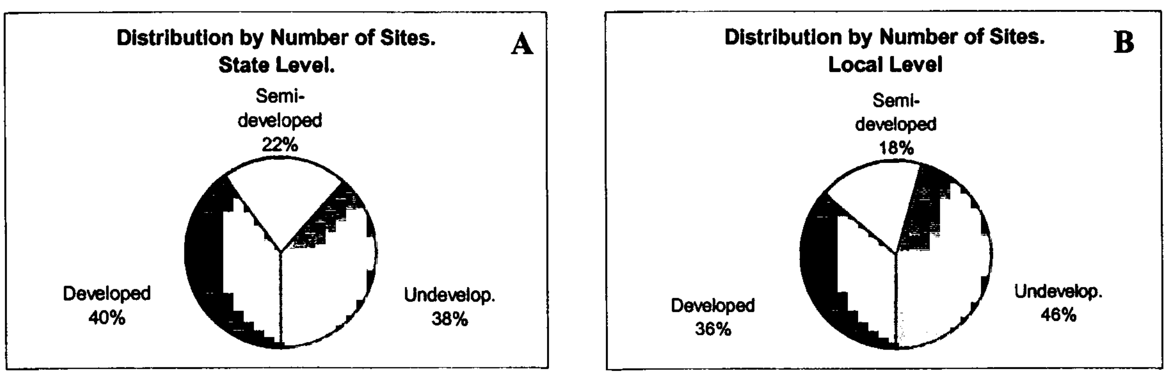


Figure 3.3: Distribution of the number of state parks and public reserved land sites at the state (A) and local (B) levels.

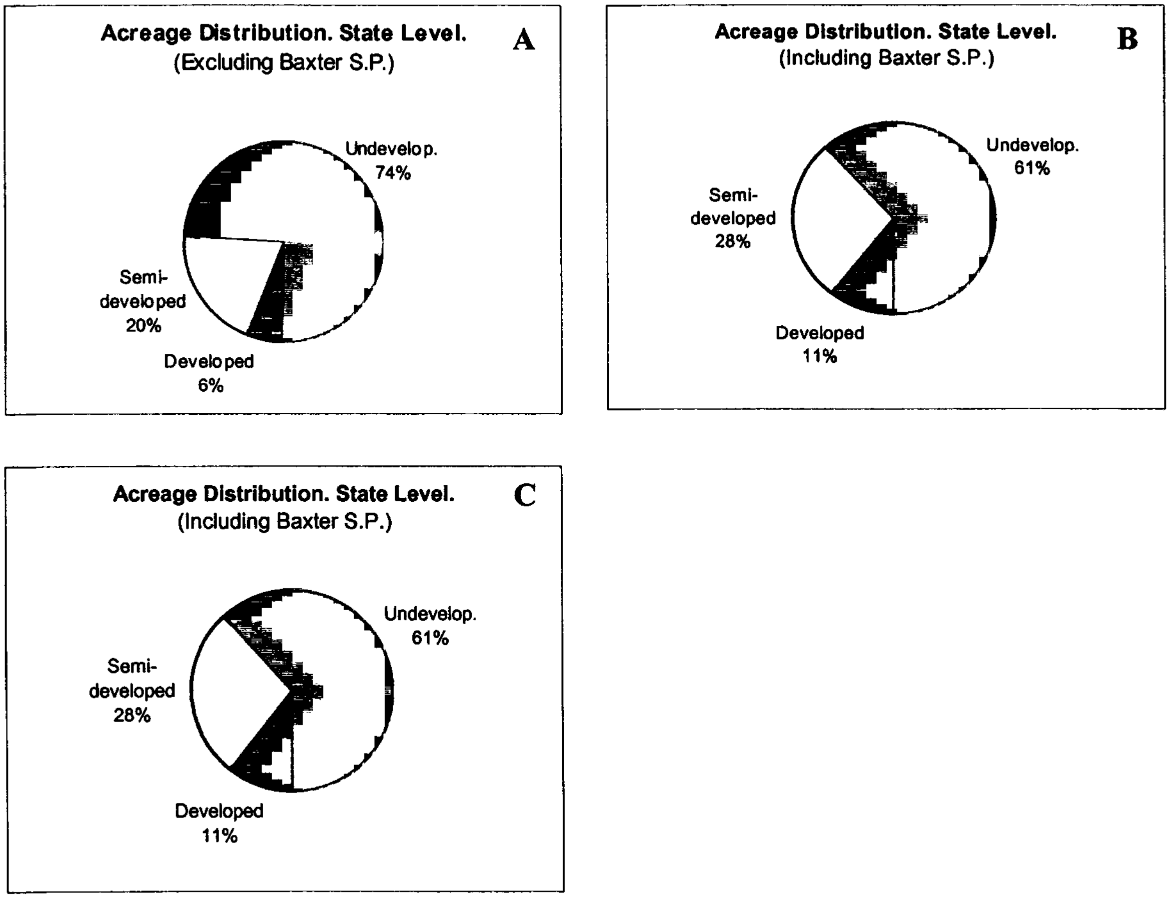


Figure 3.4: Acreage distribution of Maine State public lands at the local and state level.

The analysis of recreational uses in state parks and public reserved lands shows that 72 percent of the public units provide hiking opportunities, 53 percent camping, 80 percent wildlife watching, 66 percent picnicking, 51 percent swimming, 40 percent boat launching, 78 percent fishing, 25 percent ATV riding, 12 percent horseback riding, 40 percent mountain biking, 68 percent hunting, 53 percent snowmobiling, and 48 percent cross-country skiing. Dumping stations are located in seven units (11%), and fees are charged in 39 units (60%). At the local level, these numbers increase for certain uses such as camping, boat launching, fishing, ATV riding, horseback riding, mountain biking, hunting, snowmobiling, and cross-country skiing. The only use that experiences a small

decrease in the region is picnicking (8% less). The rest of the uses (hiking, wildlife watching, swimming) remain similar to the state averages (Table 3.5).

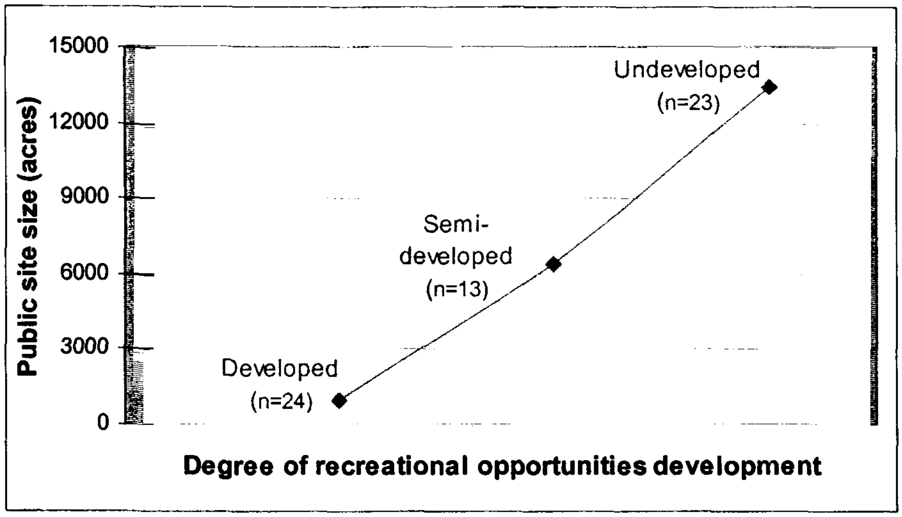
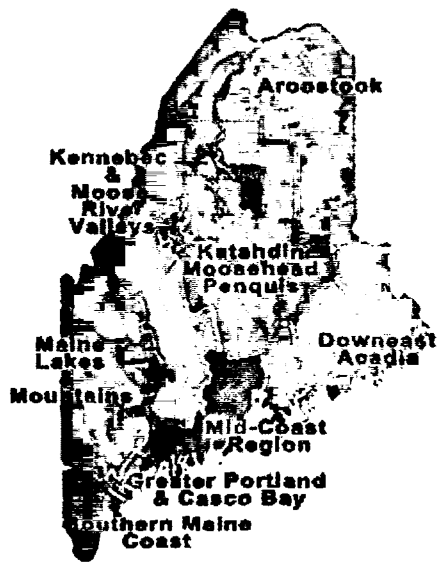


Figure 3.5: Relationship between the degree of recreational opportunity development and the mean size of the unit in acres.



Map 3.3: Recreational regions of Maine as defined by the Maine Bureau of Parks and Lands (2001).

Public Land	Acres	Hiking	Camping	Wildlife watching	Picnic	Swim	Boat Launch.	Fishing	ATV riding	Horseback riding	Mnt. Bicking	Hunting	Snow-mobiling	CC skiing	Fee charged	Rec. Opport.
Allagash Wilderness Waterway S.P.	2284	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	Undev
Aroostook S.P.	577	✓	✓	✓		✓	✓	✓				✓	✓	✓	✓	Dev
Deboullie P.R.L.	21871	✓	✓	✓			✓	✓				✓	✓	✓	✓	Undev
Eagle Lake P.R.L.	23882	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓		Undev
Houlton-Phair Junction Trail		✓							✓	✓	✓		✓			
Round Pond P.R.L.	20349	✓	✓	✓	✓			✓			✓	✓			✓	Undev
St. John Valley Trail		✓		✓					✓	✓	✓		✓			
Squa Pan P.R.L.	17985		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		Semi
Cobscook Bay S.P.	888	✓	✓	✓	✓*	✓	✓	✓					✓	✓	✓	Dev
Cutler Coast P.R.L.	2115	✓	✓	✓					✓			✓			✓	Undev
Donnell Pond P.R.L.	14162	✓	✓	✓	✓	✓	✓	✓			✓		✓	✓		Undev
Duck Lake P.R.L.	25220	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		Semi
Holbrook Island Sanctuary	1365	✓		✓	✓	✓	✓	✓						✓		Semi
Quoddy Head S.P.	481	✓		✓	✓							✓			✓	Dev
Shackford Head S.P.	90	✓														Undev
Rocky Lake P.R.L.	10904		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		Undev
Lamoine S.P.	55		✓	✓	✓		✓	✓				✓		✓	✓	Dev
Great Heath P.R.L.	6067			✓			✓	✓				✓				Undev
Roque Bluffs S.P.	274				✓	✓		✓				✓			✓	Dev
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Crescent Beach S.P.	243	✓		✓	✓	✓		✓						✓	✓	Dev
Mackworth Island	100	✓		✓		✓		✓								Dev
Pineland P.R.L.	1090	✓		✓				✓			✓					Undev
Wolfe's Neck Woods S.P.	233	✓		✓	✓									✓	✓	Dev
Two Lights S.P.	40				✓			✓							✓	Dev

Table 3.4: Recreational uses of Maine public lands with the exception of Acadia National Park and Baxter State Park.

Public Land	Acres	Hiking	Camping	Wildlife watching	Picnic	Swim	Boat Launch.	Fishing	ATV riding	Horseback riding	Mnt. Bicking	Hunting	Snow-mobiling	CC skiing	Fee charged	Rec. Opport.
Chamberlain Lake P.R.L.	9557	✓		✓				✓				✓			✓	Undev
Gero Island P.R.L.	3845	✓	✓	✓	✓			✓				✓			✓	Dev
Lagrange - Medford Trail		✓		✓					✓	✓			✓			
Lily Bay S.P.	924	✓	✓	✓	✓*		✓	✓				✓	✓	✓	✓	Semi
Little Moose P.R.L.	14000	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓		Undev
Moosehead Lake P.R.L.	11176	✓	✓	✓		✓		✓			✓	✓	✓	✓		Undev
Nahmakanta P.R.L.	42818	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓		Undev
Peaks-Kenny S.P.	839	✓	✓	✓	✓*	✓		✓				✓			✓	Dev
Scraggly Lake P.R.L.	9057	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓		Semi
Seboeis P.R.L.	12902		✓	✓	✓	✓	✓	✓			✓	✓	✓			Undev
Telos P.R.L.	22806		✓	✓				✓			✓	✓	✓	✓	✓	Undev
Wassataquoik P.R.L.	2340		✓	✓			✓	✓			✓	✓	✓	✓		Undev
Holeb P.R.L.	19651	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		Semi
Kennebec Valley Trail		✓		✓					✓	✓	✓		✓			
Lake St. George S.P.	360	✓	✓		✓•	✓	✓	✓				✓	✓	✓	✓	Dev
Peacock Beach S.P.	100			✓	✓	✓						✓			✓	Semi
Bald Mountain P.R.L.	1873	✓	✓	✓			✓	✓			✓	✓	✓	✓		Undev
Bigelow Preserve P.R.L.	36785	✓	✓	✓				✓			✓	✓	✓	✓		Undev
Dead River P.R.L.	4771	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		Semi
Four Ponds P.R.L.	6015	✓	✓	✓	✓			✓			✓	✓	✓	✓	✓	Undev
Grafton Notch S.P.	3112	✓		✓	✓			✓				✓	✓	✓	✓	Semi
Jay - Farmington Trail		✓		✓					✓	✓	✓		✓			
Mahoosucs P.R.L.	27253	✓	✓	✓	✓			✓	✓		✓	✓	✓	✓		Undev
Mt. Blue S.P.	5021	✓	✓	✓	✓*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Dev
Rangeley Lake S.P.	691	✓	✓	✓		✓	✓	✓					✓	✓	✓	Dev
Richardson P.R.L.	17757		✓	✓	✓	✓	✓	✓	✓			✓	✓		✓	Undev
Sebago Lake S.P.	1300		✓		✓*	✓	✓	✓							✓	Dev
Range Ponds S.P.	750				✓	✓	✓	✓				✓	✓		✓	Dev

Table 3.4: Continued.

Public Land	Acres	Hiking	Camping	Wildlife watching	Picnic	Swim	Boat Launch.	Fishing	ATV riding	Horseback riding	Mnt. Bicking	Hunting	Snow-mobiling	CC skiing	Fee charged	Rec. Opport.
[redacted]																
Dodge Point P.R.L	506	✓		✓		✓		✓				✓			✓	Undev
Moose Point S.P.	183	✓			✓							✓			✓	Semi
Reid S.P.	766	✓			✓	✓		✓							✓	Dev
Warren Island S.P.	70	✓	✓	✓	✓			✓				✓			✓	Semi
Damariscotta Lake S.P.	17			✓	✓	✓		✓							✓	Dev
Popham Beach S.P.	529			✓	✓	✓						✓			✓	Dev
Birch Point S.P.	56				✓	✓		✓				✓			✓	Semi
Fort Point S.P.	154				✓										✓	Dev
Swan Lake S.P.	67				✓	✓		✓				✓			✓	Dev
Ferry Beach S.P.	117	✓			✓	✓		✓							✓	Dev
Vaughan Woods S.P.	250	✓		✓	✓										✓	Semi

Table 3.4: Continued.

Notes:

The color code corresponds with the following zones: Aroostook (pink), Down east Acadia (yellow), Greater Portland & Casco Bay (red), Katahdin Moosehead Penquis (turquoise), Kennebec and Moose River Valleys (orange), Maine Lakes & Mountains (green), Mid-Coast Regions (blue), and Southern Maine Coast (purple). See Map 3.3.

✓* Dumping Station.

S.P: State Park; P.R.L: Public Reserved Land.

Dev: developed area;

Semi: semi-developed area;

Undev: undeveloped area.

Recreational Activity	% at State Level	% at Local Level
Hiking	72	75
Camping	53	75
Wildlife watching	80	83
Picnicking	66	58
Swimming	51	50
Boat launching	40	58
Fishing	78	92
ATV riding	25	50
Horseback riding	12	25
Mount biking	40	58
Hunting	68	75
Snowmobiling	53	92
Cross-country skiing	48	67

Table 3.5: Percentages of multiple-use public land that provide the listed recreational uses at the state and local level.
Data provided by the Bureau of Parks and Lands (2001).

3.6. RECREATIONAL ACTIVITIES DEMAND ANALYSIS

The population of the State of Maine, over a million people (Byerly and Deardorff, 1995), is relatively small compared with the seven million annual visitors attracted by public lands within the state (more than two million on State lands and five million on the federal park) (Vail and Hultkrantz, 2000).

Most of the studies on outdoor recreation demand found in the literature focus on the analysis of recreational activities instead of analyzing the demand for recreational opportunities that incorporates environmental, social, and managerial considerations. The Bureau of Parks and Recreation (1993) analyzed outdoors activities demand trends for the near future. Results showed that "Maine's aging population will be the major variable influencing total participation in any given activity over the next several years". Therefore, the demand for more upscale and passive activities will increase with the aging process. Findings related to forestlands are summarized in Table 3.6.

High growth activities	Moderate growth activities	Small to no growth activities	Declining activities
- Walking for pleasure - Visiting historic sites	- Canoeing, kayaking - Cross-country skiing - Lake & pond fishing - Hunting - Boating	- Downhill skiing - River & stream fishing - Hiking - Ice fishing - Picnicking - Snowmobiling - Swimming - Off-road motorbiking - Primitive camping	- Mountain biking - Developed camping - Horseback riding

Table 3.6: Growth[1] trends in 1993 for recreational activities
(Source: The Bureau Parks and Recreation 1993).

However, we should interpret these trends as coarse estimations of future demand. Recreational snowmobiling has grown exponentially in the last decade, far exceeding future levels of use expected in the 1993 report.

In the interpretation of these estimations we should also consider the discrepancies in different studies that predict future outdoor demand. Bowker *et al.* (1999) projection (1995-2050) of outdoor recreation participation based on descriptive findings from the National Survey on Recreation and the Environment, showed patterns for the national and regional level different from the 1993 Bureau of Parks and Recreation's predictions of Maine recreational trends. At the national level, recreational trend estimations for 2050 showed patterns different from Maine's recreational trends. The activities with the fastest growing outdoor recreation, measured by the number of participants, are cross-country skiing, downhill skiing, visiting historic sites, sightseeing,

[1] High growth rate is greater than 3% increase in annual user days; moderate growth rate varies from 0.9% to 3% increase in annual user days; small to no growth rate fluctuates between +0.9% to –0.9% change in total annual user days; and declining rate is less than –0.9% annual change in users days.

and biking; while the slowest-growing outdoor activities are rafting, backpacking, off-road vehicle driving, primitive camping and hunting.

For the North region of the country (which includes the states of Maine, Massachusetts, New Hampshire, Vermont, Rhode Inland, Connecticut, New Jersey, Delaware, Maryland, New York, Pennsylvania, West Virginia, Ohio, Michigan, Indiana, Illinois, Wisconsin, Montana, Iowa, and Missouri), activity trends differ slightly from the national tendency. The fastest growing activities, in terms of numbers of participants, are cross-country skiing, downhill skiing, visiting historic sites, biking, and picnicking; while the slowest growing activities are primitive camping, rock climbing, backpacking, hunting, and rafting/floating. (Table 3.7).

A comparison between Bowker *et al.* predictions for the North and the Bureau of Parks and Lands' estimations for the State of Maine reveals some discrepancies in future trends. While the Bureau predicted that hunting activities would increase in the future, Bowkers *et al* estimations showed that it will decrease both in the North and at the National level. However, both studies agree that cross-country skiing and visiting historic sites will have a fast-growing demand, and that primitive camping is a small or no-growth activity.

Another study (Cordell *et al.* 1990), based on national preferred demand for recreational trips away from home, revealed that the fastest growing activities for the American public for each decade to the year 2040 include downhill skiing, cross-country skiing, pool swimming, backpacking, visiting prehistoric sites, running/jogging, rafting and day hiking. These results contradict some of Bowker's estimations on the demand for recreational trips at the national level for the year 2050 (Table 3.7), which show that

downhill skiing, biking, snowmobiling, sightseeing and developed camping will be the fastest growing outdoor recreation activities.

Fastest Growing Outdoor Recreation Activities					
Activity days		**Number of participants**		**Primary purpose of trip**	
National	**North**	**National**	**North**	**National**	**North**
Visiting historic places (116%) Downhill skiing (110%) Snowmobiling (99%) Sightseeing (98%) Nonconsumptive wildlife activity (97%)	Snowmobiling (121%) Horse riding (103%) Down hill skiing (86%) Developed camping (83%) Sightseeing (80%)	Cross-country skiing (95%) Downhill skiing (93%) Visiting historic places (76%) Sightseeing (71%) Biking (70%)	Cross-country skiing (91%) Downhill skiing (82%) Visiting historic sites (59%) Biking (58%) Picnicking (54%)	Downhill skiing (122%) Biking (116%) Snowmobiling (110%) Sightseeing (98%) Developed camping (80%)	Down hill skiing (115%) Snowmobiling (106%) Biking (85%) Sightseeing (62%) Cross-country skiing (49%)
Slowest Growing Outdoor Recreation Activities					
Activity days		**Number of participants**		**Primary purpose of trip**	
National	**North**	**National**	**North**	**National**	**North**
Fishing (27%) Primitive camping (24%) Cross-country skiing (18%) Off-road vehicle driving (7%) Hunting (-2%)	Primitive camping (-25%) Backpacking (8%) Downhill skiing (10%) Hunting (12%) Fishing (15%)	Rafting/floating (26%) Backpacking (26%) Off-road vehicle driving (16%) Primitive camping (10%) Hunting (-11%)	Primitive camping (-16%) Rock climbing (-13%) Backpacking (-6%) Hunting (-1%) Rafting/floating (0%)	Hunting (6%) Primitive camping (0%) Off-road vehicle driving (-22%) Family gatherings (-25%) Picnicking (-45%)	Picnicking (-70%) Off-road vehicle driving (-55%) Primitive camping (-25%) Rock climbing (-22%) Rafting/floating (-20%)

Table 3.7: Fastest and slowest growing outdoor recreational activities measured by percent growth of activity days, primary purpose of the trip, and number of participants at the national level and in the north region
(Source: Bowker *et al.* 1999).

3.7 RECREATIONAL OPPORTUNITIES RECOMMENDATIONS FOR THE BIGELOW PRESERVE

At the state level, I found that the recreational character distribution of state parks and public reserved sites is nearly uniform (Figure 3.3-A). Nevertheless, this distribution does not match the acreage distribution (Figure 3.4-A), where 74 percent of multiple-use public land is classified as undeveloped. Remote and, in some cases, undeveloped opportunities require more acres than developed opportunities. In developed areas the number of encounters between parties is higher and solitude values are in less likely to be realized by visitors. Moreover, I found a linear relationship between the size of the unit and its character (Figure 3.5).

To provide society with equal recreational opportunities, we should consider the number of sites rather than just the number of acres. An equal distribution of the number of acres implies a greater number of developed sites, due to their smaller size requirement, than the number of semi-developed and undeveloped sites. Hence, the current uniform supply of developed, semi-developed, and undeveloped sites provides a diverse and balanced ROS at the state level. Although at the local level (the Maine Lakes and Mountains Region) the distribution of sites is not so even, the region balances the high density of developed opportunities in the coastal regions. The combination of access, topography, high elevations and mountain ponds, makes Bigelow more suitable for remote and undeveloped recreational opportunities. Therefore, it is not a management objective to change the undeveloped character of the Bigelow Preserve and I propose to keep the current opportunities provided.

In the previous section I have analyzed how studies about future outdoor recreation demand do not entirely agree with each other. They all agree about the increasing trend in snow-related sports, but are not specific as to whether this increase is associated with primitive areas or developed ones. Downhill skiing requires a developed infrastructure that cannot be part of a primitive or semi-primitive zone. However, cross-country skiing is an activity that can happen in any one of the previously defined ROS categories.

There are differences between the predictions for the State of Maine, the northern U.S., and the Nation, which should alert the reader to the difficulty of using this information. This discrepancy among studies makes us feel stronger about the adoption of a diverse approach that offers a wide range of recreational opportunities at a large-scale level.

At the state level, our recommendations are oriented towards increasing those recreational activities that the Bureau of Parks and Recreation (1993) estimated will have the greater demand (canoeing, kayaking, cross-country skiing, lake and pond fishing, hunting and boating), keeping the current distribution of recreational characters (developed, semi-developed and undeveloped) across the state (Figure 3.3-A). I would like to emphasize the importance of maintaining the current level of undeveloped character within public lands for two reasons: private lands rarely provide this recreational character, and the managerial, social and environmental requirements associated with undeveloped areas are more restricted than developed zones, making fewer places suitable for this category as population grows, increasing the pressure on the use of our natural resources.

For the Bigelow Preserve, I recommend keeping its current undeveloped character while increasing some of the cited most-demanded recreational activities at the state level. During the development of new management plans, managers should also include a physical carrying capacity study that evaluates and reflects the protection of the fragile ecosystems existing in the high elevation sites, and consider the conflicts between different uses. Special attention should be paid to cross-country skiing because not only is it an activity increasing in demand at the national and state level but also just 48 percent of the multiple-use state lands provide this use. The private sector provides 69 percent of the current total supply.

There are some activities that present different degrees of "flexibility" for implementation in different classified areas. For each new proposed activity or activity enhancement we need to consider the requirements to make it happen. According to the ROS defined in Appendix A, canoeing, kayaking and fishing, which require a relatively close-to- road access, occur in semi-primitive non-motorized, semi-primitive motorized, and roaded natural classified areas; boating is more restricted and is only permitted in roaded natural areas. Hunting and cross-country skiing are suitable activities for all four categories (Table 3.8).

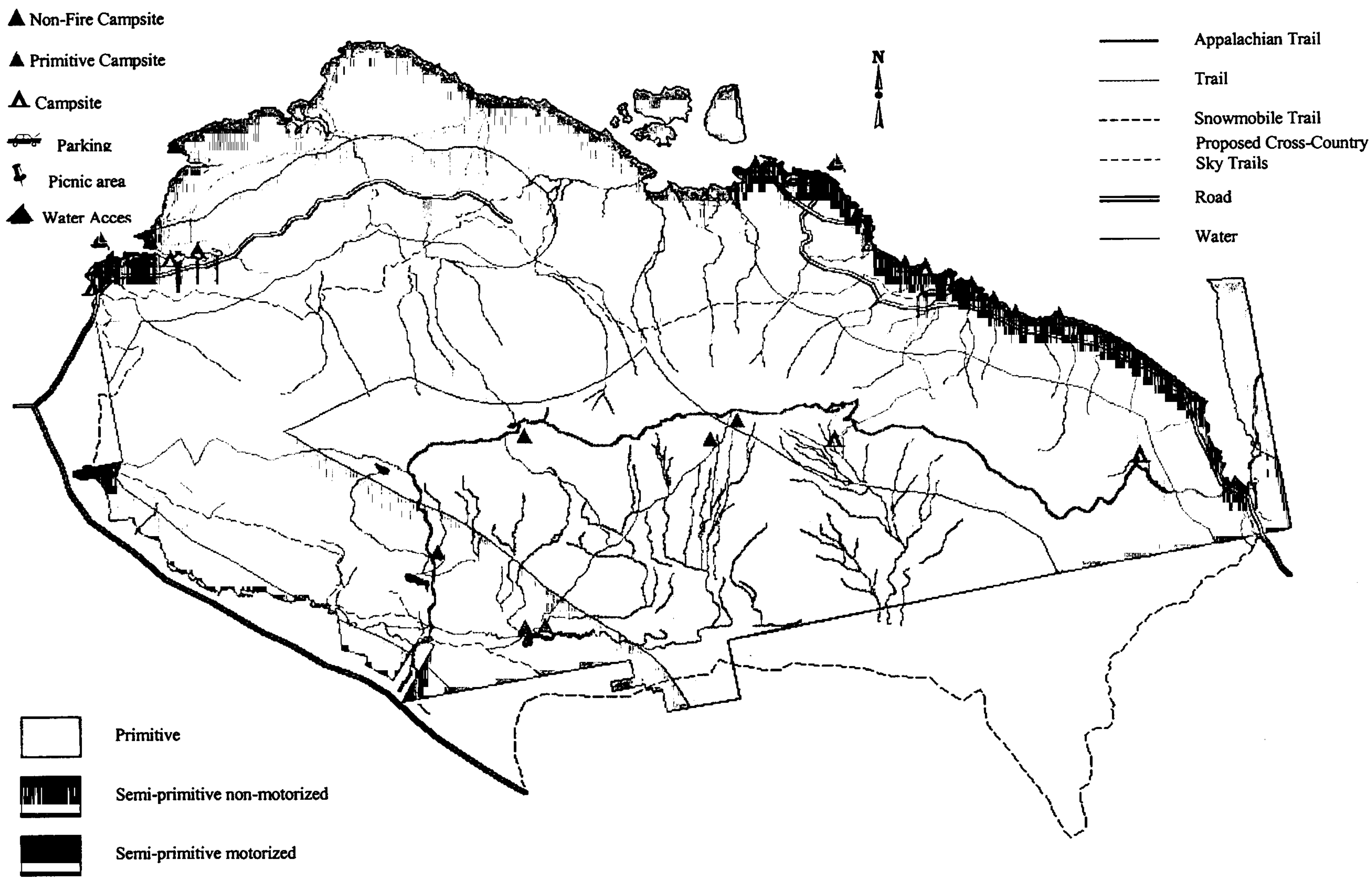
Activity	**Recreational Opportunity Classes**			
	Primitive	Semi-primitive non-motorized	Semi-primitive motorized	Roaded natural
Canoeing		✓	✓	✓
Kayaking		✓	✓	✓
Fishing	✓	✓	✓	✓
Boating				✓
Hunting	✓	✓	✓	✓
Cross-country skiing	✓	✓	✓	✓

Table 3.8: Recreational activities that classes of opportunities can provide.

Over the last ten years, the recreational use of the Bigelow Preserve has tripled. If this trend continues, we will need to take management action to be able to satisfy future demand. However, in order to estimate quantitative use levels, we need to carry out a physical carrying capacity study that evaluates the disturbance to the biological system and the deterioration of the physical environment. A study about the current social carrying capacity would help to contrast our estimations with those based on previous studies. For future management direction of the Preserve, I recommend the following guidelines to increase the supply of use levels without changing the current ROS:

- Keep the current distribution of primitive, semi-primitive non-motorized and semi-primitive motorized areas.
- Increase the amount of cross-country use by providing grooming trails in the North semi-primitive non-motorized part of the Preserve (a proposed trail network is shown in Map 3.4), and leaving the rest of the area without grooming trails so those searching for "primitive" cross-country skiing, where they open their own paths, are not disturbed by the other type of skiers.
- Increase water access for fishing, canoeing, and kayaking. I do not propose to construct more miles of paved road, just small connections of the existing two roads, the West Flagstaff Road and the East Flagstaff Road, with the shoreline to facilitate the lake access.
- Increase the number of parking spaces, considering the physical carrying capacity of the Preserve within the semi-primitive zone.
- Create a picnic area in the West part of the Preserve nearby the existing West Flagstaff Road.

- Increase the number of campsites, but just in places with road access within the semi-primitive motorized zone. Do not increase the number of campsites in the primitive and semi-primitive non-motorized zones.



Map 3.4: Current and proposed recreational facilities and trails in the Bigelow Preserve.

Chapter 4. FOREST GROWTH AND YIELD PROJECTIONS FOR THE BIGELOW PRESERVE: 2001-2101.

4.1. CHAPTER ABSTRACT.

In an effort to estimate potential future forest growth responses and commercial timber uses of the Bigelow Preserve forest, I calculated growth and yield functions based on four different timber management intensities. Ranges from "high intensity" to "no management" were defined for each forest cover type. Results showed that silvicultural systems that produced the highest timber volumes did not correspond with silvicultural systems that produced maximum revenues at the forest level. Maximum revenues were achieved by a combination of management intensities, depending on the forest cover type. High intensity management was not always the most profitable option. An analysis of timber products (sawtimber and pulpwood) revealed that maximum revenues were always associated with high volume of pulpwood harvest and the production of larger diameter trees generated lower revenues despite their higher market value. This chapter provides the growth and yield information needed for the development of the modeling environment, created in the following chapters, to support tactical planning and decision-making.

4.2. INTRODUCTION.

The main goal of this chapter is to compare and analyze the results of different silvicultural systems, individually defined for each forest type, on forest growth and yield, and available future timber supply potentials of The Bigelow Preserve (Western Maine). I used the USDA Forest Service Forest Vegetation Simulator (FVS) to model

different silvicultural systems for a 105-year period (Bush 1995). For the following chapter, this information was essential in the development of a modeling environment that allowed us to create an array of different management scenarios.

The Bigelow Preserve was created in June of 1976 to set aside land for the use and enjoyment of the public, as well as the protection of important and fragile ecosystems. Within a multiple-use framework, timber harvesting represents an integral part of the overall management of the 36,392 acres of public land, 33,272 of which are forested (Bureau of Public Lands 1989). Estimates of wood supply over future decades can help managers develop sustainable timber management plans for the area while integrating timber production with other products, services, and conditions of the forest.

The Bureau of Parks & Lands' existing twelve-year management plan (Bureau of Public Lands - Department of Conservation 1989), together with the 1998 inventory data of the Bigelow Preserve, provides the management history of the forest for the last decade and offers a basis for evaluating today's stocking levels and conditions and predicting the evolution of the forest. I also have considered personal communications with professional foresters from the area.

4.3. INVENTORY DATA.

The 1998 Maine Bureau of Parks and Lands inventory, which represents the potential supply available for harvest and utilization (Gadzik *et al.* 1999), used a point sampling method with a 10-prism factor. Each cruise line contained 12 cruise points. The starting location and direction of the lines were both random. Merchantable height to a four-inch top diameter was measured in sixteen-foot logs (with trees recorded to the

nearest half log) for hardwood and in inches for pulpwood. The inventory size class distribution assumed sawlogs with a minimum of 12 inches diameter at breast height (d.b.h.) (11.1 to 13.0 inches) for hardwood species, and a minimum of 10 inches d.b.h. (9.1 to 11.0 inches) for softwood species. Pole timber varied from 6 (5.1 to 7.0) to 10 (9.1 to 11.0) inches in d.b.h for hardwood species, and 6 (5.1 to 7.0) to 8 (7.1 to 9.0) inches for softwood species, and seedlings and samplings were a maximum of 4 inches in d.b.h. (3.1 to 5.0).

For all trees with a minimum 2-inch d.b.h., the inventory provided information about species type, d.b.h., merchantable height, percent soundness, tree grade, and cut/leave prescription. A tree was designated as "cut" if it met one of three conditions: 1) mature (a tree in a physiological state of decline due to age) 2) grade five suppressed tree (cull tree) and 3) high risk (live, at least 50 percent sound, and in danger of dying within ten years).

At the stand level, inventory data presented information about the stand age, site index, stand area, sample size, and timber type designation. The timber type designation is a three-character code, where the first character represents the stand's species dominance, the second the stand's size class distribution (seedling/sapling, pole, or sawtimber), and the third the stand's percentage of crown closure stocking of merchantable trees.

The Bigelow Preserve's forest includes stands of spruce-fir (more than 66 percent softwood species), cedar (more than 66 percent cedar), aspen (more than 66 percent aspen species), intolerant hardwood (more than 66 percent intolerant hardwood species of fire origin such as paper birch, red maple, and aspen), tolerant hardwood (less than 33

percent softwood species), and mixwood (softwood species represent between 33 and 65 percent of the species composition). The forest species distribution (Figure 4.1) shows a dominance of mixwood species (40 percent) and tolerant hardwoods (34 percent) within the Preserve, and a size class distribution where pole and sawtimber stands constitute almost 91 percent of the forest (Figure 4.2). Over two thirds of the forested land is well or adequately stocked, with more than 67 percent crown closure (Figure 4.3).

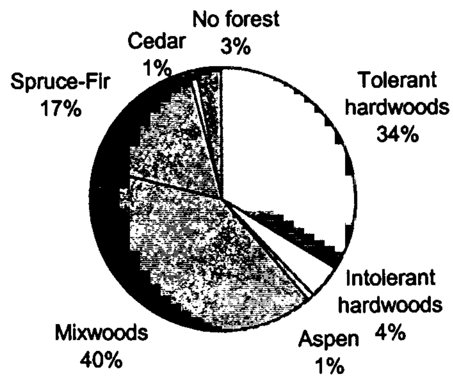


Figure 4.1: Distribution of growing stock volume by forest types in the Bigelow Preserve, 1998.

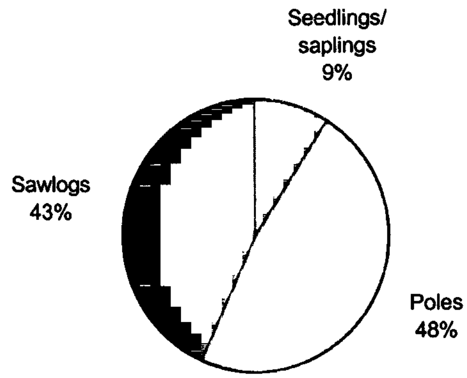


Figure 4.2: Stand d.b.h. size class distribution of the Bigelow Preserve's forest in percent of acres: sawlogs, pole timber, seedlings and samplings[1], 1998.

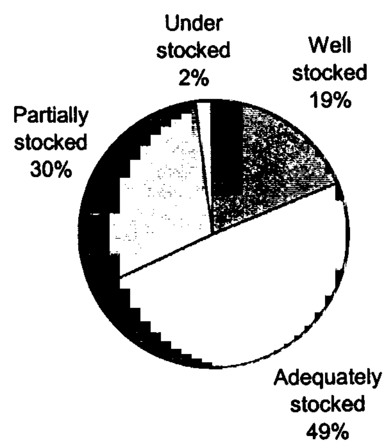


Figure 4.3: Overstory crown closure stocking distribution of the Bigelow Preserve's forest: well stocked, adequately stocked, partially stocked, and under stocked[2], 1998.

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[1] Sawlogs: a minimum of 12 inches for hardwoods, and 10 inches for softwood, pole timber: 6 to 10 inches for hardwood species, and 6 to 8 for softwood, seedlings and samplings: a maximum of 4 inches.

[2] Well stocked: 85 to 100% crown closure, adequately stocked: 67 to 85% crown closure, partially stocked: 33 to 66%crown closure, and under stocked: less than 33 % crown closure.

4.4. FOREST VEGETATION SIMULATOR OVERVIEW.

The Forest Vegetation Simulator (FVS), based on the previously developed Stand Prognosis Model, is an individual-tree, distance-independent growth model (Stage, 1973). FVS was created to "make consistent forecasts of forest stand development across a broad range of planning scales... [The model] reflects the idea that knowledge of current forest conditions and how forests can change can be used to predict future forest conditions" (Crookston, 1997). The USDA Forest Service has developed calibrated variants of the model for different geographical regions of the country. I used the Northeastern TWIGS (NE-TWIGS) variant of the FVS, developed by the Northeastern Forest Experiment Station in the late 1980s, to predict the Bigelow Preserve forest's growth and yield (Bush 1995).

NE-TWIGS uses the following minimum species parameters: d.b.h., basal area in trees with diameters larger than or equal to the tree in question, and site index variables to calculate diameter growth annually in cycles of 1 to 5 years (Schuster et al, 1993). FVS, and its particular variant NE-TWIGS, requires three types of input files to project growth: a tree list file, which stores all the tree measurements from the inventory; a stand list file, where the user specifies the stand-related variables such as the sampling method, site index, geographic location, and topographic variables; and the location file designed to organize stand data at the landscape or larger spatial scales. Based on these files, the model simulates the application of specific silvicultural systems and computes stand-level statistics.

NE-TWIGS variant uses four mathematical models to calculate growth and yield projections for the forest: the Mortality Model, the Large Tree Model (which applies to trees with d.b.h 4 inches or larger), the Small Tree Model (for trees less than 1.5 inches), and the Partial Regeneration Establishment Model (which only accounts for the sprouting function and the NATURAL and PLANT keywords allowing the user to include natural regeneration information in the simulation from other data sources). For d.b.h. between 1.5 and 4.0 inches, the model uses a smoothing of the large-tree diameter and small-tree height equations (Bush, 1995).

4.5. METHODS

We used NE-TWIGS to project the future growth and yield of the Bigelow Preserve forest. First, I defined two management systems: even-aged and uneven-aged management. Then, I characterized four harvesting methods: clearcut and shelterwood (within the even-aged regime), and group selection and individual tree selection (within the uneven-aged regime). I also defined intermediate treatments such as planting, herbicide release, precommercial thinning (PCT), and commercial thinning. I systematically tested different operational levels for each treatment to find those sustainable silvicultural prescriptions that would produce the highest yields of available timber, keeping operational costs as low as possible. As a reference point, I simulated the evolution of all the stands under "no management" conditions. Finally, although natural regeneration was the primary method for establishing new trees in the stands, I also prescribed planting to change the species composition distribution within the Preserve's forest.

FVS works at the stand scale. However, in order to estimate the growth of over 33,000 acres of forest within the Bigelow Preserve, for each forest type I simulated the response of an average stand, estimated by all the inventory data points within each forest type, to different silvicultural systems. The purpose of this work has been to estimate future responses of forest vegetation at the landscape level; average stands were created to estimate the evolution of the growing stock. This approach represents a simpler, though less detailed, operative method than simulating each stand individually and combining them together afterwards. Following is the alternative silvicultural systems prescribed for each type of forest.

4.5.1. Spruce-fir stands.

We simulated the evolution of spruce-fir stands subject to three different silvicultural systems over 100 years. In the first system (S-Fcc), clearcutting constituted the harvesting method with a 60-year rotation period. Five years after final harvesting, stands were herbicide released, suppressing hardwood species and favoring softwood species. Ten years later, the stands were pre-commercially thinned (PCT) leaving 1,000 trees per acre (favoring spruce and fir species). At age 40, a commercial thinning from below to the B line[3] (leaving stands fully stocked) with a cutting efficiency[4] of 1.0 was carried out, increasing the proportion of spruce to take advantage of the species' greater

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[3] The B line represents the lower stand stocking level in the stocking guide developed for spruce fir stands.

[4] The cutting efficiency in FVS represents the percentage of trees in any particular class to be cut. A cutting efficiency of 0.7 allows cutting only 79 percent of the trees in a pre-defined class. This parameter alters the residual stand structure and associated residual quadratic mean.

longevity, resistance to decay and budworm attack, as well as higher value (Seymour, 1994).

Because FVS does not simulate natural regeneration, this information had to be independently estimated and included in the simulation right after the PCT was scheduled. Regardless of the real behavior of the regenerated vegetation during the time of its establishment (immediately after harvest) and the PCT, I only introduced the 1,000 remaining trees after PCT with an average age of 10 years in the simulation. This number of stems per acre is the desired tree density left in the forest after PCT. I made the assumption that all the sites had the capacity of naturally regenerating full stocking levels. I did not simulate the stands' natural regeneration before PCT in FVS. Although PCT and herbicide release are part of the silvicultural prescription for spruce-fir stands, these silvicultural treatments are not simulated in FVS either. However, I included the results of their applications when incorporating the number of stems and species composition distribution of the natural regeneration information within the model. Based on the stand's timber type designation (defined above), the species composition average of the youngest spruce-fir stands and mature spruce-fir stands in the study area, and results found by Newton *et al.* (1992) on young spruce-fir forest released by herbicides, I estimated that immediately after PCT the species composition would follow the distribution in Table 4.1. Although it is true that the natural-regeneration species distribution occurring after the final harvesting of a mature stand is not identical to the species composition of the stand before the harvest, the predominant species of the mature stand will be the most likely seed producers contributing to regeneration after harvesting (Brissette 1996).

Species	Percentage distribution (%)	Number of trees per acre
Red spruce	35.0	350
Balsam fir	25.0	250
Northern white cedar	15.0	150
Black spruce	10.0	100
White pine	2.0	20
White spruce	1.0	10
Total softwood	**88.0**	**880**
Red maple	6.3	63
Other hardwoods	2.0	20
Paper birch	2.0	20
Hemlock	0.7	7
Larch	0.4	4
Yellow birch	0.3	3
Pin cherry	0.2	2
Sugar maple	0.1	1
Total hardwoods	**12.0**	**120**

Table 4.1: Species distribution and number of trees per acre by species included in FVS as a spruce-fir stand's natural regeneration after PCT.

The second silvicultural system (S-Fsh), defined by Seymour (1994) as the "irregular" shelterwood for spruce-fir stands, resulted in a two-aged forest stand structure. The rotation length was between 75 and 80 years. Around the stand age of 30 years (or 30 years after final removal), I thinned the stands from a diameter range (0 to 2 inches) with a 1.0 cutting efficiency value. Thirty-five years later, the regeneration cut removed all trees down to four inches in d.b.h. except for 75 residual trees per acre. Retention removal was scheduled fifteen years later, at the same time that PCT was conducted on naturally regenerated vegetation, leaving 1,000 trees per acre.

We included the natural regeneration in the model right after PCT, following the species composition in table 1 and an abundance of 1,000 stems per acre. In general, clearcuts benefit the establishment of intolerant species, which are mostly hardwood species in the Preserve. However, herbicide release suppresses hardwood species in favor of softwood species. Therefore, both silvicultural systems S-Fcc and S-Fshel had a high

percentage of spruce and fir species in the natural regeneration. I used the same species distribution (Table 4.1) in the regeneration of both systems.

The third system (S-Fis) included a single-tree selection harvesting method with a 20-year cycle over 100 years. The selection cut was defined by the following parameters: a target residual basal area (79 ft^2/acre), a maximum diameter at the time of harvesting (30 inches), and a constant ratio, q, between the numbers of trees in adjacent 2-inch d.b.h. classes (1.9). High q values retain more small-diameter trees in the stand than low q values. The number of remnant trees after selection harvest was two per acre, with a d.b.h. of 28 inches or larger. I included natural regeneration 10 years after each selection cut and used data ingrowth to the one-inch diameter class from studies conducted by the USDA Forest Service, Northeast Experiment Station in Maine. The data (unpublished) came from spruce-fir plots, with silvicultural prescriptions identical to the ones just described for our stands in this third silvicultural system. The Forest Service data contains only the natural regeneration information after the first two shelterwood cuts, from the middle-late 1950s untill today; information about the third and following cuts are not yet available. I considered the ingrowth to the one-inch category during the 20 years following the selection entry for two compartments (plots). The Forest Service data show that, after the first entry, the ingrowth to the one-inch diameter class was 1,327 and 1,210 trees per acre for each compartment respectively, and 355 and 296 trees per acre respectively after the second entry. No data are available for the third and future entries yet. For these compartments, the number of stems per acre ten years after selection harvest was 32,242 (Brissette, 1996), which represents a highly stocked stand. Considering the species percentage distribution shown in Table 4.1 and the Forest

Service data, I estimated the ingrowth to the one-inch diameter likely to happen after each defined selection entry. I used the average between the first and second entry's ingrowth data for the third, fourth, and fifth periods after each selection cut.

4.5.2. Tolerant hardwood stands

We defined three silvicultural systems for tolerant hardwood stands. The first system (THsh) included a two-cut shelterwood treatment where the regeneration establishment cut (or first entry) occurred in mature stands with an average age of sixty years, and a residual basal area of 65 square feet per acre. The overstory removal was scheduled forty years later, leaving ten percent of basal area. The total length of the rotation was 100 years. Thirty-five years later, I performed a light thinning from below if the stand's stocking level was above the quality line in the northern-hardwood stocking guide (Leak *et al.* 1987). Fifteen years afterwards, I carried out a commercial thinning to the B line. Natural regeneration data were estimated from Leak, Solomon and DeBald's (1987) findings on the species composition of stocked mil-acres, ten to fifteen years after cutting tolerant hardwood (beech-birch-maple) stands with three different harvesting methods: clear cut, group selection and individual-tree selection. The species composition distribution of the natural regeneration considered in this silvicultural system was the average species composition distribution of the naturally regenerated stands occurring after the group selection removal and individual-tree selection removal defined in the authors' study. This distribution represented 77 percent tolerant species (beech, sugar maple, eastern hemlock, red spruce and balsam fir), 21 percent intermediate species (yellow birch, white ash, and red maple), and 2.5 percent intolerant species (paper birch

and aspen). I also considered the stand composition of the youngest and mature tolerant-hardwood stands to calculate the final species distribution of natural regeneration (Table 4.2). Based on Hornbeck and Leak's (1992) information on stand regeneration after harvest of northern hardwoods, I used 25,000 as the number of stems per acre of natural regeneration.

The second silvicultural system (THgs) consisted of a fifth-acre group selection harvest, every 20 years over a one-hundred-year period. In every entry, the patch of forest cut 20 years earlier was thinned from below, leaving 800 trees per acre. This system created groups of different tree heights scattered throughout the forest. The species composition of the natural regeneration included in the simulation model had a greater composition of tolerant species than the previously defined silvicultural system (Table 4.2). In this case, the natural regeneration was also based on Leak, Solomon and DeBald's (1987) results on natural regeneration on hardwood stands after a group selection harvest, and the species composition of the youngest and mature hardwood stands in the Bigelow Preserve. I assumed that the total number of stems per acre 10 years after harvest entry was 25,000 (Hornbeck and Leak 1992).

The third silvicultural system (THis) included individual tree-selection removals with a cutting cycle of 20 years during a one-hundred-year period. For each cut entry, the residual basal area was 70 square feet per acre; the maximum d.b.h. at the time of harvesting was 22 inches; the q value was 1.6; with two residual trees per acre with 28 inches or larger d.b.h. This system created a homogeneous multistory structure throughout the forest. The species composition distribution was also based on Leak, Solomon and DeBald's (1987) findings and the species composition of the youngest and

mature tolerant-hardwood stands in the Bigelow Preserve. In addition, I assumed that during the 20-year period after each selection entry, the number of naturally regenerated stems per acre that reach the one-inch diameter class followed the same pattern as in the results found for spruce-fir stands (Table 4.1).

Species	Group Selection	Shelterwood	Ind.-Tree Selection
Sugar maple	30	37	44
American beech	17	21	24
Balsam fir	8	10	13
Red spruce	7	8	11
White spruce	1	2	2
Yellow birch	14	9	3
Red maple	8	5	2
Other hardwoods	3	1	0
Paper birch	4	2	0
Quaking aspen	1	1	0
Hophornbeam	4	2	0

Table 4.2: Species composition distribution (in percentage) of natural regeneration of tolerant hardwood stands ten years after the regeneration removal in the two-cut shelterwood harvest system (THsh), the cut entry in the group selection harvesting system (THgs), and the cut entry individual-tree selection system (THis).

4.5.3. Intolerant hardwood stands

Inventory data provided two types of intolerant hardwood stands, those where aspen represented more than 66 percent of the total species composition (called aspen stands), and those in which more than 66 percent of the stand was a mix of aspen, red maple, and birch species. For the second type, the rotation periods were longer than average rotations commonly used (around 60 to 65 years) for these species. The main reason for extending rotations was the poor quality of the soils where these intolerant hardwood stands are located, presenting an average site index of 36.6. After several FVS simulations, I concluded that rotation periods of around 80 years produce sustainable levels of timber.

For the stands with a majority of aspen, red maple and birch, I developed three silvicultural systems to simulate in FVS. The first one (IHcc) accounted for a final clearcut harvest of mature stands every 80 years. Stands were pre-commercially thinned to a density of 900 stems per acre ten years after the final harvesting cut, decreasing the proportion of quaking aspen and paper birch.

We assumed that natural regeneration would be similar to the average of the species composition of the youngest intolerant hardwood stands. However, vegetation removal methods that leave open spaces free of vegetation (e.g. clearcuts) provide environments favorable to the natural reproduction of shade intolerant species, while harvesting methods that partially remove the overstory favor the reproduction of shade tolerant species. Therefore, the natural regeneration included in the simulation also accounted for the harvesting method specified within each silvicultural system. Considering the species composition changes (by cutting method) shown in Leak, Solomon and DeBald's (1987) study for tolerant hardwood species stands' natural regeneration, I assumed that species composition change occurring in the natural regeneration of intolerant hardwood stands after different harvesting methods would be similar to that in tolerant hardwood stands, but with an opposite effect. Hence, I assumed that the decreased representation of naturally regenerated tolerant species after a clearcut (compared to the regeneration after an individual-tree selection cut for the same stands) would be the same as the decreased representation of intolerant species after an individual-tree selection cut (compared to a clearcut). The same assumptions were made for the next two silvicultural systems.

The second silvicultural system for intolerant hardwood stands (IHsh) was a two-cut shelterwood. The regeneration establishment cut, with a residual basal area of 60 square feet per acre, occurred around the age of 45 years. Thirty-five years later, the overstory removal cut retained 25 percent of the overstory. The rotation period was 80 years.

The third system (IHgs) involved a group selection cut where every entry cut one third of the stand in gaps of one half acre every 30 years for a one-hundred-year period. In each entry, the forest area removed 30 years earlier was thinned from below, leaving 900 trees per acre.

Aspen stands were located in areas with higher site indexes (an average site index of 60) than was true of the rest of the intolerant hardwood stands, which let us shorten the rotation periods by 20 to 40 percent depending on the silvicultural treatments. For these stands, I simulated three silvicultural systems. The first one (Acc50) involved pulpwood rotations with 50-year rotations and PCT ten years after final harvest, leaving 900 stems per acre. The second system (Acc65) also included clearcutting as the harvesting method and PCT, but the rotation period was 65 years. Forty-five years after final harvesting, I scheduled a commercial thinning with a residual basal area of 80 square feet per acre. The third silvicultural system (Ags) was a group selection cut of a third of the stand every 20 years in gaps of one-half acre. In every entry, sites previously cut were thinned (PCT), leaving a density of 900 stems per acre.

4.5.4. Mixwood stands

Mixwood stands were subject to three silvicultural treatments in the simulation. In the first (Mcc), I harvested mature timber stands with the clearcut method, followed by natural regeneration. The cutting cycle was 70 years. Other silvicultural treatments included herbicide release five years after final harvesting, which suppressed hardwood species and favored softwood, and PCT ten years later, leaving a stand density of 1,000 stems per acre. The species composition of the natural regeneration, based on the species composition average of the youngest and mature mixwood stands (Table 4.3), were included in FVS after the PCT.

The second system (Msh) included a two-cut shelterwood treatment where the regeneration establishment cut (or first entry) occurred in mature stands with an average age of 55 and a residual basal area of 40 square feet per acre. The overstory removal was scheduled fifteen years later, leaving 25 percent of the stand overstory. The total length of the rotation was 70 years. At the same time as the overstory removal, I reduced the stand natural regeneration stocking to 1,000 stems per acre using PCT. The natural regeneration was included in FVS after PCT with the species composition and distribution shown in Table 4.3. Based on Leak *et al.* (1987) results on species composition change after different harvesting methods, I assumed that the percentage of tolerant hardwoods would be higher in the natural regeneration stands after shelterwood and selection cuts than after clearcuts and herbicide release. Therefore, I assumed that natural regeneration would follow the same species distribution as in the existing youngest mixwood stands, with a higher percentage of tolerant species.

The third silvicultural system (Mis) consisted of individual tree-selection removals with a cutting cycle of 20 years during a one-hundred-year period. The residual basal area was 75 square feet per acre; the maximum d.b.h. at the time of harvesting was 22 inches; the q value was 1.7; with five residual trees per acre with 28 inches or larger d.b.h. The species composition of the natural regeneration followed the distribution described in Table 4.3 for selection cuts. I assumed the same numbers of naturally regenerated stems per acre that reached the one-inch diameter class after each entry as in the case of spruce-fir stands (Table 4.1).

Species	Clearcut and herbicide release (%)	Shelterwood and selection cuts (%)
Balsam fir	29.0	32.5
Red spruce	16.0	19.5
North white cedar	4.5	4.5
White spruce	1.3	1.3
White pine	1.1	1.1
Other softwoods	1.1	1.1
Black spruce	1.0	1.0
Yellow birch	4.8	8.1
Other hardwoods	4.2	0.0
American beech	3.5	6.8
Sugar maple	1.5	6.5
Brown ash	1.1	1.1
White ash	0.8	0.8
Hemlock	0.8	0.8
Red maple	12.0	3.0
Paper birch	5.4	2.0
Quaking aspen	3.0	0.0

Table 4.3: Natural regeneration species composition and distribution (in percents) included in FVS after different harvest methods: clearcut with PCT and herbicide release, shelterwood, and individual tree selection.

We established three categories by grouping defined silvicultural systems according to their level of timber production intensity: management intensity one accounted for silvicultural systems S-Fcc, THsh, IHcc, Acc50, and Mcc; management intensity two included systems S-Fsh, THgs, IHsh, Acc65, and Msh; and management intensity three represented systems S-Fis, THis, IHgs, Ags, Mis.

In the analysis of financial benefits, I assumed that the rate of change in all dollar values was equal to the rate of change of the purchasing power of the dollar over the planning horizon, and a discount rate value (real) of four percent.

4.6. YIELD CURVE DEVELOPMENT AND RESULTS

The NE-TWIGS variant of FVS allowed us to simulate the forest response (yield projections) to the defined treatments within each system. In this paper, I present the average yield curves for each forest type (softwood, cedar, tolerant hardwoods, intolerant hardwoods, aspen, and mixwood).

For the one-hundred-year study period, the silvicultural systems simulated for spruce-fir stands produced different outputs in terms of the distribution of merchantable standing volume (Figures 4.4, 4.5, and 4.6), harvested timber volumes (Figure 4.7), and timber products (sawtimber and pulpwood) (Figure 4.9). The S-Fcc silvicultural system provided the lowest total merchantable volume of timber (3,770 cubic feet/acre), while S-Fsh increased this timber volume by 43 percent and S-Fis by 36 percent. S-Fcc also produced the lowest percentage of merchantable sawtimber volume (39 percent of the total harvested volume), concentrating timber harvesting in the two years 2001 and 2061. The S-Fis system presented the highest total merchantable volume of timber (5401 cubic feet/acre) and the highest percentage of merchantable sawtimber volume (59 percent of the total harvested volume) scattered over six entries, one every twenty years. This last system was sustainable in the sense that it never removed more volume than the spruce-fir forest grew in each rotation. Under "no management" conditions, the inventory doubled by the end of the simulated period (Figure 4.8).

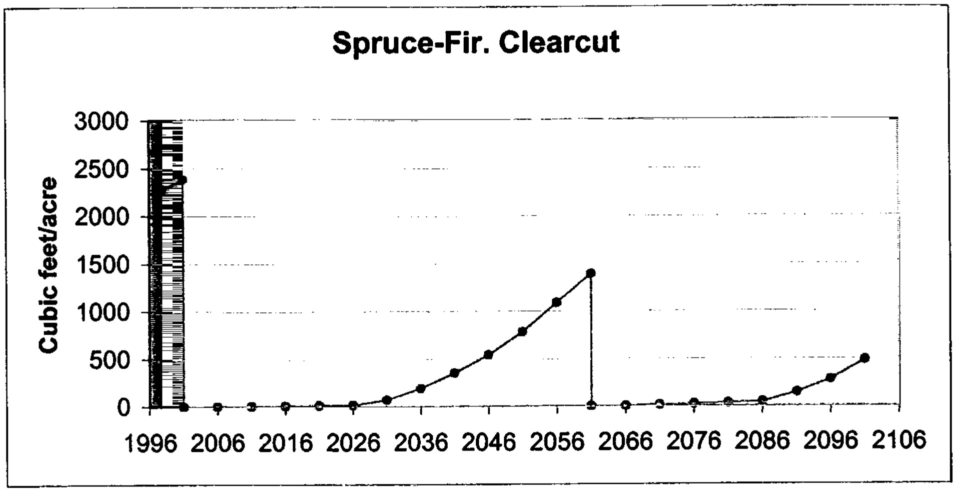

Figure 4.4: Merchantable standing volume distribution for spruce-fir stands subject to the clearcut silvicultural system.

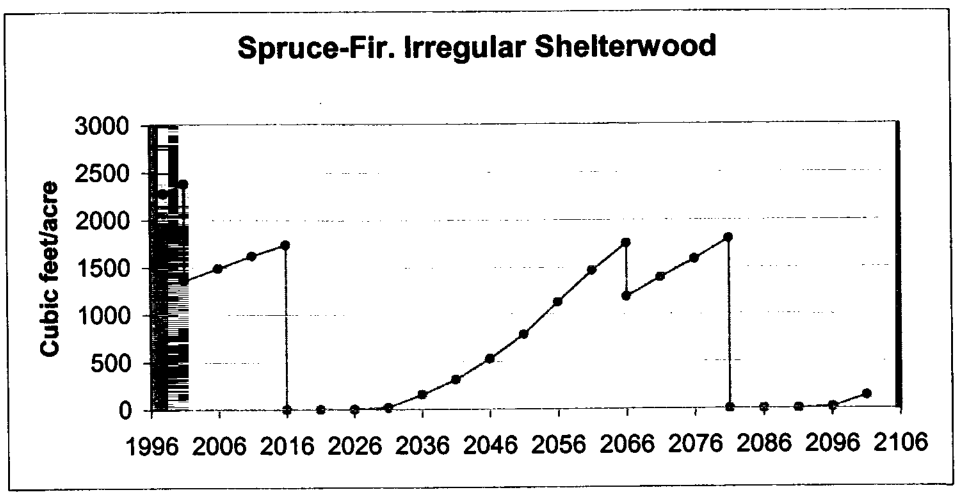

Figure 4.5: Merchantable standing volume distribution for spruce-fir stands subject to the irregular shelterwood silvicultural system.

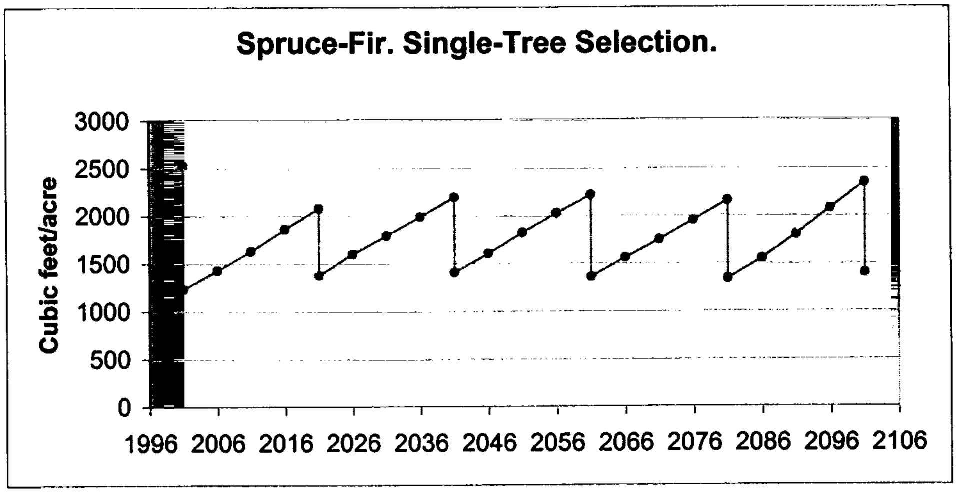

Figure 4.6: Merchantable standing volume distribution during a 100-year period for spruce-fir stands subject to the single-tree selection system.

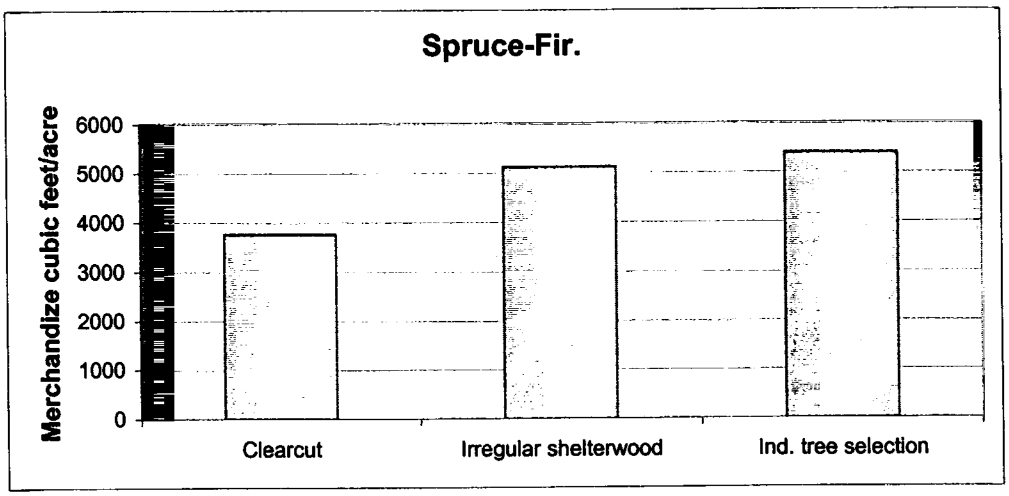

Figure 4.7: Comparison of total merchantable harvested volume (cubic feet/acre) in spruce-fir stands under the three different silvicultural systems.

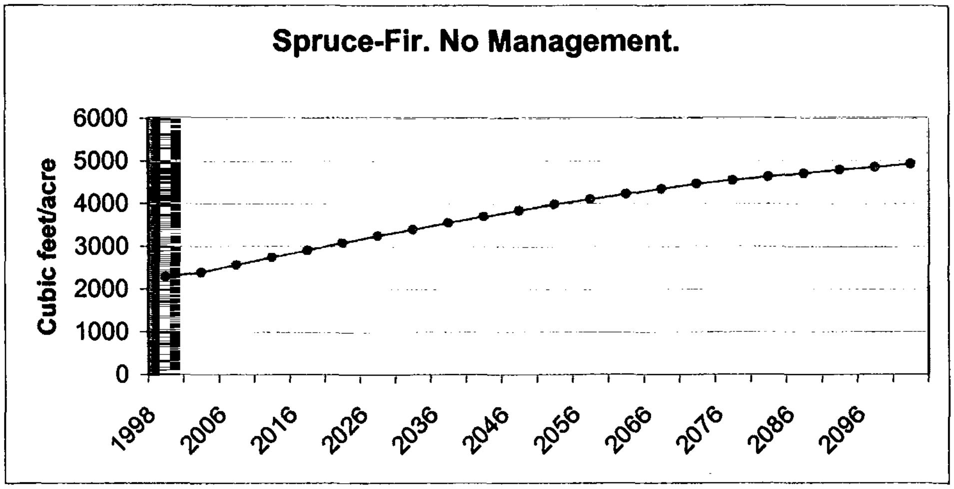

Figure 4.8: Merchantable stocking for spruce-fir stands without timber management.

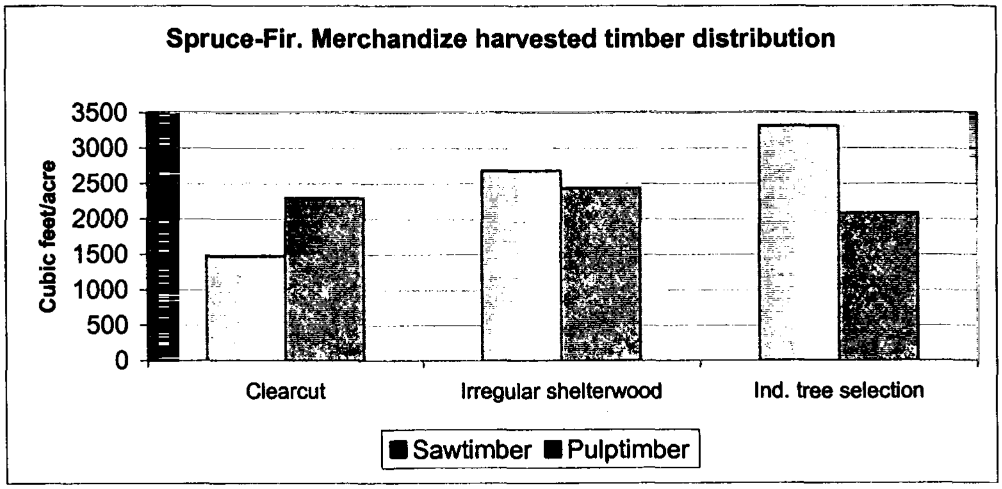

Figure 4.9: Comparison of the total merchantable harvested sawtimber and pulpwood for spruce-fir stands under three silvicultural systems.

The analysis of the three silvicultural systems simulated for tolerant hardwood stands revealed that the THgs silvicultural system produced the minimum merchantable timber volume (4,069 cubic feet per acre) during the simulation period. The THis system not only produced a 12 percent higher yield than THgs (Figure 4.10), but the standing inventory volume per acre after each selection cut was greater too (Figure 4.11), and it increased with time, while the THgs remaining inventory (Figure 4.12) after each entry

decreased by half (from 2080 cubic feet per acre in 2001 to 934 cubic feet per acre in 2101). In addition, the Thsh system (Figure 4.13) provided the highest merchantable timber volume (24 percent greater than THgs and 10 percent greater than THis). Even if the total volume harvested was different for the three analyzed systems, the percentages of sawtimber and pulpwood were very similar among systems (Figure 4.14). The sawtimber volume of the THis system represented 65 percent of total harvested volume, 64 percent for THsh, and 62% for THgs. The "no management" action led hardwood tolerant stands yield to one and a half times its current inventory volume (Figure 4.15), which represents 25 percent less than the spruce-fir stands' yield under "no management" conditions.

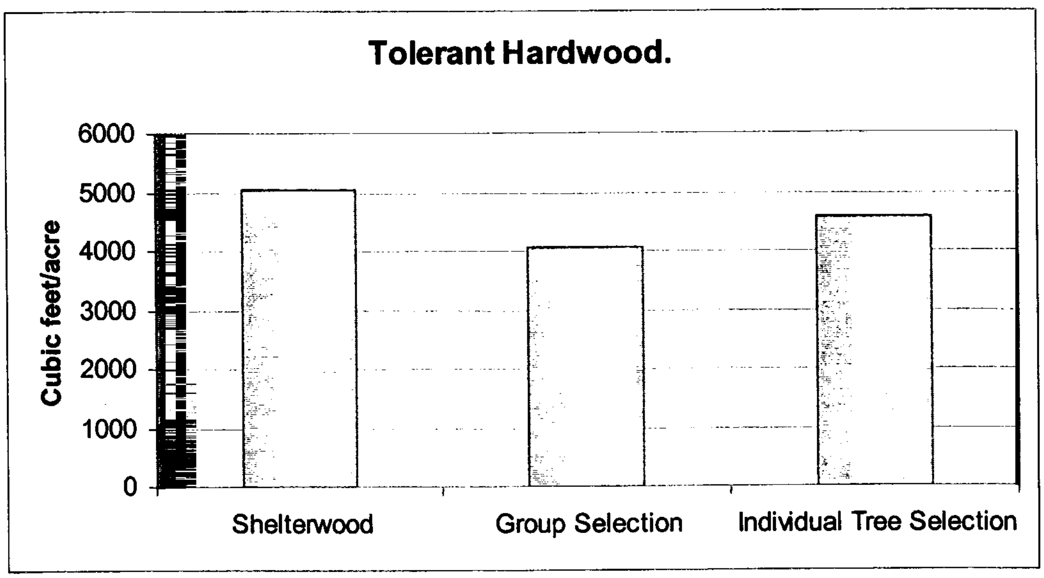

Figure 4.10: Comparison of total merchantable harvested volume (cubic feet/acre) in tolerant hardwood stands between three different silvicultural systems.

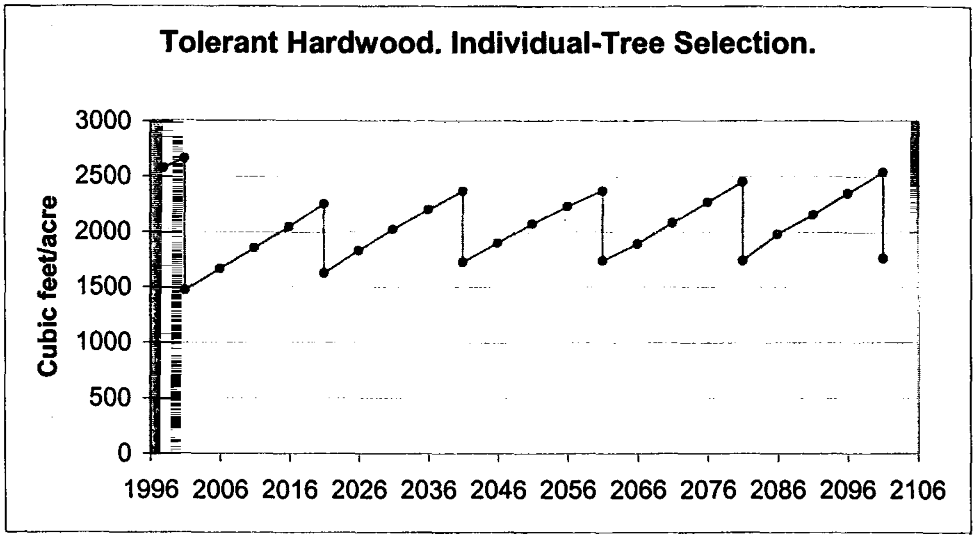

Figure 4.11: Merchantable standing volume distribution during 100-year period for tolerant hardwood stands subject to the individual-tree selection silvicultural system.

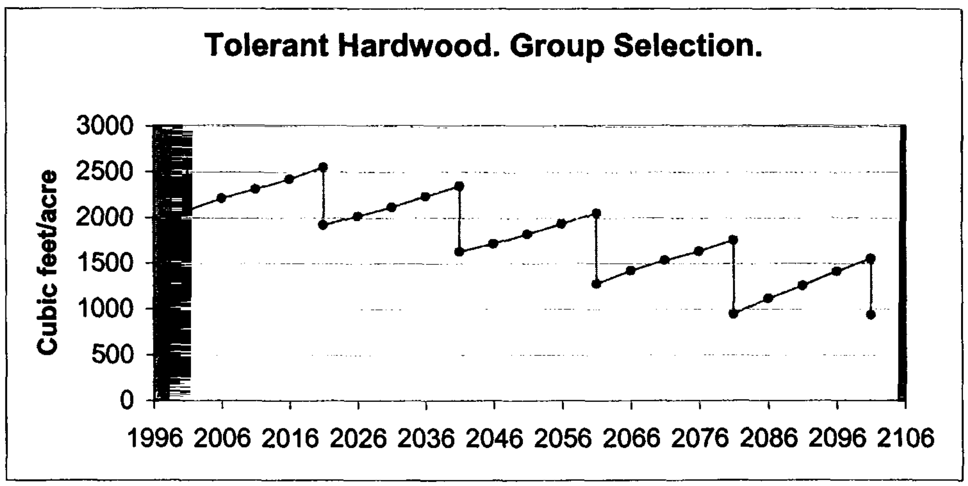

Figure 4.12: Merchantable standing volume distribution during a 100-year period for tolerant hardwood stands subject to the group selection silvicultural system.

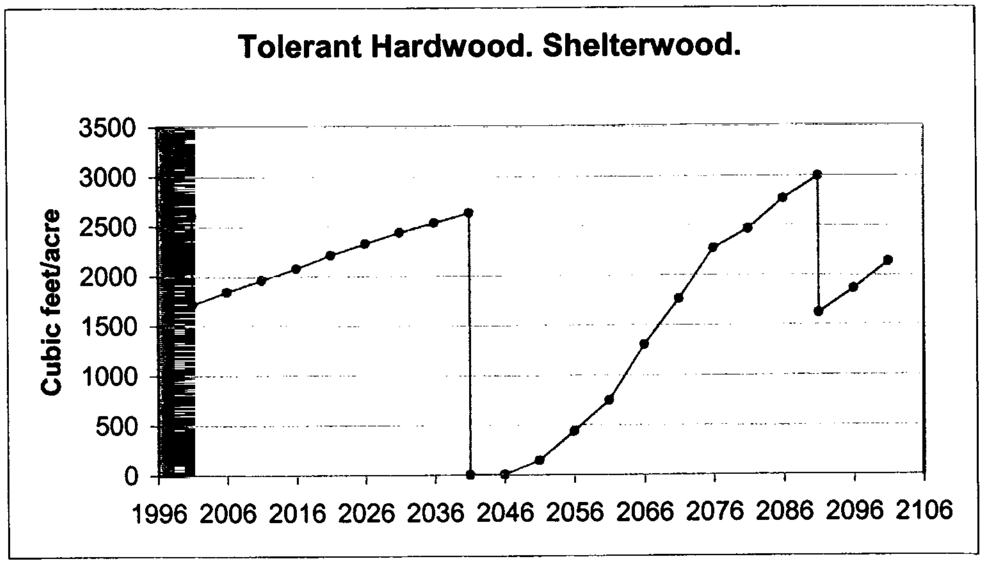

Figure 4.13: Merchantable standing volume distribution for tolerant hardwood stands subject to the shelterwood silvicultural system.

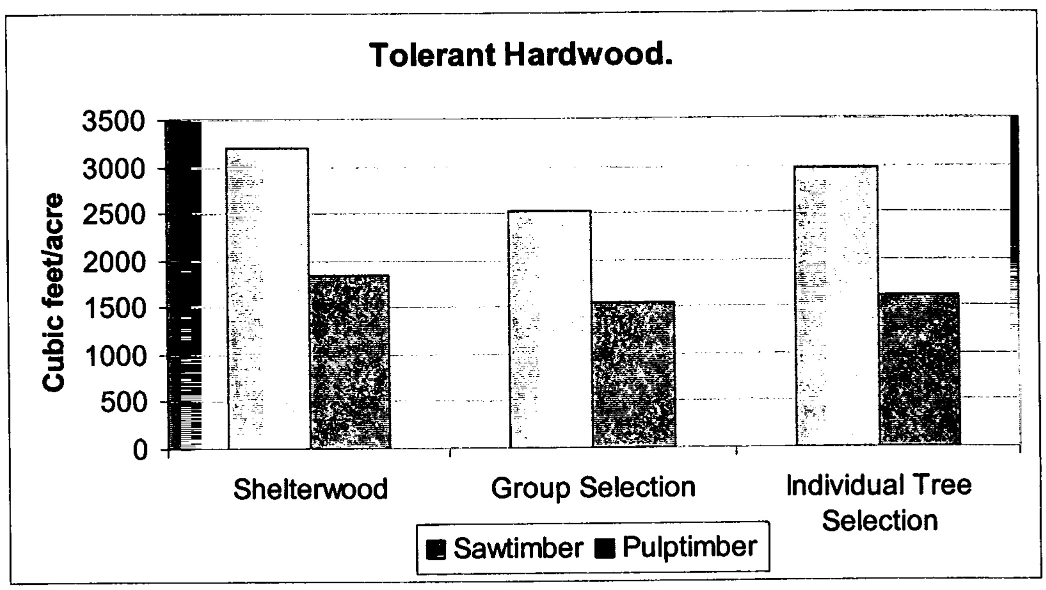

Figure 4.14: Comparison of the total merchantable harvested sawtimber and pulpwood for tolerant hardwood stands.

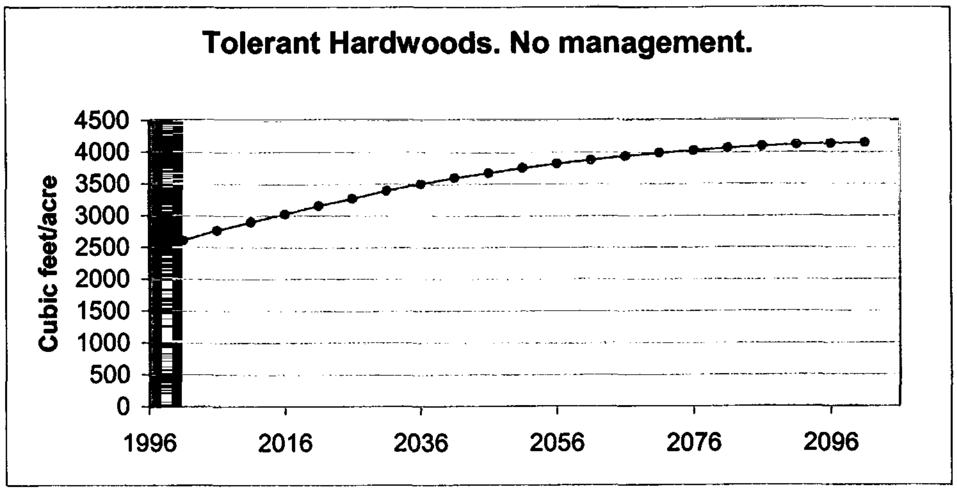

Figure 4.15: Merchantable stocking for tolerant hardwood stands without timber management.

For intolerant hardwood stands, the low quality of the sites is reflected in the lower slope of the inventory curves shown in figures 4.16, 4.17, and 4.18 if compared with previous stand types. The IHcc system presented a yield production (3,248 cubic feet per acre) 56 percent higher than IHsh, and 10 percent higher than IHgs (Figure 4.19). However, this relationship reversed for the percentage of merchantable sawtimber volume. IHgs' production of sawtimber represented 41 percent, IHsh 40 percent, and IHcc 33 percent of the total harvested volume (Figure 4.20). The IHgs system did not support a high merchantable stocking level in the forest after cut entries (Figure 4.18). An extended simulation for a 150-year period showed that the level of volume per acre left after each entry kept decreasing through time until it stabilized at around 200 cubic feet per acre. As with spruce-fir stands, under the no-management conditions the stocking of the merchantable intolerant hardwood stands more than doubled by the end of the simulated period (Figure 4.21).

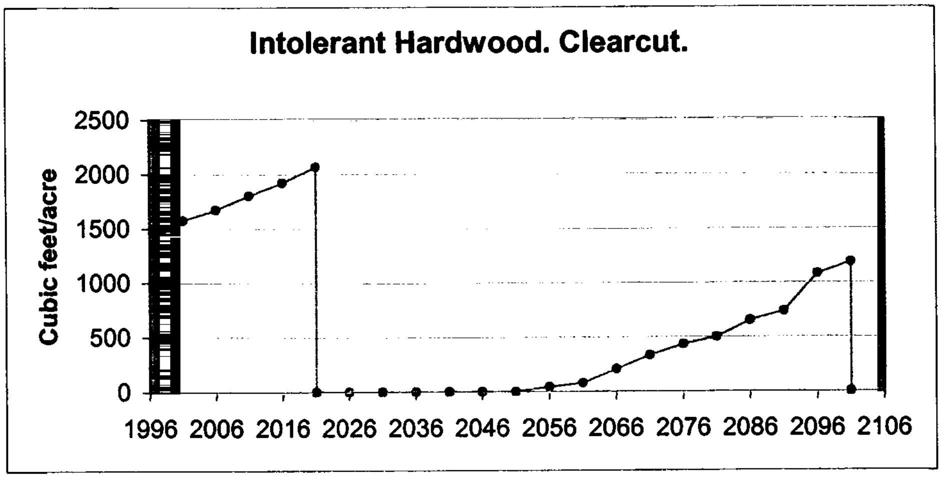

Figure 4.16: Merchantable standing volume distribution for intolerant hardwood stands subject to the intolerant hardwood silvicultural system.

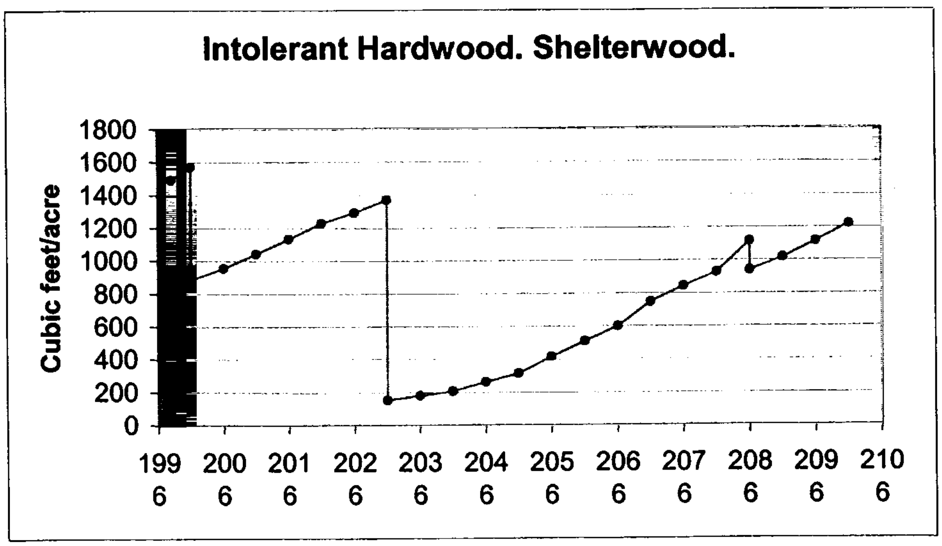

Figure 4.17: Merchantable standing volume distribution for intolerant hardwood stands subject to the shelterwood silvicultural system.

Note: the second regeneration removal (scheduled on 2056) did not remove any Merchantable volume.

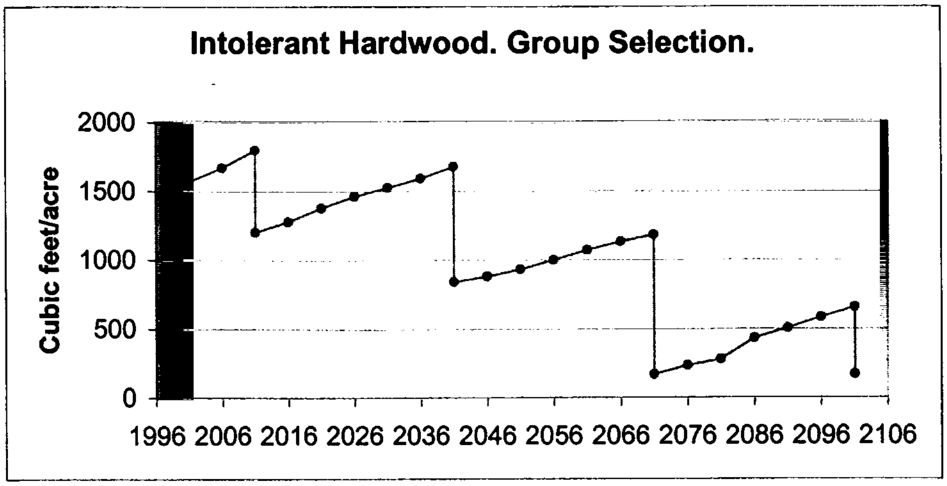

Figure 4.18: Merchantable standing volume distribution during a 100-year period for intolerant hardwood stands subject to the group selection system.

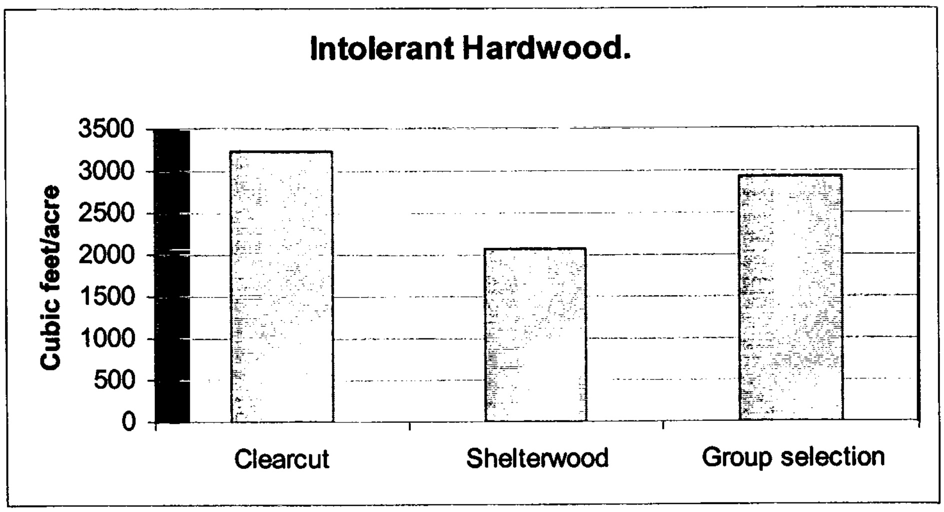

Figure 4.19: Comparison of total merchantable harvested volume (cubic feet/acre) in intolerant hardwood stands between the three defined silvicultural systems.

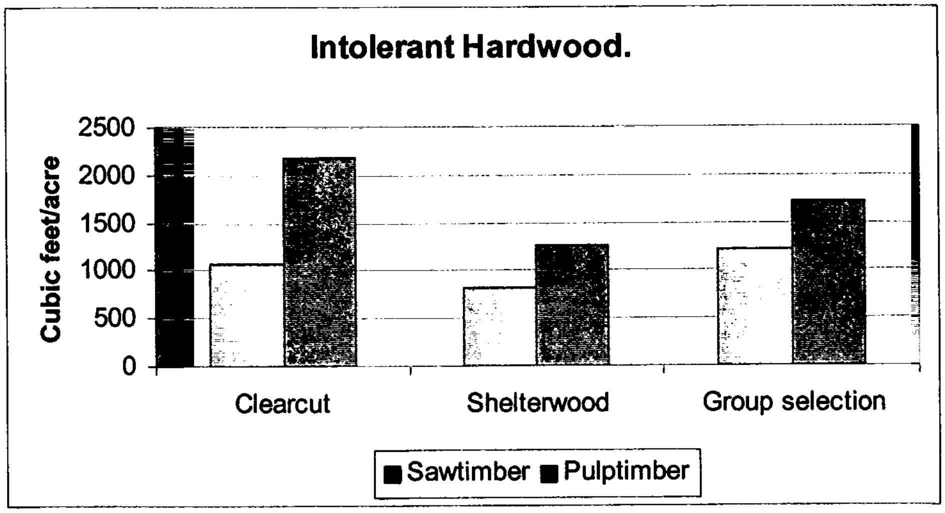

Figure 4.20: Comparison of the total merchantable harvested sawtimber and pulpwood for intolerant hardwood stands.

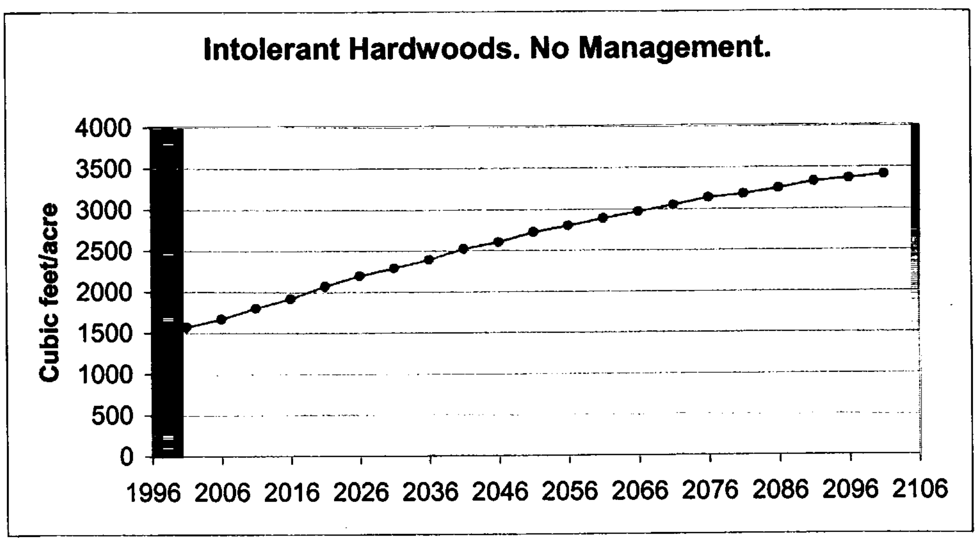

Figure 4.21: Merchantable stocking for intolerant hardwood stands with no timber management.

Aspen stands presented a different behavior than the rest of the intolerant hardwoods. Although Ags generated the highest volume of merchantable timber (4,741 cubic feet per acre), the difference was not as significant (not used in a statistical sense) as for the other intolerant hardwood stands: seven percent more than Acc65, and only two

percent more than Ags (Figure 4.22). The defined silvicultural systems for this forest type produced the lowest percentages of sawtimber: Acc50 and Acc65 produced 30 and 32 percent of the total respectively, and Ags 41 percent (Figure 4.23).

Both clearcut-based silvicultural systems, with 55-year and 65-year rotations, were not able to reach 100 percent of the initial inventory volume at the end of the rotation (Figures 4.24 and 4.25) and only Acc65 reached 75 percent of the initial amount. Like the other intolerant hardwood stands, the inventory volume remaining after each group selection entry cut decreased through the simulation period until it reached a level of around 200 cubic feet per acre, at which point this volume remained constant after the following removal cuts (Figure 4.26). The no-management option led to increase the inventory volume by 1.75 time (Figure 4.27).

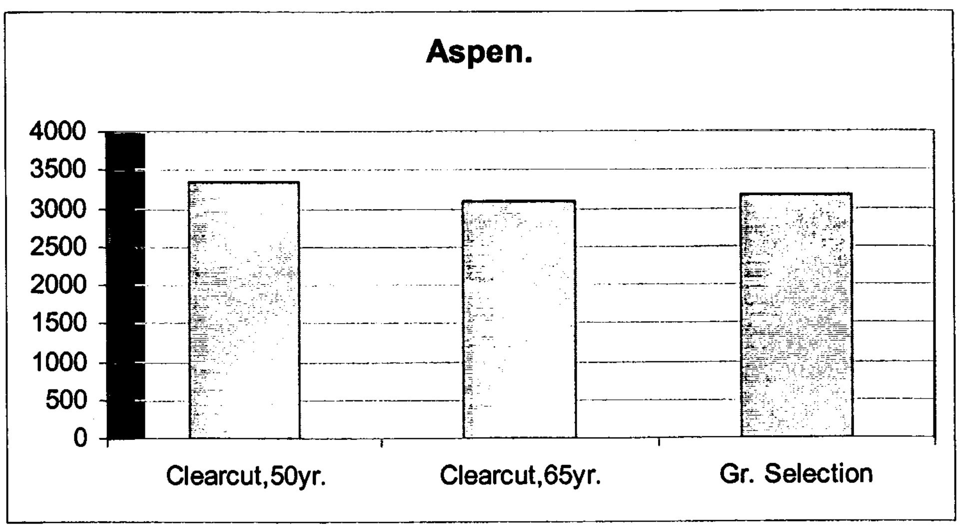

Figure 4.22: Comparison of total merchantable harvested volume (cubic feet/acre) in aspen stands between the three defined silvicultural systems.

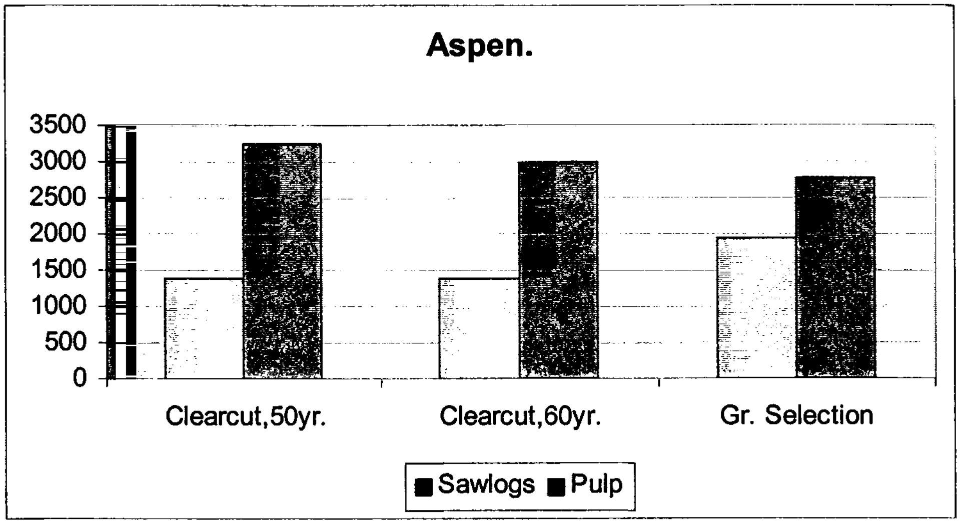

Figure 4.23: Comparison of the total merchantable harvested sawtimber and pulpwood for aspen stands.

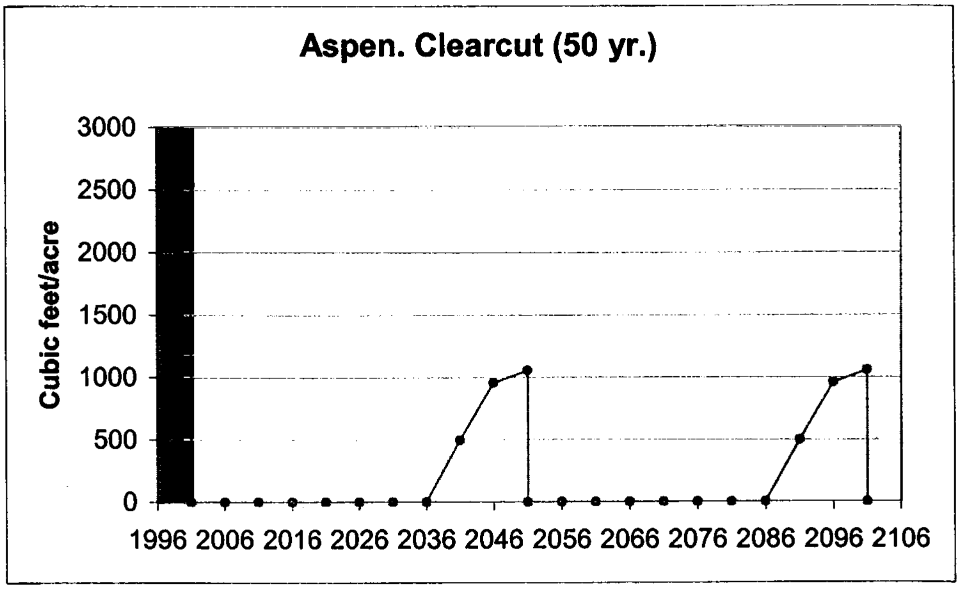

Figure 4.24: Merchantable standing volume distribution for aspen stands subject to the clearcut with 50-year rotation silvicultural system.

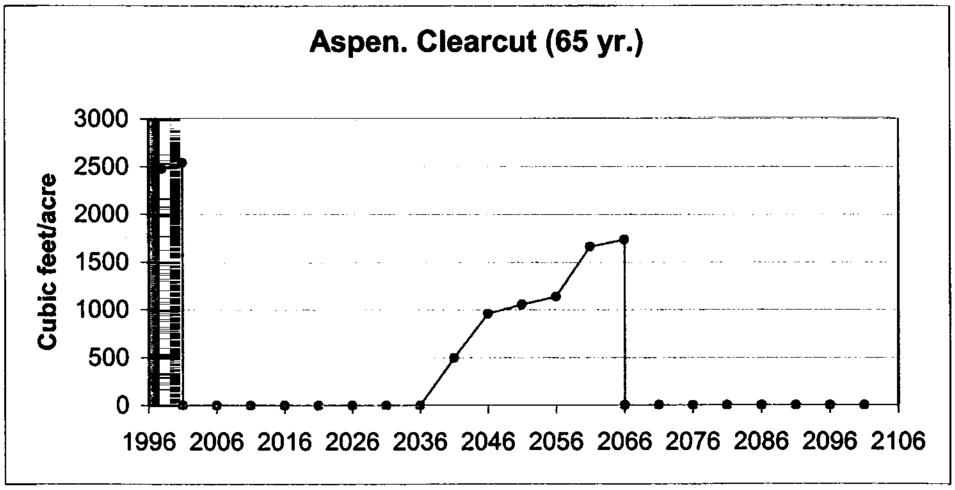

Figure 4.25: Merchantable standing volume distribution for aspen stands subject to the clearcut with 65-year rotation silvicultural system.

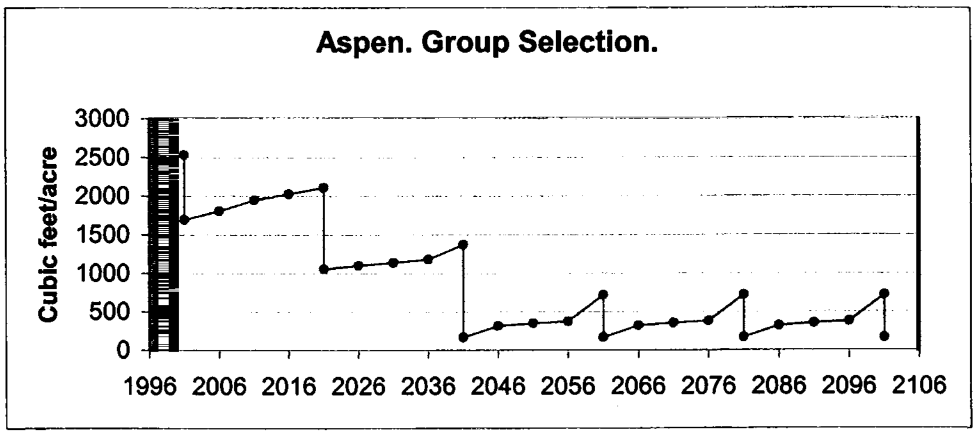

Figure 4.26: Merchantable standing volume distribution for aspen stands subject to the group selection silvicultural system.

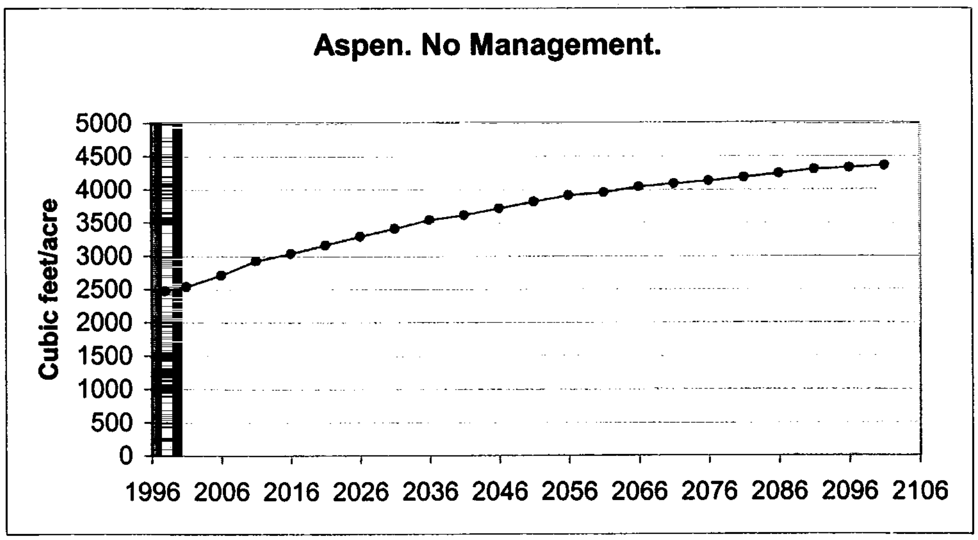

Figure 4.27: Merchantable stocking for aspen stands with no timber management.

The defined silvicultural systems for mixwood stands did not differ greatly with regard to yield. The Mis system provided the highest volume per acre (4585 cubic feet per acre), which represented ten percent more than Mcc's yield, and seven percent more than Msh's yield (Figure 4.28). The Mis system supplied 61 percent of the total merchantable volume as sawtimber, while Msh and Mcc produced 50 and 38 percent respectively (Figure 4.29). Mis retained the highest levels of inventory volume (Figure 30), followed by Msh (Figure 4.31 and Figure 4.32). The remaining merchantable inventory after each individual-tree selection removal entry increased through the simulated period, retaining around 1,277 cubic feet per acre after the first entry in 2001, and reaching 1,666 in 2101 (Figure 4.29). "No management" conditions in mixwood stands let the forest more than double the initial inventory volume (Figure 4.33).

Figure 4.28: Comparison of total merchantable harvested volume (cubic feet/acre) in mixwood stands among the three defined silvicultural systems.

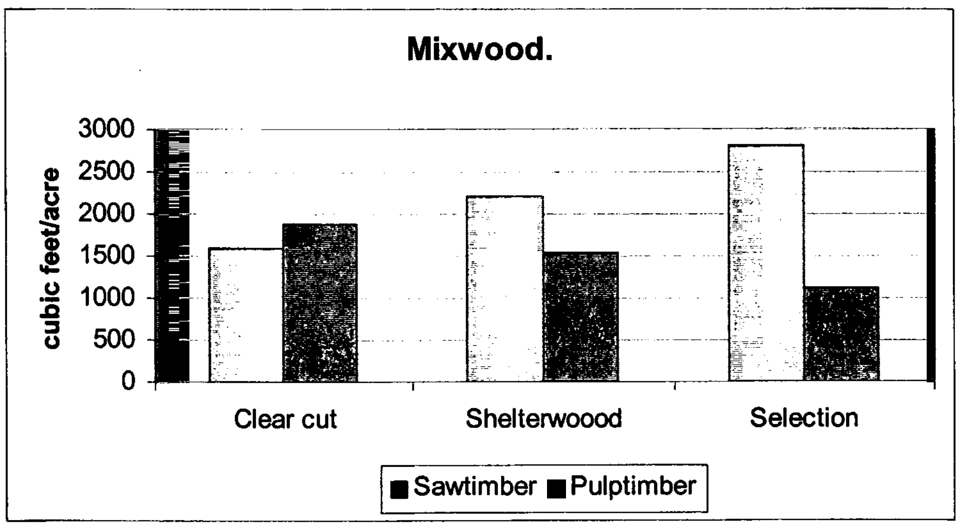

Figure 4.29: Comparison of the total merchantable harvested sawtimber and pulpwood for mixwood stands.

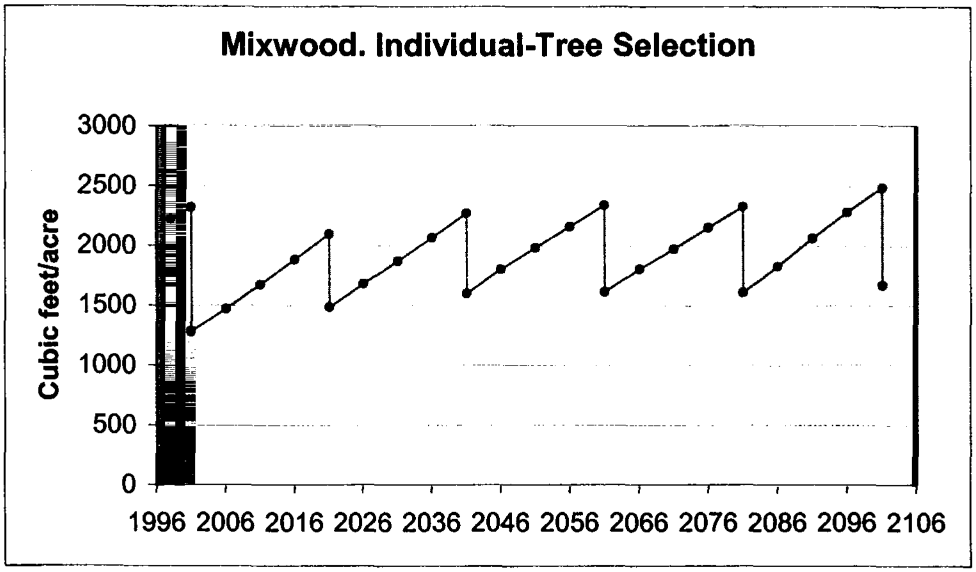

Figure 4.30: Merchantable standing volume distribution during a 100-year period for mixwood stands subject to the individual-tree selection silvicultural system.

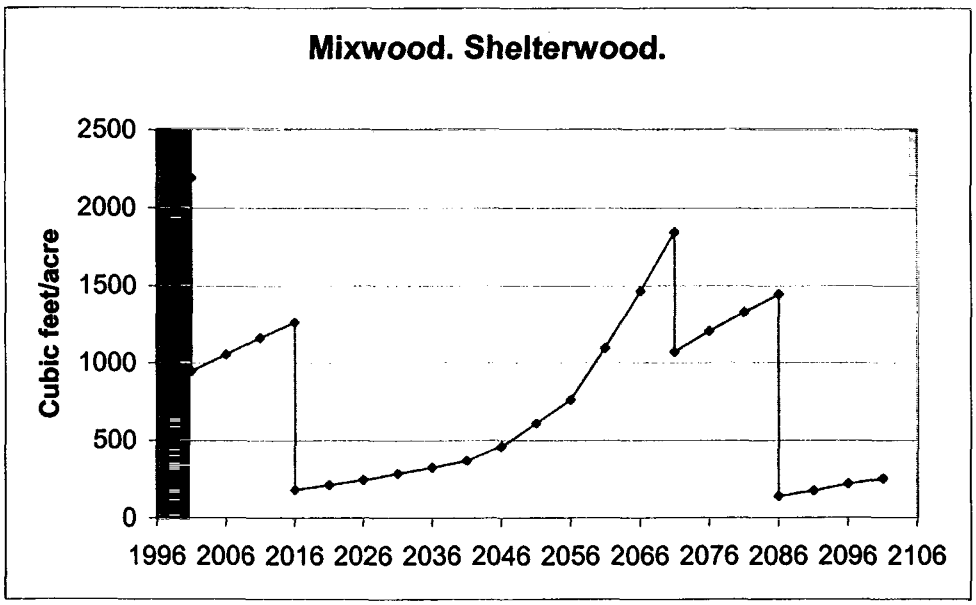

Figure 4.31: Merchantable standing volume distribution for mixwood stands subject to the shelterwood silvicultural system.

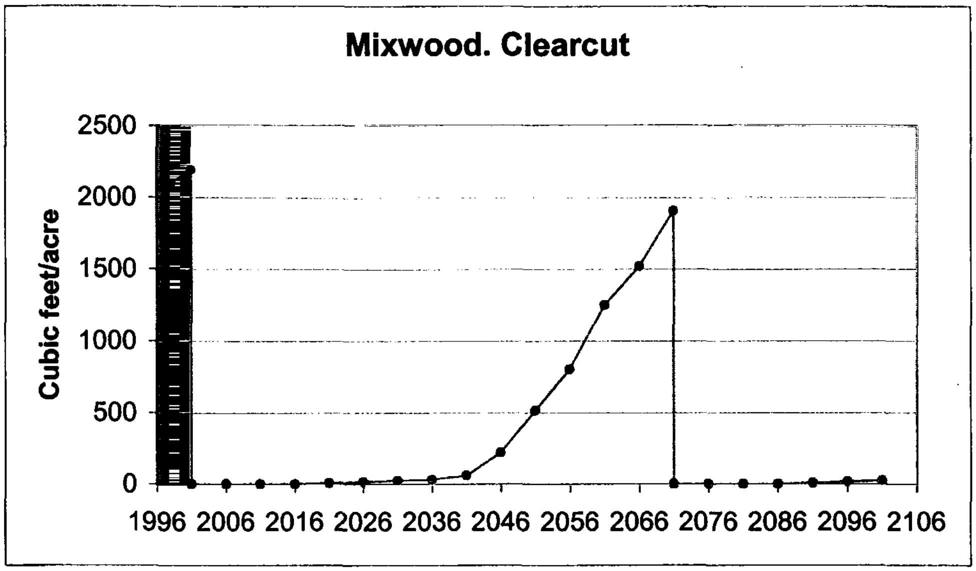

Figure 4.32: Merchantable standing volume distribution for mixwood stands subject to the clearcut silvicultural system.

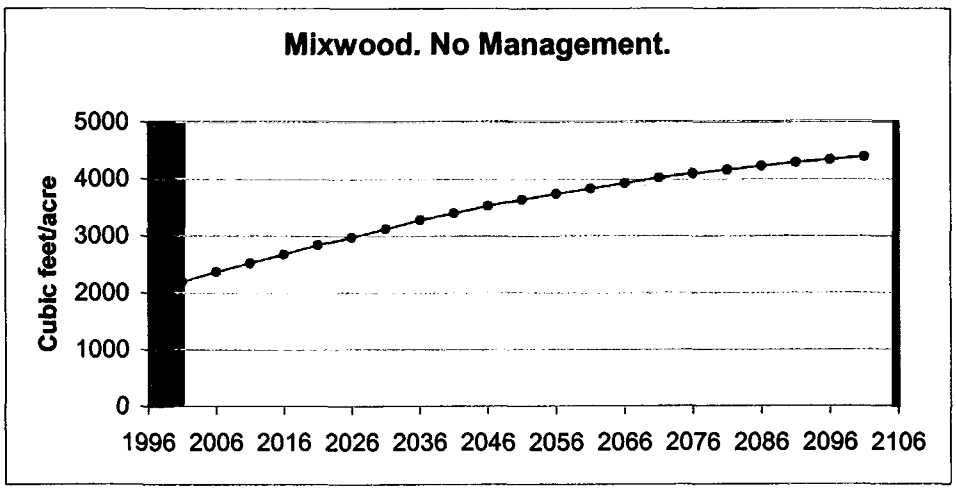

Figure 4.33: Merchantable stocking for mixwood stands with no timber management.

At the landscape scale, using the average stands conditions within each forest type, spruce-fir stands under S-Fis supplied the highest yields of timber, followed by tolerant hardwood under THsh, and aspen stands under Acc50 silvicultural systems.

Figure 4.34 shows the silvicultural systems that supplied the highest yields for each forest type in the Bigelow Preserve. Under "no management" conditions, spruce-fir stands also produced higher harvested volumes at the end of the simulation period than any other forest type.

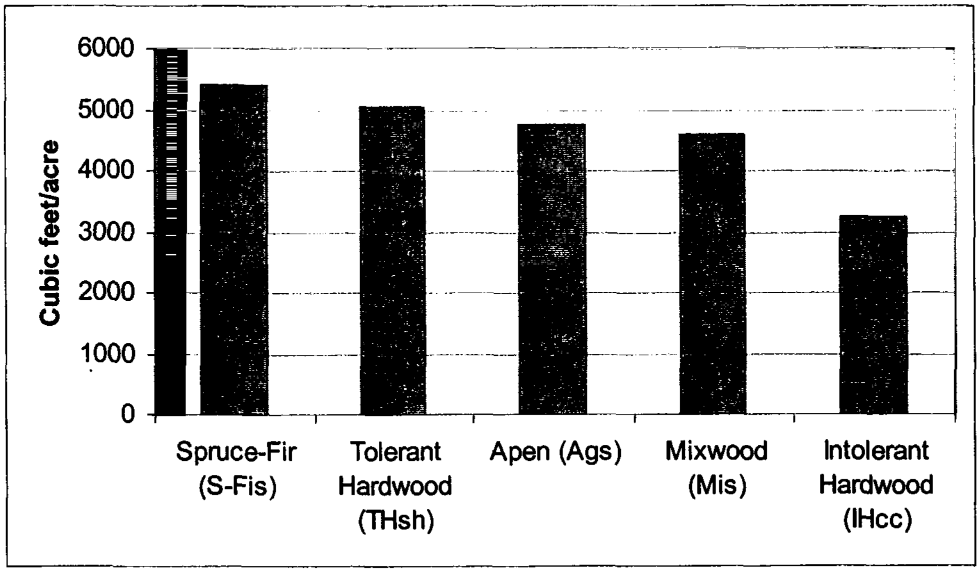

Figure 4.34: Silvicultural systems that produced the highest yield levels for each average forest type stand.

For timber revenue calculations, I estimated stumpage prices for pulpwood and sawtimber in the Bigelow Preserve from the market price of logs. The inventory volume of the commercially valuable timber available to harvest within a given silvicultural system was multiplied by the mill delivery price of logs, adjusted for size and species composition. This gave us the value of the forest products as delivered without considering other factors that would affect the final value of the products. To get a more realistic value I deducted the estimated costs of extraction, transportation, administration and profit margin for an efficient harvester. I considered cut-to-length machinery outputs to calculate harvesting costs and performance within each type of vegetation removal. I

also considered the costs associated with planting, precommercial thinning, herbicide release, road construction and maintenance, and trail construction and maintenance.

The analysis of the financial benefits associated with each silvicultural system showed that, while ensuring that fragile ecosystems were protected from timber harvesting practices, the maximum average net present value (NPV) for the entire forest was 214 dollars per acre. This amount included those acres not harvested due to the protection of the alpine, subalpine and riparian ecosystems, and areas with high risk of erosion. This scenario included the Acc65 silvicultural system for aspen stands, IHcc for intolerant hardwood stands, THis for tolerant hardwood stands, Mcc for mixwood stands, and S-Fcc for spruce-fir stands. However, the NPV could reach a higher value, 263 dollars per acre, if the representation of spruce-fir stands in the forest were increased by 15 percent at the expense of reducing some of the hardwood stands in those areas where the presence of beech (*Fagus grandifolia*) increased after European settlement in the region. Achieving the species composition distribution of a presettlement forest for this area (Figure 4.35), the NPV decreased by ten percent relative to the previous case.

An analysis of the three defined management intensities revealed that keeping the same management intensity in the forest did not increase financial revenues (Figure 4.36). Although, management intensity one produced a higher NPV (206 dollars per acre) than the other two levels, it was 22 percent lower than finding the right combination of intensities for each stand type. Intensities two and three presented a very similar NPV, 131 and 130 dollars per acre respectively.

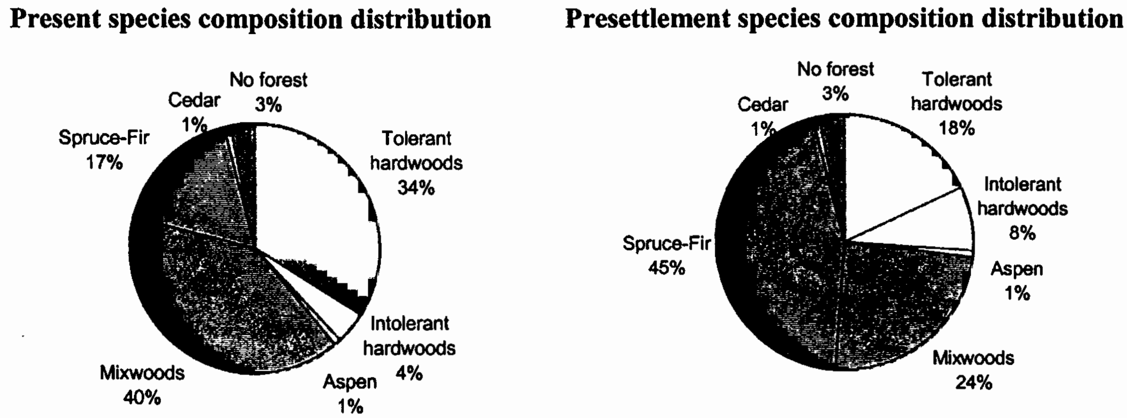

Figure 4.35: Present and estimated presettlement species composition distribution[5] for the Bigelow Preserve.

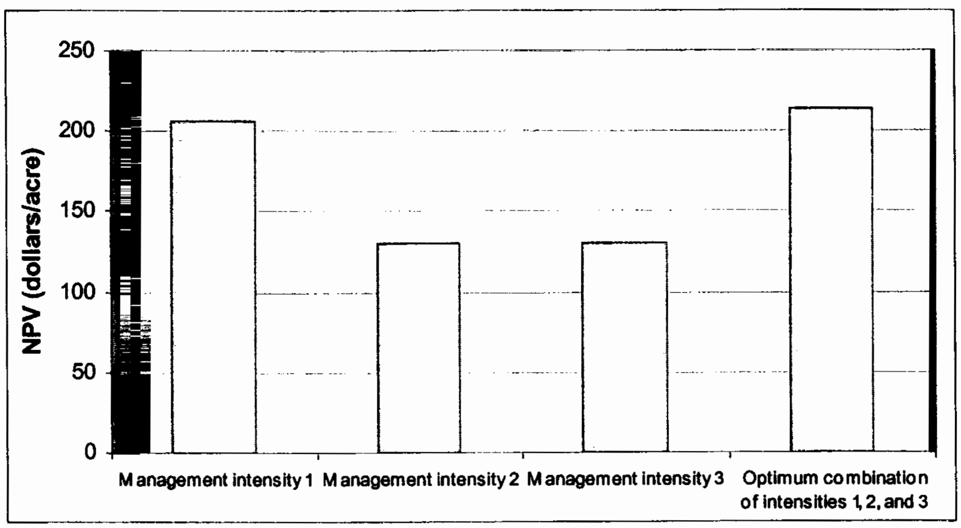

Figure 4.36: Net Present Value averaged for every acre of the forest management under the silvicultural systems defined under management intensities one, two, three, and the optimum financial combination of the three of them.

The silvicultural systems associated with obtaining the maximum revenues from timber production did not coincide with the silvicultural systems that produced the highest harvested volume (Figure 4.34) for each forest cover type. While for spruce-fir,

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[5] Based on Lorimer's study (1977).

mixwoods, intolerant hardwoods and aspen stands the most profitable system involved clearcuts, and for tolerant hardwoods it was individual tree selection cuts, the highest volume yields were provided by individual tree selection systems defined for spruce-fir and mixwoods, group selection system for aspen, shelterwood system for tolerant hardwoods, and clearcut system for intolerant hardwoods.

Maximum revenues were associated with high harvested pulpwood volumes (Table 4.4). An analysis of the timber products (pulpwood and sawtimber) revealed that there was a direct relationship between pulpwood and NPV and an indirect relationship between sawtimber and NPV (Figure 4.37). At the forest level, there was not enough price premium for large diameter trees to justify the costs of producing them; in other words, the cost of producing higher tree diameters did not compensate their higher market value. Because these results are averaged for the entire forest within each forest type, the individual analysis of a particular stand might be different.

Management scenario for the forest	**Sawtimber (bft/acre/yr)**	**Pulpwood (tons/acre/yr)**	**NPV ($/acre)**
Management intensity 1	116.25	0.55	206
Management intensity 2	128.40	0.49	131
Management intensity 3	156.36	0.45	130
Combination of management intensities that maximizes NPV	110.39	0.53	214
Combination of management intensities that maximizes NPV and increases spruce-fir stands by 15%	105.38	3.50	263
Combination of management intensities that maximizes NPV and accomplishes presettlement species composition.	114.31	3.47	238

Table 4.4: NPV, and timber volumes for sawtimber and pulpwood products for different scenarios based on the management intensity of timber harvesting practices.

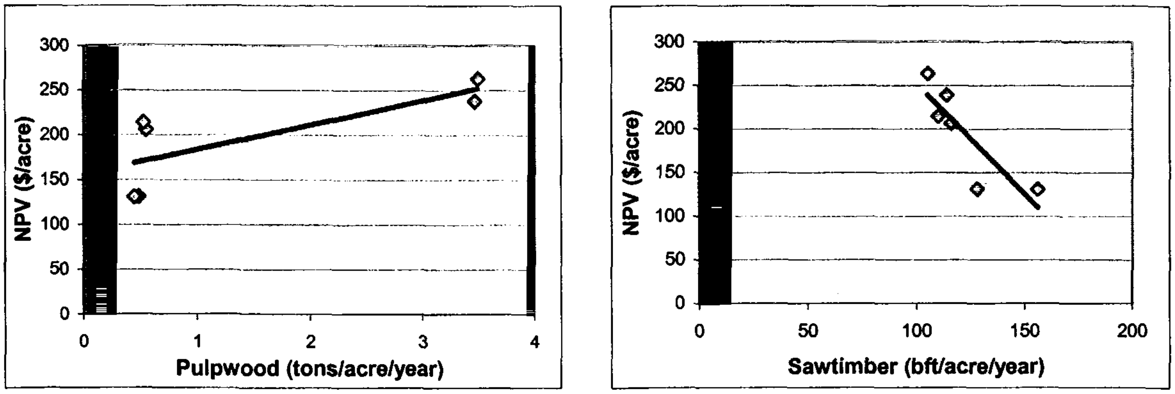


Figure 4.37: Relationship between harvested pulpwood volume and NPV (A) and sawtimber volume and NPV (B).

4.7. CONCLUSIONS

The information presented in this chapter was relevant in the development of a modeling environment where different management scenarios could be simulated (chapter 5). We found that FVS is a flexible tool in the estimation of forest growth and yield at both at the stand and forest levels. However, because NE-TWIGS does not simulate natural regeneration, this information had to be independently estimated and included in the simulation. This limitation can result in an inaccurate estimation of forest growth in the forest. The incorporation of natural regeneration equations within the software based on field data would strength the utility and accuracy of this program.

Silvicultural systems adopted for each forest type represented some of the intensity management levels currently practiced in the North East with some variations on the silvicultural parameters, adjusted for the study area given its biophysical conditions. The primary management goal (e.g., maximizing revenues, products or harvested volume) would define what combination of management intensities is optimal in order to achieve it. In no case, the same level of management intensity applied to the entire provided the best solution for a given goal.

Chapter 5. GIS ANALYSIS AND COMPUTER SIMULATION, AN INTEGRATED APPROACH TO SUPPORT TACTICAL PLANNING AND DECISION MAKING. ADVANTAGES AND LIMITATIONS

5.1 CHAPTER ABSTRACT

This chapter describes a combination of computer technologies used to support tactical planning and tradeoff analysis in forest ecosystem management. I analyzed the capabilities that the linear-programming based software "Spectrum" provides, how its input-output data integrate with FVS (Forest Vegetation Simulator, a growth and yield simulation computer program), and a geographic information system at the landscape level. I carried out a close overview of the capabilities and limits of the simulation building process in Spectrum, including the input of geographical data requirements and manipulation, the managerial information, the natural processes integration, and goal and constraints definition. The overview also included the Spectrum solution generation and spatial solution allocation, which determine where, when, and what management strategies should be implemented. I developed a model for the State-owned Bigelow Preserve in western Maine and created a wide array of management scenarios, varying from "no management" to "high intensity timber management", as well as a variety of multiple-use scenarios that included the protection of fragile ecosystems, the creation of recreational opportunities, the visual quality protection of the area, the achievement of European presettlement species composition and vertical structure, and the achievement of a defined sustainability criteria. We concluded that Spectrum and its spatial link, Spectra Visio, represent a powerful decision support tool. Spectra Visio not only allows the spatial manipulation of Spectrum solutions, crucial step during strategic planning, but

also provides an accuracy assessment for the constructed model. The model building process was one of the keys to both a successful analysis and flexibility to change management goals. Spectrum's restriction on six layers of spatial information limits the creation of a more complete model that would allow us to include unpredicted future goals or modifications.

5.2. INTRODUCTION.

Biophysical information and data analysis can reveal the current status of natural forests and their evolution through time. Data collection and monitoring studies help us to predict future outputs based on past observations. However, one of the major tasks in forest ecosystem management is to incorporate uncertainty into the decision making processes. Forest ecosystem behavior is difficult to forecast, as social needs and values as they change through time.

Today, computer technology helps us to explore spatial and temporal problems that have been difficult to address previously. There is no single computer application designed to address these complex problems, however it is possible to use a variety of software packages to achieve our desired results. The integration of geographic information systems (GIS) with computer modeling permits a better understanding of the potential solutions to achieve desired goals. While data analysis and computer simulations cannot replace the complex process of decision making or eliminate uncertainty, they can provide decision support in forest ecosystem management through exploration of potential outcomes of a wide range of management scenarios to address likely future needs.

Within this context, the Spectrum computer software represents a powerful tool to manipulate, analyze and integrate information with other computer programs. This Forest Service software (USDA 1995a) allows the user to create models of forests and simulate forest interactions and responses, across landscapes and through time. Based on linear (including goal) programming techniques, this model-builder tool can integrate different social interests and help to develop strategies for implementing forest policy on the ground. Spectrum's primary applications are 1) to identify possible paths to achieving desired goals, 2) to provide precise information needed in strategic planning, and 3) to facilitate decision-making through exploring tradeoffs among alternative management scenarios.

A management plan is "a geographically-explicit treatment schedule designed to achieve the objective set for each resource value of interest. [It] must specify what treatments are to be implemented, in what amounts, where and when" (McLean *et al.* 1999). Spectrum, with its geographic information system (GIS) link "Spectra Vision" serves as a powerful tool for exploring a wide range of management plans without investing a large amount of time. Once the model of the forest is built, changes in management restrictions and goals take very little extra work.

Forest values tradeoff analysis quantifies how competing forest uses affect economic, social and environmental values of the forests. Also, tradeoff analysis can break down scientific information so that policy makers can understand the implications of their decisions and make better, more informed decisions. The modeling capacity of Spectrum provides the user with the opportunity to define which outputs he or she wishes to follow through the simulation period and to analyze the tradeoffs among different

management scenarios. Whether one wants to use monetary units, biodiversity indices, recreational opportunities, basal area, or visual quality of the forest depends on the user's preferences and the available information.

In the process of building up a simulation model of a forest, Spectrum needs to be integrated with other computer programs to optimize its capabilities. GIS and growth and yield programs are some of the software packages that Spectrum should be integrated with, as no one program provides integrated data to better understand complex ecosystems. The version used in this study, Spectrum 2.5, only allows "Model I" formulations, which define decision variables that follow the life history of a given land unit. In a "Model II" formulation, a land unit may be represented by several different decision variables within the planning horizon (Davis *et al.* 2001).

To demonstrate the capabilities and limitations of this management tool, I developed a model of the Bigelow Preserve, a State-owned management unit located in western Maine. The Maine Bureau of Parks and Lands has managed these 36,392 acres of public land since 1976. The main management direction has been to support a wide range of uses of the forest while protecting fragile ecosystems within the area.

The first objective of this chapter was the integration of mathematical programming tools with geographic information systems and forest growth simulation models and as part of a model development and results analysis process. Special attention was given to the interactions among the software packages and the advantages and limitations resulting from their integration. In an attempt to create a range of management alternatives and evaluate the different benefits that forest can provide, the second objective was to build a model that would allow us to simulate a range of management

scenarios for the Preserve from, “no timber management” to “high intensity management”, through several cases of multiple-use management plans. By providing an array of management scenarios and outcomes related to each of them represents a powerful decision making tool to guide managers and decision makers to come up with that management plan that accomplishes desired goals. Though an analysis of the results found in this chapter, chapter 6 examines the tradeoffs associated with accomplishing different management goals, and the relationship among outputs, while providing guidance for the decision making process by breaking down these results.

5.3. METHODS: SPECTRUM MODEL LOGIC AND STRUCTURE

The Spectrum modeling system requires four main groups of information to create a forest model: geographic information, managerial information, natural processes, and goals and constraints (Figure 5.1).

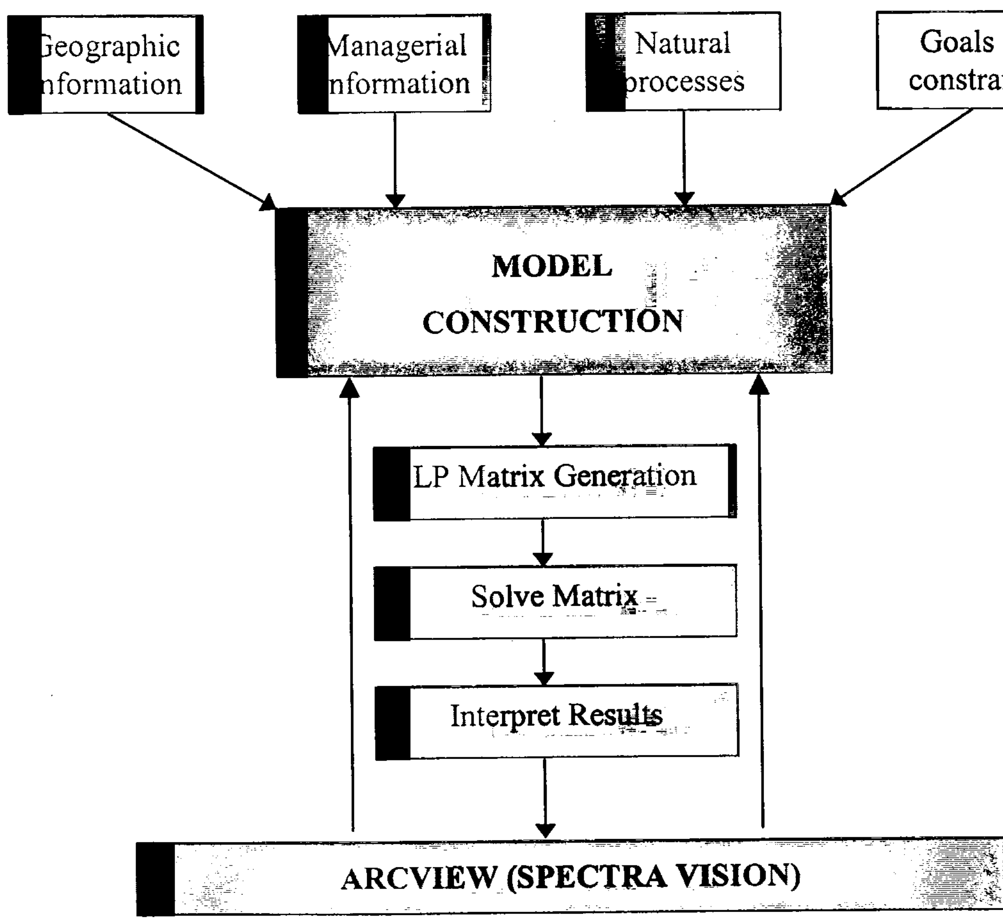


Figure 5.1: Structure of the model construction and solution processes in Spectrum .

5.3.1. Geographic information

The first step in constructing a landscape model is to decide which physical information is needed, keeping in mind that Spectrum solutions, which represent management strategies, are based on the chosen data. For example, if our goal is to

protect the visual quality of a landscape, we need not only to identify and quantify those actions that create a visual impact, but also to identify the visually sensitive areas by the physical elements that characterize them (elevation, slope, proximity to viewpoints). These physical elements must be included in the model. A clear knowledge of goals and how they translate into developing strategies on the ground will help in the selection of the physical information.

Ideally, physical information should be in a geographical format, to allow the use of geographic information systems to create sets of spatial polygons (discrete parcels), each of which can be described in terms of several layers of information. Each polygon (or a defined group of them) represents a homogeneous (or non-contiguous homogeneous) "analysis unit" in Spectrum and, basically, any Spectrum plan consists of how analysis units are associated with different management strategies or prescriptions. Spectrum allows up to six layers of analysis unit information. Within each layer, one may define up to 125 land attributes to characterize each analysis unit.

It is important to distinguish between the number of analysis units for the modeling phase and the number of management units of a final management plan; they need not to match. A "management unit" can be defined by grouping analysis units with the same management prescriptions. This way, we can keep the individualism of each analysis unit during the development of a desirable plan without having an unworkable number of management units for the implementation of the management strategies. The only disadvantage of having a large number of analysis units is that it increases the model size, and bigger models require more computer memory and time to produce solutions.

To define the analysis units for the Bigelow Preserve, I used the 1998 Bureau of Parks and Lands inventory data, roads, trails, and water bodies coverages, and the 1999 USGS National Elevation Dataset with 30-meter pixel resolution (US Geological Survey 1999). We exported all the vector coverages into ARC/INFO® format; geo-referenced into Clarke 1866 Spheroid, NAD83 datum, and Universal Transverse Mercator projection (zone 19); and constructed topology. In addition, I also geo-referenced raster coverages to the same projection, spheroid and datum as the vector coverages.

We used ARC/INFO® 8 to analyze all vector coverages. Buffer zones (Figure 5.2), created for each road, trail and water coverages, helped us to define different levels of spatial constraints to achieve desired goals. For example, if our goal were to reach a specific level of visual quality in the study area, buffers along the trails identified some of the areas sensitive to visual impact. Raster information was manipulated with Erdas Imagine® 8.5, creating two new raster information imageries: the elevation and the slope. Erdas Imagine's GIS package allowed us to integrate the coverage resulting from joining all vector coverages (inventory, road buffers, trail buffers and the water buffers) with the raster information (elevation dataset) by estimating the mean elevation and the mean slope values for each polygon of the vector coverage. Incorporating the slope and elevation information did not increase the final number of polygons or analysis units, so did not affect model memory requirements or solution time.

Each analysis unit imported into Spectrum had six layers of information. Within each layer, I defined the following land attributes:

- A three-character inventory code, where the first character represented species composition (Table 5.1), the second diameter class (seedling/sapling, pole, sawtimber), and the third crown closure percentage (Map 5.1).

- Distance to roads: I defined three buffer distances to roads –from zero to one half mile, from half to two miles, and more than two miles (Map 5.2). These distances were part of the mapping criteria used to provide different recreational opportunities (Appendix A).
- Distance to trails: I also defined three buffer distances to hiking trails slightly modifying the US Forest Service classification for scenery management (USDA Forest Service 1995b) for immediate foreground (from zero to 600 feet), foreground (from 600 feet to half mile) and middleground (more than half mile) (Map 5.3).
- Distance to water bodies based on the Land Use Regulation Commission (LURC 1971): 100-foot buffers for ponds and lakes, and 75-foot buffers for streams and rivers (Map 5.4).
- Elevation. The mean elevation calculated for each polygon was grouped under one of the following categories: water level (less than 1300 feet), level 1(1300 to 1969 feet), level 2 (1970 to 2624 feet), level 3 (2625 to 3279 feet), level 4 (3280 to 3939 feet), level 5 (more than 3940 feet) (Map 5.5).
- Slope. The mean slope estimated for each polygon was also grouped into one of the following categories: level 1 (less than 10 percent), level 2 (11 to 20 percent), level 3 (21 to 30 percent), level 4 (31 to 50 percent), level 6 (more than 51 percent) (Map 5.6)

Species Code	Dominant Species
S - >66 % softwood	*Picea rubens* Sarg, *Abies balsamea* (L.) Mill., *Picea mariana* (Mill.) B.S.P., *Thuja occidentalis* L., *Pinus strobus* L., *Tsuga canadiensis* (L.) Carr.
M - 33-66 % softwood	*Abies balsamea* (L.) Mill., *Picea rubens* Sarg *Thuja occidentalis* L., *Tsuga canadiensis* (L.) Carr., *Betula alleghaniensis* Britton, , *Acer rubrum* L, *Betula papyrifera* Marsh, *Fagus grandifolia* Ehrh.
H - <33% softwood	*Acer saccharum* Marsch, *Fagus grandifolia* Ehrh, *Betula alleghaniensis* Britton.
C - >66% cedar	*Thuja occidentalis* L.
A - >66% aspen	*Populus tremuloides* Michx.
F - intolerant hardwoods	*Betula papyrifera* Marsh, *Acer rubrum* L., *Populus tremuloides* Michx.

Table 5.1: Principal species composition in each forest cover type in the Bigelow Preserve.

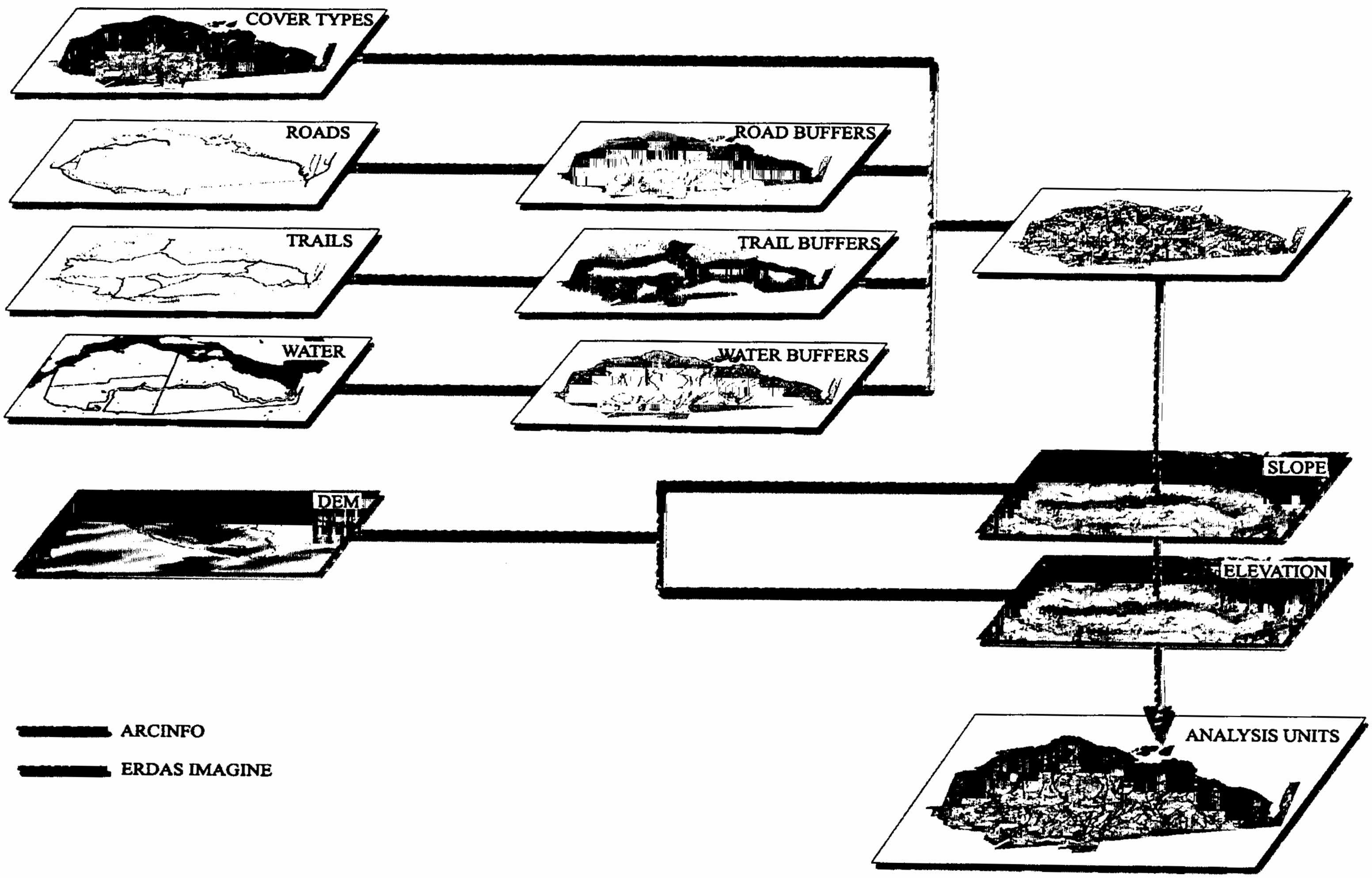
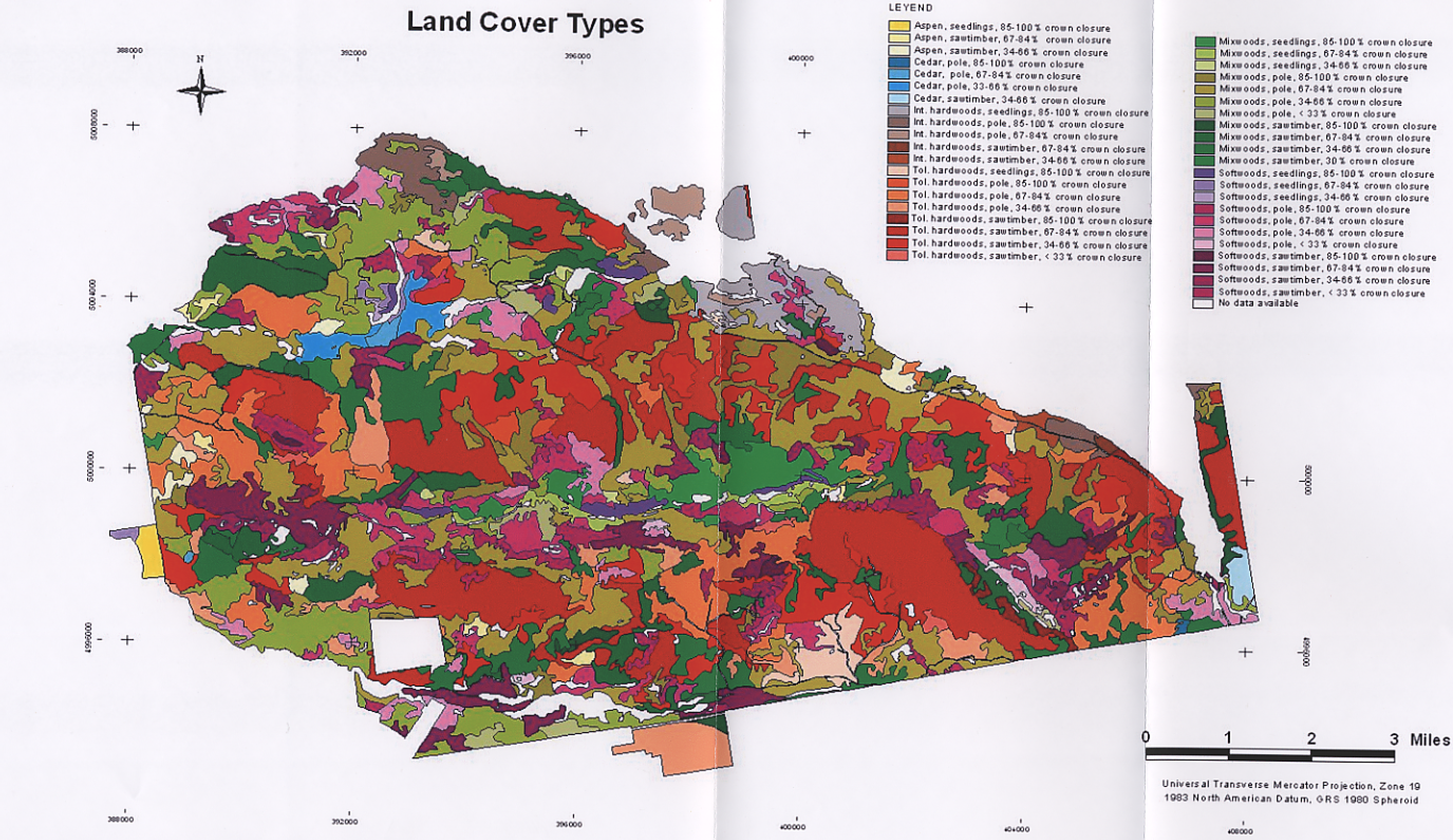
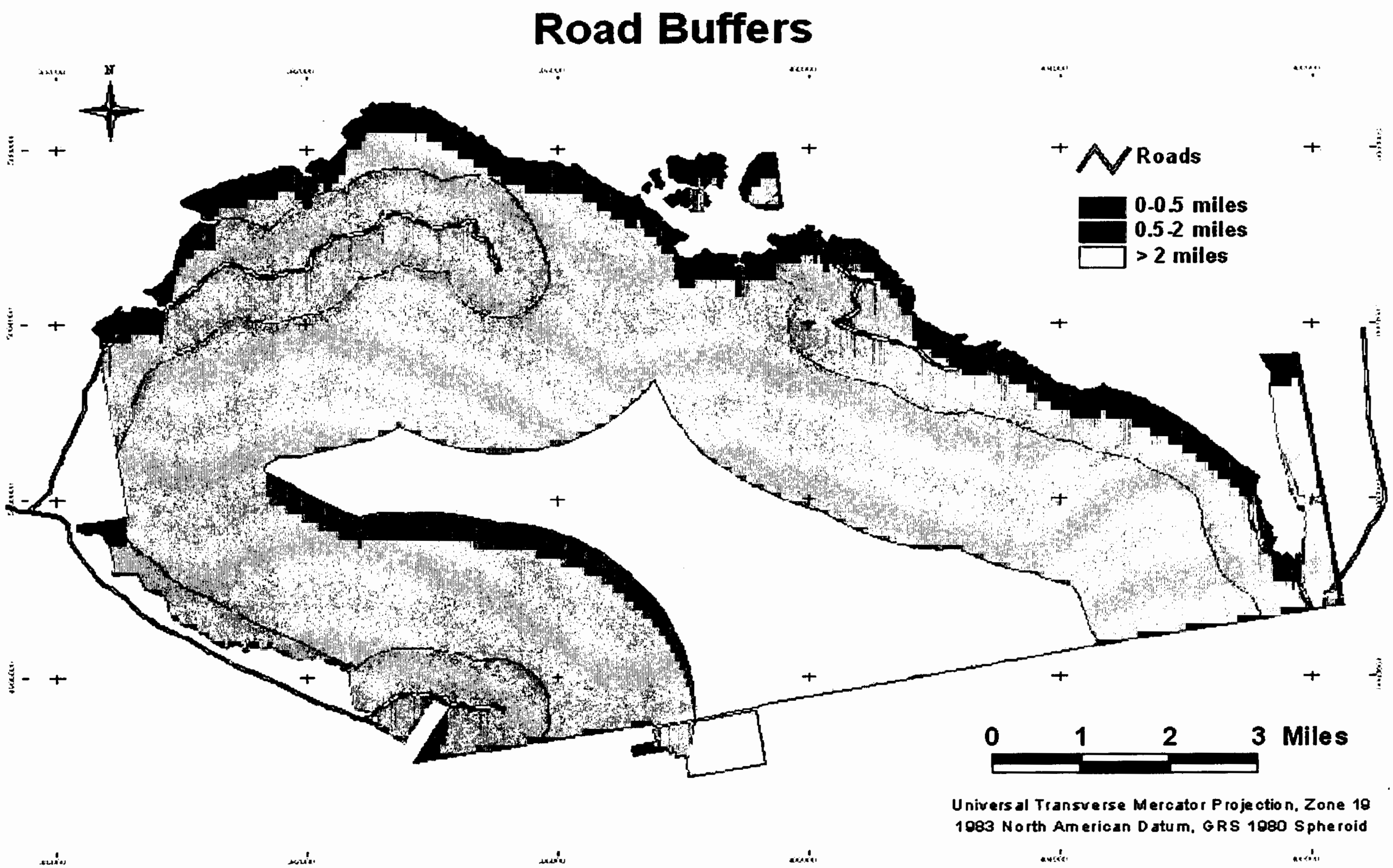


Figure 5.2: Creation of Spectrum spatial analysis units through GIS analysis and image processing.

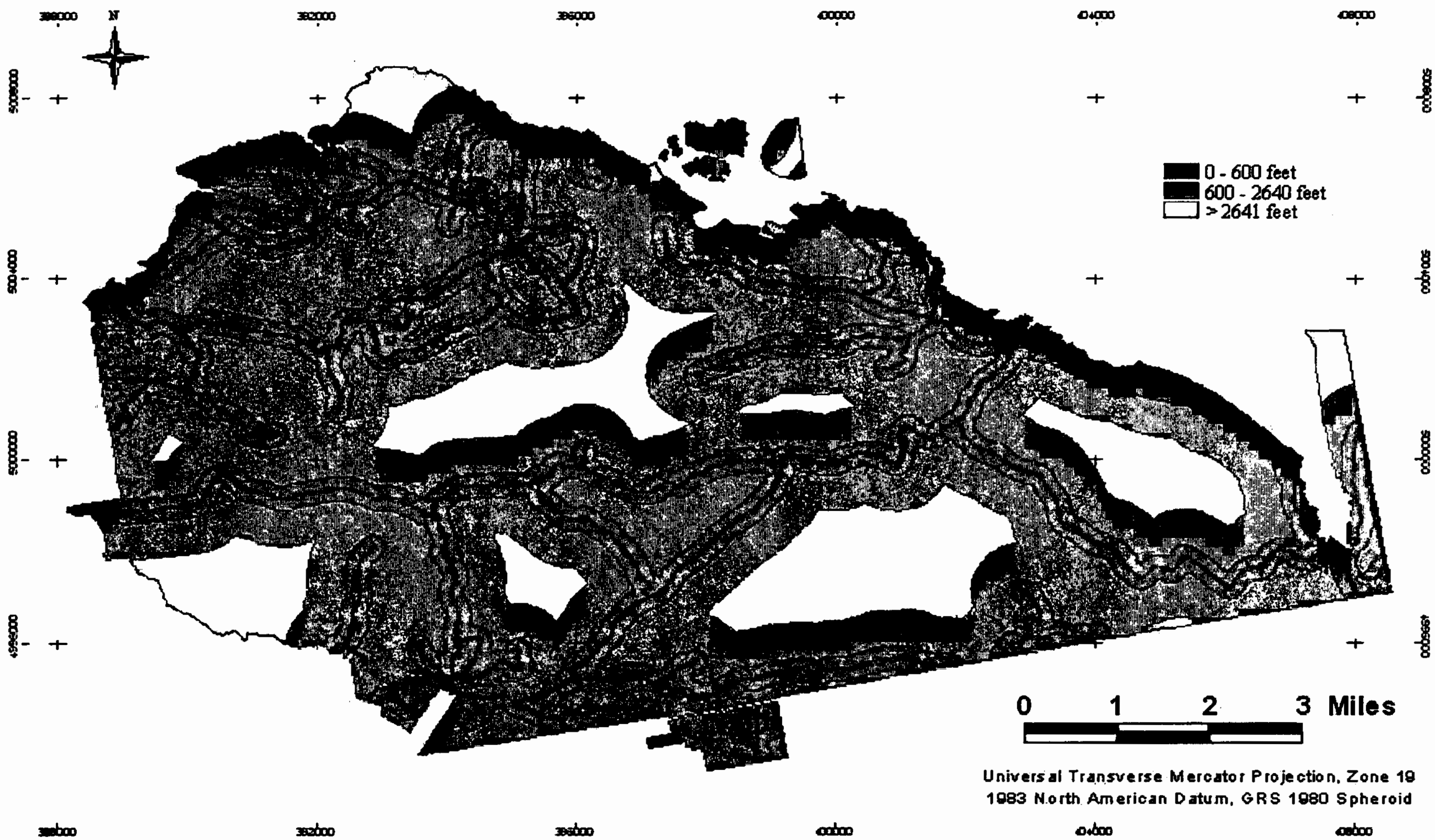


Map 5.1: Vegetation types of the Bigelow Preserve.
Source: Maine Bureau Parks and Lands inventory data (unpublished information)

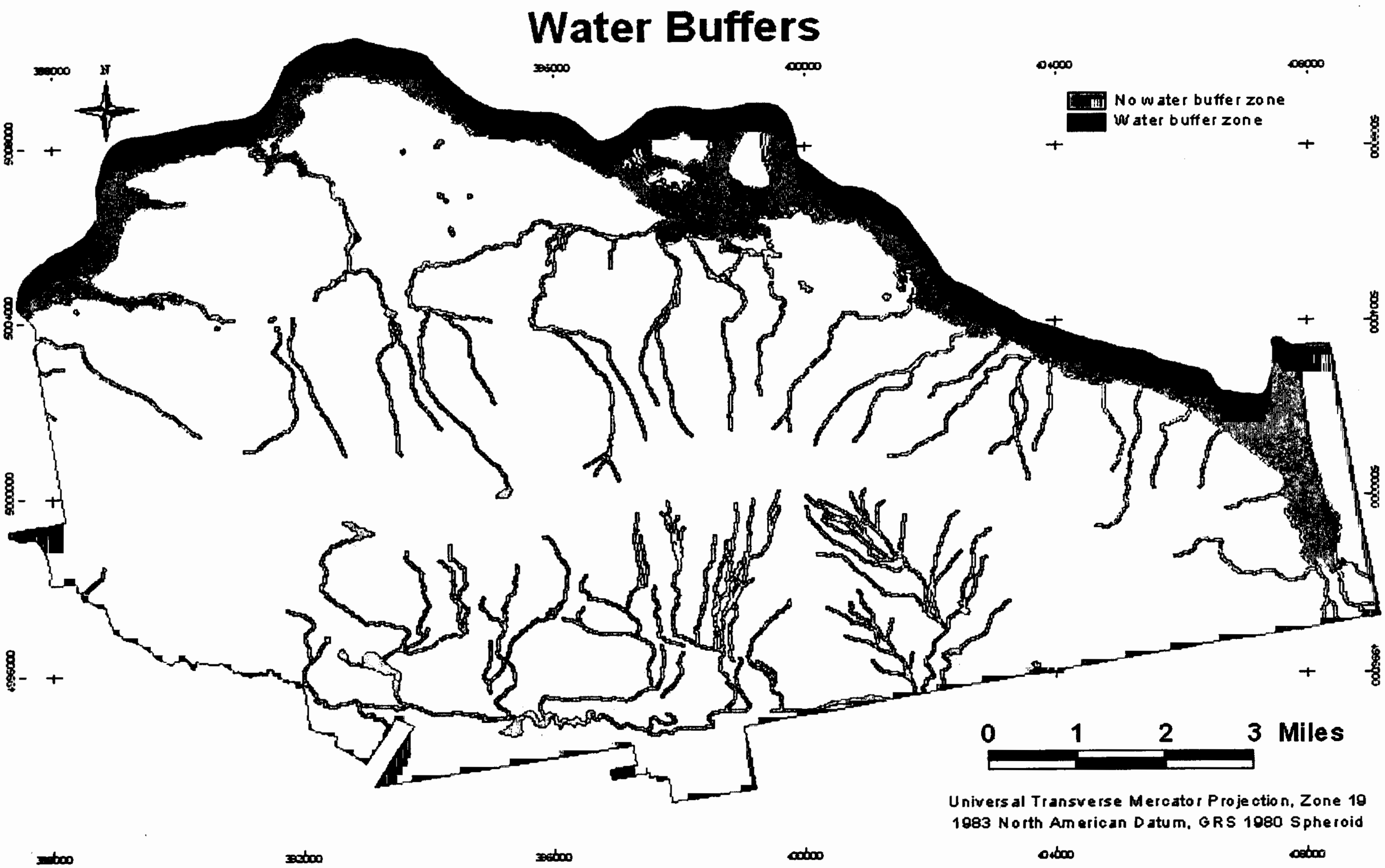


Map 5.2: Road buffers map of the Bigelow Preserve.

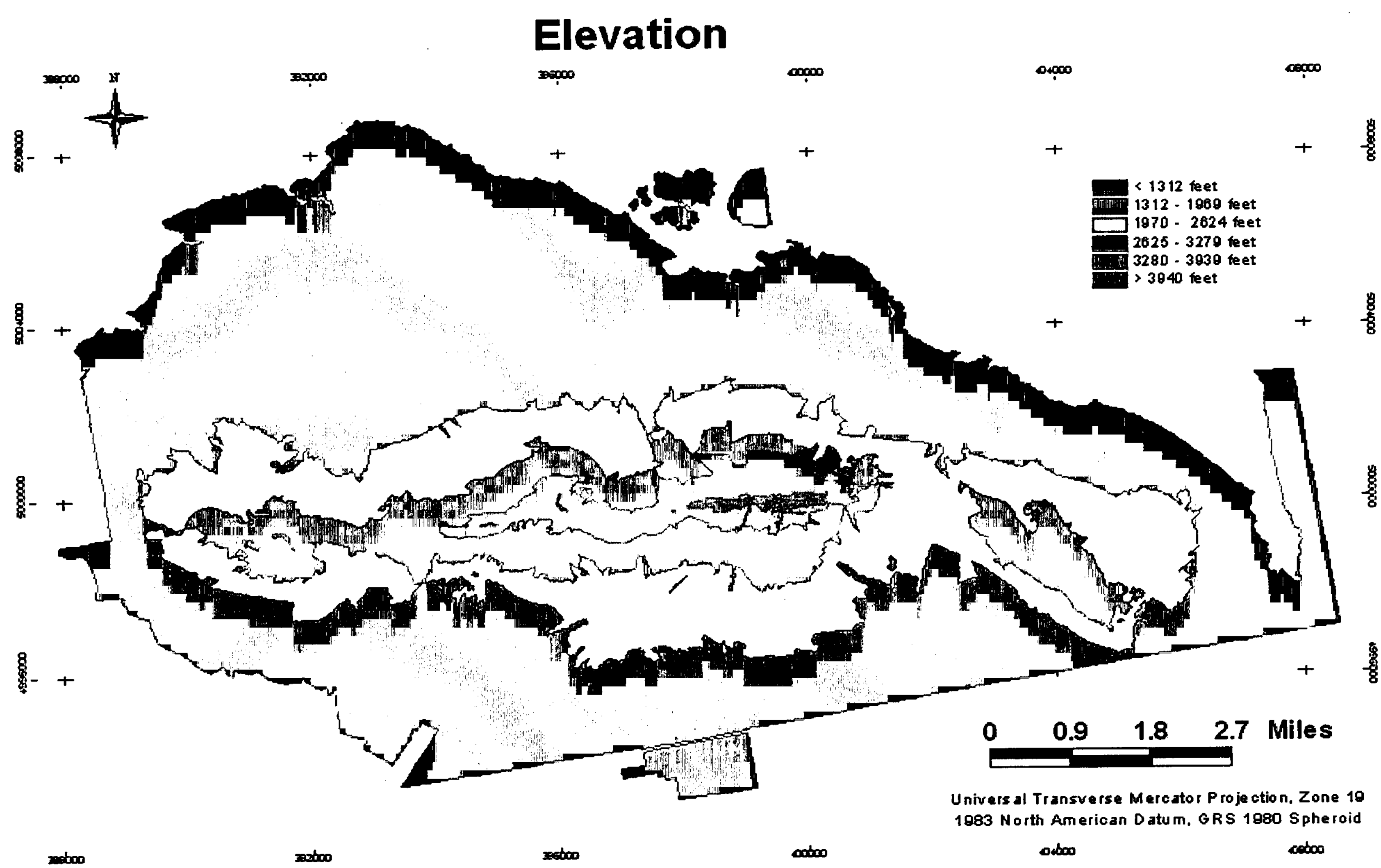
Trails Buffers



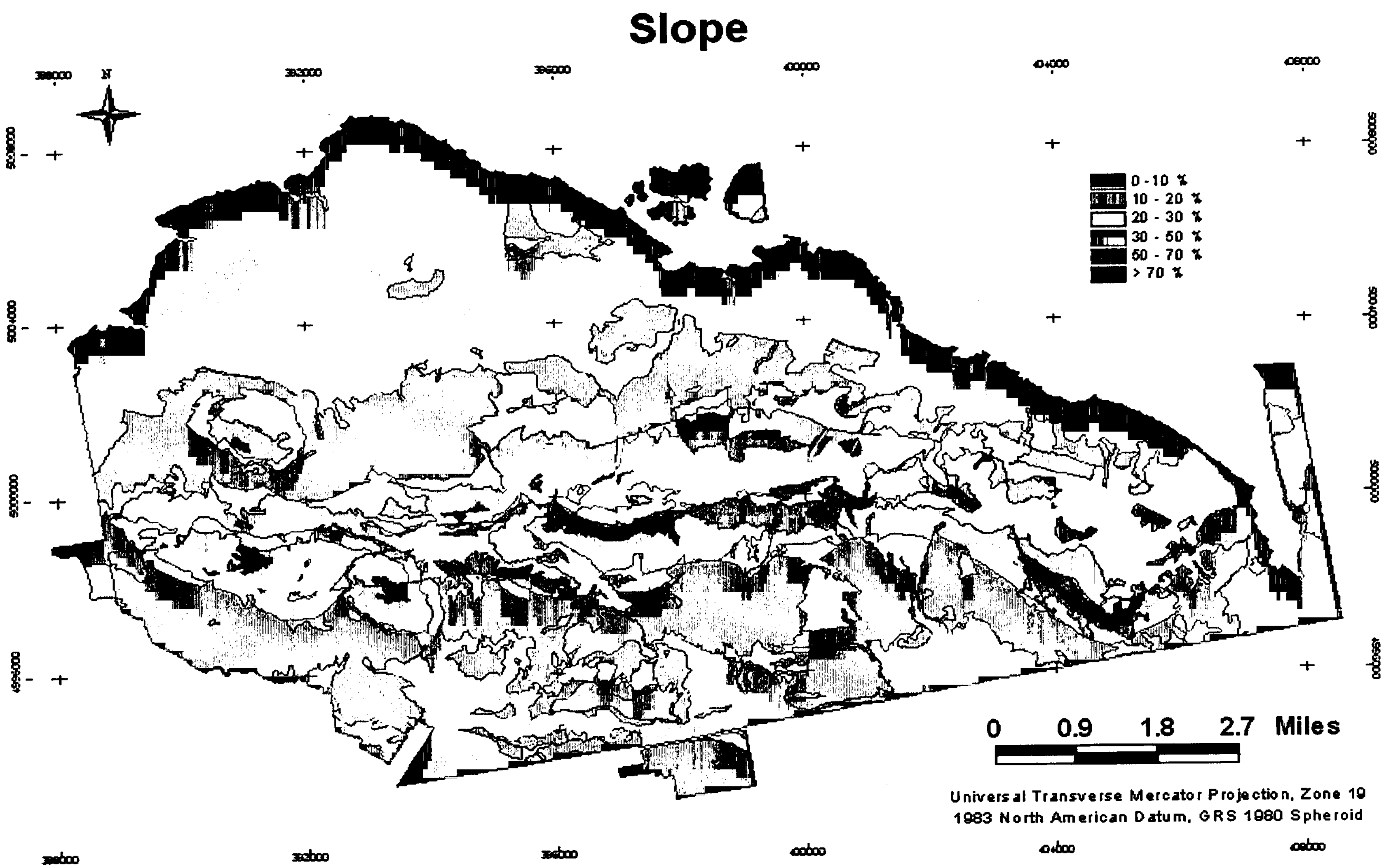
Map 5.3: Hiking trail buffers map of the Bigelow Preserve.



Map 5.4: Water buffers map of the Bigelow Preserve (100 feet for ponds and lakes, 75 feet for streams).



Map 5.5: Elevation map of the Bigelow Preserve.



Map 5.6: Slope map of the Bigelow Preserve.

5.3.2. Managerial information

In any Spectrum model-building process, one must specify four main groups of information to complete the managerial information section: 1) a planning horizon; 2) the activities, outputs and conditions that we want to quantify or consider in the model; 3) the silvicultural treatments, and 4) a definition of the management actions to be considered.

The planning horizon is the total amount of time that the simulation last, which is divided into equal time intervals called "periods". I considered 21 periods of 5 years each, making the Bigelow Preserve model's planning horizon 105 years.

One of the purposes of model building is to allow us to quantify the benefits that the forest can provide today and for generations to come. This quantification process translates in Spectrum into the definition of "activities", "outputs" and "conditions". Activities are all those human actions that may occur in the forest, such as habitat enhancement, trail and campsite maintenance, erosion control, and silvicultural activities. Outputs represent the results of those defined activities, which can be commodity oriented (number of campsites, timber production, non-timber forest products) or non-commodity oriented (acres of a specific habitat type, tons of sediment, wildlife populations). Conditions are the different environmental states that occur in the area such as visual quality or fire risk. Table 5.2 summarizes the activities, outputs and conditions considered in this study.

Spectrum considers each activity, output and condition as either a dependent or an independent variable. Independent variables take their values directly from the yield tables. A yield table is a set of independent variables (basal area, inventory volume, harvested volume, etc) and their yield streams (how these independent variables change

over time). Dependent variables are functions of independent variables and their relationship can have different degrees of complexity. Each combination of relationships among variables is called a "yield composite". One can create as many yield composites of new groups of relationships as are needed.

ACTIVITIES	OUTPUTS
Trail maintenance	Forest inventory
Camp maintenance	Volume harvested (pulpwood & sawtimber)
Road construction	Acres of well stocked forest
Road maintenance	Acres of adequately stocked forest
Planting	Acres of partial stocked forest
Precommercial thinning	Acres of under stocked forest
Commercial thinning	Acres of sapling/seedlings stands
Herbicide release	Acres of pole stands
Harvest	Acres of sawtimber stands
CONDITIONS	Acres of the forest with even-age management
Recreational opportunities	Acres of the forest with uneven-aged management
Visual quality	Acres of the forest not managed
Forest structure	Acres of fragile ecosystems
Species composition	Net present value

Table 5.2: Activities, outputs and conditions defined in the Bigelow Preserve simulation model.

Spectrum can also associate economic information with activities (always interpreted as costs by Spectrum) and outputs (revenues). For timber revenue calculations, I estimated stumpage prices for pulpwood and sawtimber in the Bigelow Preserve from the market price of logs. The inventory volume of the commercially valuable timber available to harvest within a given silvicultural system was multiplied by the mill delivery price of logs, adjusted for size and species composition. From this amount I deducted the estimated costs of extraction, transportation, administration and profit margin for an efficient harvester. I considered cut-to-length machinery outputs to calculate harvesting costs and performance within each type of vegetation removal. I also considered the costs associated with planting, precommercial thinning, herbicide release, road construction and maintenance, and trail construction and maintenance.

Spectrum has 18 pre-defined treatment types, which represent the many possibilities of vegetation manipulation that can be used with any management action. The program allows creation of new treatment types by manipulating a set of pre-defined treatment properties according to associated usage rules included in the software. Each management action can require none, one or more treatment types. I did not create any new treatment type in our model; I used the pre-defined ones.

Definition of a management action requires a specification of attributes, called "emphasis" and "intensity", a schedule, and a relationship between these three, the analysis units that this management action might affect, and a yield composite. A management emphasis describes the general management goal (timber production, recreation), while intensity describes the varying levels of management used to achieve the goal (clearcutting, individual tree selection, primitive recreation opportunity) (USDA1995a). Table 5.3 shows the principal emphases and intensities used in our model. For each forest cover type (Table 5.1), I defined three levels of timber management, varying from high intensity management (intensity one), where clearcuts were the dominant final harvesting method, to low intensity management (intensity three), where individual tree and group selection cuts were the dominant final harvesting methods. Changing the species composition of the forest represented another emphasis, for which I defined three different intensities: to change mixwood stands into softwood forest, tolerant hardwood stands into softwood stands, and tolerant stands into intolerant hardwood stands. I also defined an emphasis and intensity associated with not managing the forest for timber production.

Emphasis		Intensity
Timber	1	Aspen: clearcuts with a 50-year rotation Intolerant hardwoods: clearcuts with an 80-year rotation Tolerant hardwoods: two-cut shelterwood Mixwood: clear cuts with a 70-year rotation Softwood: clearcut with a 60-year rotation
	2	Aspen: clearcut with a 65-year rotation, cut size less than 5 acres Intolerant hardwoods: two cut shelterwood Tolerant hardwoods: group selection cut Mixwood: two cut shelterwood Softwood: irregular shelterwood
	3	Aspen: group selection cut Intolerant hardwoods: group selection cut Tolerant hardwoods: individual tree selection cut. Mixwood: individual tree selection cut Softwood: individual tree selection cut
No management		No timber management
Species composition change		Change mixwood stands into softwood forest Change tolerant hardwoods into softwoods Change tolerant hardwoods into intolerant hardwoods

Table 5.3: Summary of the emphases and intensities created for each forest cover type of the Bigelow Preserve simulation model.

We doubled the number of management intensities described in Table 5.3 by adding a sustainability criterion to each of them, duplicating the number of management actions as well (each management action is associated with a management intensity). The sustainability criteria had two main requisites. First, the forest inventory volume before any final harvesting entry should be at least 75 percent of the inventory volume of that same stand in a well-stocked and mature state (a stand's mature state was defined by the point at which the stand reaches the mean annual increment maximum). This restriction ensured that rotations were long enough to let the stands reach mature stages. Second, I enforced an equal distribution of the number of acres that could be accessed for merchantable volume removal among all the time periods (area control). The potential ecological impact of timber removal can be diminished if, instead of harvesting all the

forest in the first periods, the removal entries are spread out across the planning horizon by dividing the forest into groups of equal land acreage. I assumed that the capacity of a forest to absorb disturbances, also called "forest resilience", is directly related to the size of the impacted area. About half of the Bigelow Preserve forest is in a mature state. From a financial point of view, these sawtimber stands are ready to be harvested. Under the sustainability criteria, instead of harvesting all mature stands during the first period, I spread out the harvesting removal entries across the planning horizon until new stands reached maturity. Under the sustainability criteria, harvesting removals averaged 3,100 acres per period. This area control restriction also diversified the forest structure at the landscape level.

There are two principal types of schedules –those based on stand age and those based on time, the latter being the type used in our model. In age-based schedules, the management action begins when the affected analysis unit reaches a certain age. Time-based schedules begin in a specific time period within the planning horizon. Spectrum also provides specific schedules for uneven-aged, shelterwood, and clearcut prescriptions. The final step in creating management actions is to indicate the area(s) of the forest where a given management action can happen. In other words, we need to "theme" management actions to analysis units by using the land attributes or the analysis units names. In Spectrum, the term theme represents the "combination of land attributes, treatment types, and qualifiers [which identify the data types] that describes the conditions under which a particular piece of information applies" (USDA Forest Service 1995a)

5.3.3. Natural processes formulation.

Spectrum does not simulate natural forest biophysical processes. This information has to be brought in as input data by constructing or importing (in comma delimited format) the yield tables. Natural processes such as timber growth and yield must be estimated with the help of other simulation programs or models. Typically, a forest growth and yield table tracks variables related to the standing inventory and the removed volume for each period. Each yield table might contain one or more "yield streams", each of them associated with an independent variable such as basal area, inventory volume, or harvested volume, and each yield stream may contain one or more coefficients (the values of basal area, inventory volume and harvested volume for each period). The way Spectrum accounts for inventory and harvests depends on the yield table type.

There are two main types of yield tables: time-dependent, and age-dependent. The type of yield table for independent outputs produced by a management action should match the type of schedule defined in this management action. Therefore, all the output values produced by a management action with a time-based (age-based) schedule should be linked to a time-dependent (age-dependent) yield table. While time dependent yield tables require that yield streams related to inventory amount and harvested volume must be entered independently, in age-based yield tables some yield streams represent both inventory and harvested amounts (USDA Forest Service1995a).

We used the Northeastern TWIGS variant (Bush 1995) of the Forest Vegetation Simulator (FVS), a growth model developed by the Forest Service in the late 1980s, to estimate stand response to different silvicultural prescriptions. Each group of silvicultural treatments, prescribed for each stand type and simulated in FVS, corresponds with a

defined management action in Spectrum. Hence, the FVS's outputs constitute the Spectrum yield tables. I manipulated the FVS output data prior to importing it into Spectrum. For each period, I included the number of trees per acre, the basal area, the stand quadratic mean diameter (QMD), the merchantable inventory volume before any harvesting removal occurring within each period, and the merchantable timber volume harvested in any final or intermediate cut. I also considered the sawtimber volume and pulpwood volume as independent yield streams. Table 5.4 shows an example of the time-dependent yield table for a mixwood stand simulated for the 105-year planning horizon. The silvicultural system applied to this stand included a two-cut shelterwood treatment where the regeneration establishment cut occurred in period 3, with a residual basal area of 40 square feet per acre. The overstory removal was scheduled fifteen years later, leaving 25 percent of the stand overstory. The total length of the rotation was 70 years. At the same time as the overstory removal, I reduced the stand natural regeneration stocking to 1,000 stems per acre by carrying out a pre-commercial thinning.

Period	No. trees	BA (feet^2/acre)	QMD (inches)	Inventory (feet^3/acre)	Harvested vol. (feet^3/acre)	Pulp (tons/acre)	Sawlog (bd. feet/acre)
1	728	134	6.8	2188	0	0	0
2	671	139	7.1	2364	0	0	0
3	620	143	7.5	2516	1497	28.275	2841
4	36	42	15.7	1112	0	0	0
5	36	44	16.3	1202	0	0	0
6	35	47	16.8	1285	1098	6.231	5499
7	919	9	1.3	213	0	0	0
8	829	12	1.6	243	0	0	0
9	771	20	2.2	275	0	0	0
10	732	31	2.8	310	0	0	0
11	702	45	3.4	346	0	0	0
12	678	61	4.1	432	0	0	0
13	657	78	4.7	577	0	0	0
14	637	93	5.2	731	0	0	0
15	618	107	5.6	1091	0	0	0
16	599	120	6.1	1436	0	0	0
17	581	132	6.4	1845	781	21.458	71
18	38	44	14.7	1190	0	0	0
19	37	48	15.5	1312	0	0	0
20	37	52	16.2	1435	1302	7.069	6708
21	918	8	1.3	170	0	0	0

Table 5.4: Yield curve associated with management action "two cut shelterwood" for mature mixwood stands.

5.3.4. Goals and constraints.

Through scheduling management actions subject to explicit management objectives and constraints, Spectrum helps us to explore feasible management alternatives (Greer, 1996). Linear and goal programming are mathematical programming techniques designed to allocate limited resources among competing demands in such a way as to identify an alternative that maximizes what is desirable and minimizes what is undesirable from a set of feasible solutions.

In order to model desired and/or undesired outputs and conditions, one needs to define an objective function subject to a set of one or more constraints. An objective function is a mathematical expression designed to achieve one of the following criteria for a given outcome or group of results: maximization, minimization, maximization of a

minimum level (maxmin), and minimization of a maximum level (minmax). Both constraints and objective functions are linear functions of a group of identities commonly named “decision” or “activity” variables. Defining the values for decision variables translates into defining a management strategy in terms of the levels and types of activities that can be implemented (Kent 1989). Consequently, there are two principal approaches to achieving a specific goal in the modeling process: 1) to design an objective function that quantifies the desired or undesired outcome and apply a max, min, maxmin, or minmax criterion, or 2) to achieve that goal by creating constraints that will ensure reaching a desirable level and type of activities. As a general rule, I modeled those goals with unknown optimal or desired levels (e.g. we want to achieve the maximum financial benefit of the forest, but we do not know what that maximum revenues might be because it depends on other complex constraints) as objective functions. Those goals for which optimal or desired levels were known (e.g. if the goal is to protect all fragile ecosystems and we know where those ecosystems are located and the attributes that characterize them in our model, we can write constraints that will ensure their protection such as banning those management actions that might impact these ecosystems) were modeled as constraints. The restrictions on inputs represent an operational substitute for a desired goal as an output.

In developing the Bigelow Preserve model, I addressed five main management objectives: 1) to accomplish a desired recreational opportunity spectrum based on previous studies, 2) to maximize the visual quality of the land, 3) to protect fragile ecosystems, 4) to manage in the direction of reproducing the same species composition and vertical structure as the European presettlement forest in this region, and 5) to

maximize the net present value (NPV). I modeled only the "maximization of the NPV" goal as an objective function, considering the rest of the goals as constraints that could not be violated.

5.3.4.1. Recreational management.

In order to estimate the recreational opportunities that best suited the study area and to provide management guidance, I conducted a recreational supply and demand analysis at the state and local level (Chapter 3). The study concluded that the Bigelow Preserve should retain its remote and undeveloped character while providing primitive and semi-primitive recreational opportunities. Within this context, the number of non-mutually exclusive recreational opportunities the Bigelow Preserve can provide is up to three. Table 5.5 summarizes the criteria modified from the USDA Forest Service ROS classification (Douglass 1993) and used to determine the number of acres suitable for each recreation opportunity.

PRIMITIVE	
Remoteness	Area at least two miles from all roads or trails with motorized use.
Size	5,000 acres or larger.
Managerial setting	Unmodified natural or natural appearing environment. Management intensity 3, the intensities related with species composition change and no management are allowed (Table 5.3). Management of vegetation must happen during the time of the year with less recreational use.
Human evidence	Unnoticeable. Non-motorized trails and primitive campsites allowed, no other structures or on-site facilities are permitted. Use native materials. Interpretation through self-discovery.
Access	Access travel is non-motorized on trails or cross-country. Access for people with disabilities can be most difficult and very challenging.
SEMI-PRIMITIVE NON-MOTORIZED	
Remoteness	Area at least half mile from roads or trails used with motor vehicles.
Size	Larger than 2,500 acres but can be smaller if contiguous with a primitive class.
Managerial setting	Natural appearing environment. Subtle on-site controls. All management intensities are allowed except those that include clearcuts, and only selection cuts allowed in the 600-foot corridor along the hiking trails and campsites. Vegetation management allowed during the time of the year with less recreational use.
Human evidence	Some setting modifications are acceptable, no evidence of motorized use of trails and roads. Campsites area allowed, and other structures are rare and isolated. No on-site facilities, except for rustic and rudimentary facilities primarily for site protection. Use native materials. Interpretation through self-discovery.
Access	Access and travel is non-motorized on trails, some primitive roads or cross-country
SEMI-PRIMITIVE MOTORIZED	
Remoteness	Area within half mile of primitive roads, or trails with motorized use.
Size	Larger than 2,500 acres.
Managerial setting	Predominantly natural appearing environment for most of the planning horizon. All management intensities allowed, and only selection cuts allowed in the 600-foot corridor along the hiking trails and campsites. The vegetation alteration only takes place during the time of the year with less recreational use.
Human evidence	Noticeable vegetation alteration is allowed, but no construction. Strong evidence of motorized primitive roads and trails. Interpretation through very limited on-site facilities.
Access	Motorized use of primitive roads, trails and cross-country.

Table 5.5: Managerial and mapping criteria that define the potential recreational opportunities. Based on the USDA Forest Service Recreational Opportunity Spectrum.

In areas where management intensity 2 and 1 are possible, I created a 600-foot buffer corridor to ensure that no major vegetation manipulation, such us clearcuts or final removal cuts in a two-cut shelterwood system, would be exposed in the immediate foreground of any potential recreational user. I found that no more than 34 percent of the

land was eligible for primitive use, and no less than 15 percent fell into the semi-primitive motorized category. Hence, I established three levels of recreational management (Table 5.6). The first level provided 34 percent of the forest with primitive recreational opportunities (the maximum percentage that the current conditions permit given the criteria described in Table 5.5), 51 percent with semi-primitive non-motorized, and 15 percent with semi-primitive motorized. The second level of recreational management offered 85 percent of the land for semi-primitive non-motorized recreational use and 15 percent of semi-primitive motorized use. The third level only accounted for semi-primitive motorized recreational opportunities. To include these three levels of recreational management in our Spectrum model, I used a "constraint" approach by using the land attributes to eliminate those zones that fell in each recreational opportunity category from the management actions that were not permitted (managerial criterion in Table 5.5). For example, to ensure that no clearcuts could occur in primitive zones, I created a set of acreage constraints, meeting the primitive mapping criteria, and associated it with all management actions that included clearcuts. I forced these acreage constraints to have a value zero over the entire planning horizon.

Recreational opportunity	**Level 1**	**Level 2**	**Level 3**
Primitive	34	-	-
Semi-primitive non-motorized	51	85	-
Semi-primitive motorized	15	15	100

Table 5.6: Land percentage distribution among recreational opportunities for three levels of recreation management.

5.3.4.2. Visual quality.

The visual quality of an area depends primarily on the land attributes that make the area "visible" to the general public. Landscape visibility "addresses the relative importance and sensitivity of what is seen and perceived in the landscape" (USDA Forest

Service 1995b). The sensitivity of an area to visual impact change depends primarily on the topography of the terrain and the location of the observer. In the modeling process, I developed a visual sensitivity index for each analysis unit based on the slope and altitude attributes (Table 5.7). Values 0 and 1 represented a low index value, 2 a medium value, and 3 a high value.

Elevation (feet a.m.s.l.)	**Slope (%)**		
	0-10	**10-50**	**>50**
< 1969	0	1	2
1969 - 3279	1	2	3
> 3280	2	3	4

Table 5.7: Visual sensitivity index based on elevation and slope.

We assumed that harvesting activities that remove the vegetation almost entirely (clearcuts) cause a major visual impact due to a dramatic change in the color and texture of the landscape. However, partial vegetation removals (thinnings, shelterwood cuts, selection cuts) do not necessarily produce a visual impact in the background. Especially if we avoid large geometric shapes in thinned areas, the small changes in color and texture blend into the landscape. Shelterwood cuts can cause a visual impact if the observer is next to the area where the removal occurred. However, they are more difficult to distinguish in the background because, when the final overstory removal occurs, the regeneration is already established. In some cases, thinnings that open the overstory and give some "sense of order" do not produce a negative visual impact; they can even enhance it (Álvarez and Otero 1998).

We defined three levels of visual quality management. The first level reduced the risk of major visual impacts in high and medium visually sensitive zones by not permitting management intensity one. Shelterwood cuts were allowed only in zones away from the accessed sites (roads, hiking trails and campsites). In the 600-foot buffer

corridor along the roads, hiking trials and campsites no management intensity one or two could occur. This level achieved the maximum potential of visual quality in the area.

The second level of visual quality only ensured no major visual impact in high visual sensitivity zones. It also prohibited management intensities one and two in the 656-foot corridor. The third level of visual quality had no visual restrictions.

5.3.4.3. Fragile ecosystems.

The fragile ecosystems or vulnerable zones in the Bigelow Preserve consist of the alpine and subalpine vegetation, zones with high risk of soil erosion, and the riparian ecosystems adjacent to water bodies. The water buffer zone varied from 100 feet for ponds and lakes to 75 feet for rivers and streams. I protected fragile ecosystems by banning any timber management action and assigning the "no management" timber emphasis and intensity to these areas through constraints. However, no timber management did not ensure that recreational use could not jeopardize some re creational zones located in fragile ecosystems. The modeling process of the recreational impact of excessive or unsustainable use on these areas was not included in this study.

5.3.4.4. Presettlement conditions.

Management prescriptions directed towards achieving forest conditions prior to European settlement (i.e., presettlement) included reaching the species composition and vertical structure of that forest. While there are other variables that characterize forest condition (relative species abundances and frequencies, stand and forest age distributions and land fragmentation levels), due to the lack of quantifiable data, the complexity of

data analysis, and the simulation limitations, I did not considered them in this study. Nevertheless, they are ecological indicators as important as the variables included.

The presettlement forest was not static but, rather, a dynamic ecosystem changing in response to natural disturbances, climate change, and impacts of aboriginal inhabitants. We interpreted evidence from the literature for guidance as to how forests might look like today without the influence of a heavily populated society. Although it is true that there are some limitations and bias related to the methods to estimate forests conditions in the past (pollen analysis, land survey witness tree, historical records, etc), it is the only information available today.

Based on Lorimer's (1977) and Hosmer's (1902) studies on presettlement forests in Maine and the topography and soil quality of the study areas, I estimated the presettlement species composition distribution for the Bigelow Preserve (Figure 5.3). The present forest has a higher representation of tolerant hardwoods and a lower representation of spruce-fir forest than Lorimer's species composition distribution for north-central Maine. Lorimer's species composition distribution represented one of our management goals in the model building process.

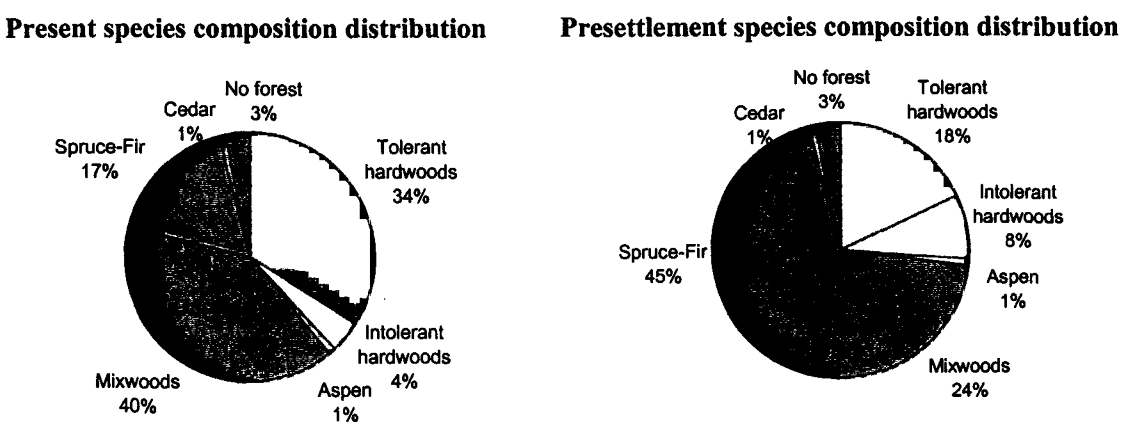


Figure 5.3: Present and estimated presettlement species composition distribution for the Bigelow Preserve.

The structure of the presettlement hardwood forest was defined by infrequent large-scale natural disturbances. The estimated fire return interval was about 800 years; hurricane blowdowns occurred primarily in the coastal areas, and stand replacement windstorms were rare in Maine, with a return interval of 1,150 years (Lorimer, 1977). In 1954, Hurricane Carol brought down a large percentage of standing trees on the top of the Bigelow Range[1]. Small-scale disturbances, caused by the mortality of individual trees or groups of them and resulting in small gap openings, were more common. Hence, the structure of the presettlement hardwood forest was irregular uneven-aged. However, one of the major large-scale disturbances that affected spruce and fir species was the spruce budworm epidemic which, according to Coolidge (1963), killed about 40 percent of spruce species and 75 percent of fir species at the beginning of the 20th century. The potential threat of spruce budworm epidemics does greatly reduces the probability of a completely irregular uneven-aged forest structure, at least at the stand level. However, spruce-fir stands include other softwood species that are not sensitive to the spruce budworm. In addition, the total representation of softwood species within a softwood stand is, by its inventory definition, more than 66 percent, which implies that hardwood species may be present. Therefore, even in the case of a disease breakout, there would still be trees in any spruce-fir or mixwood stand (including some spruce and fir trees not affected), ensuring more than one vertical stratum in the forest stand. Even if tree mortality might decrease the stand stocking levels, it would still have mixed ages. During

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[1] Personal communication David B. Field, June 2002.

the model building process, I assumed that presettlement conditions included multi-layer vertical structure.

I defined two levels for the presettlement-conditions management goal: 1) achieving presettlement species composition distribution and structure, and 2) only presettlement species composition.

5.3.4.5. Net present value.

Finally, while developing the objective function that would maximize the NPV, I assumed that the rate of change in all dollar values was equal to the rate of change of the purchasing power of the dollar for the planning horizon. The discount rate value used was four percent (real).

5.3.5. Solution process.

Spectrum transforms the data, relationships, objectives, and constraints into a matrix that is formatted for solution via a linear programming (LP) “solver” program. Model changes require matrix regeneration. In LP, a feasible solution is the one that satisfies all of the model constraints, while an optimal solution is the feasible solution that maximizes (or minimizes) the value of the objective function. In Spectrum, an optimal plan represents the management strategy that achieves the desired goals, by allocating each analysis unit's acres to one or more management actions.

Spectrum uses C-WHIZ 4.0, a self-contained optimizer software package, to solve the LP matrix. C-WHIZ reads Spectrum's MPS format matrix file, transforms it into a value table and an index array, performs the necessary iterations to find the optimal

solution, and delivers the results back into Spectrum. The matrix is held in the computer's random access memory (RAM), which limits the size of the model depending on how much space is available (Ketron Management Science 2000).

Given a feasible solution, Spectrum offers up to eleven different solution report types, each of them having four presentation options and four format options. The production of a comma-delimited format file is necessary to export a solution into a spreadsheet program or ArcView® GIS 3.2 for further analysis. "Spectra Vision" is an ArcView® GIS extension that links Spectrum solutions with corresponding spatial information. This link represents an important element in the model building process because it provides us with a visual representation of the constructed model. The solution's visualization allows us to perceive more easily inconsistencies and intuitively implausible results.

5.4. RESULTS

We simulated 44 different management scenarios, representing different combinations of the five defined management goals, their levels, and the defined sustainability criteria. The simulated management scenarios (Table 5.8) varied from "no management" to "high intensity timber management". A variety of multiple-use scenarios between these extremes included protection of fragile ecosystems, the creation and/or maintenance of recreational opportunities, the visual protection of the area, and the achievement of presettlement species composition and vertical structure conditions. Each management scenario represented a management strategy for the Bigelow Preserve or, in

linear programming language, a desired solution given a set of goals subject to constraints.

Scenarios	Sustainability criteria		Fragile ecosystems		Presettlement conditions			Recreational opportunities			Visual quality		
	yes	no	yes	no	L1	L2	no	L1	L2	no	L1	L2	no
NPV		✓		✓			✓			✓			✓
NPVenv		✓	✓				✓			✓			✓
NPVenvRec1		✓	✓				✓	✓					✓
NPVenvRec2		✓	✓				✓		✓				✓
NPVenvSC1		✓	✓		✓					✓			✓
NPVenvSC1Rec1		✓	✓		✓			✓					✓
NPVenvSC1Rec2		✓	✓		✓				✓				✓
NPVenvSC1VQ1		✓	✓		✓					✓	✓		
NPVenvSC1VQ1Rec1		✓	✓		✓			✓			✓		
NPVenvSC1VQ2		✓	✓		✓					✓		✓	
NPVenvSC1VQ2Rec2		✓	✓		✓				✓			✓	
NPVenvSC2		✓	✓			✓				✓			✓
NPVenvSC2Rec1		✓	✓			✓		✓					✓
NPVenvSC2Rec2		✓	✓			✓			✓				✓
NPVenvSC2VQ1		✓	✓			✓				✓	✓		
NPVenvSC2VQ1Rec1		✓	✓			✓		✓			✓		
NPVenvSC2VQ2		✓	✓			✓				✓		✓	
NPVenvSC2VQ2Rec2		✓	✓			✓			✓			✓	
NPVenvVQ1		✓	✓				✓			✓	✓		
NPVenvVQ1Rec1		✓	✓				✓	✓			✓		
NPVenvVQ2		✓	✓				✓			✓		✓	
NPVenvVQ2Rec2		✓	✓				✓		✓			✓	
Sustenv	✓		✓				✓			✓			✓
SustenvRec1	✓		✓				✓	✓					✓
SustenvRec2	✓		✓				✓		✓				✓
SustenvSC1	✓		✓		✓					✓			✓
SustenvSC1Rec1	✓		✓		✓			✓					✓
SustenvSC1Rec2	✓		✓		✓				✓				✓
SustenvSC1VQ1	✓		✓		✓					✓	✓		
SustenvSC1VQ1Rec1	✓		✓		✓			✓			✓		
SustenveSC1VQ2	✓		✓		✓					✓		✓	
SustenvSC1VQ2Rec2	✓		✓		✓				✓			✓	
SustenvSC2	✓		✓			✓				✓			✓
SustenveSC2Rec1	✓		✓			✓		✓					✓
SustenvSC2Rec2	✓		✓			✓			✓				✓
SustenvSC2VQ1	✓		✓			✓				✓	✓		
SustenvSC2VQ1Rec1	✓		✓			✓		✓			✓		
SustenvSC2VQ2	✓		✓			✓				✓		✓	
SustenvSC2VQ2Rec2	✓		✓			✓			✓			✓	
SustenvVQ1	✓		✓				✓			✓	✓		
SustenvVQ1Rec1	✓		✓				✓	✓			✓		
SustenvVQ2	✓		✓				✓			✓		✓	
SustenvVQ2Rec2	✓		✓				✓		✓			✓	
NoManag	✓		✓		✓					✓	✓		

Table 5.8: Summary of the constraints and sustainability criteria applied to each management scenario for an objective function that maximizes the Net Present Value.

Scenarios were named according to the management goals that each of them achieved in a systematic way:

- "NPV": maximization of the NPV
- "Env": fragile ecosystems and soil erosion protection
- "Rec1": primitive, semi-primitive non-motorized, and semi-primitive motorized recreational opportunities (level 1 of recreational management)
- "Rec2": semi-primitive non-motorized, and semi-primitive motorized recreational opportunities (level 2 of recreational management)
- "VQ1": protection of high and medium visually sensitive zones (level 1 of visual quality)
- "VQ2": protection of high visually sensitive zones (level 2 of visual quality)
- "SC1": presettlement species composition and forest irregular vertical structure (level 1 of presettlement conditions)
- "SC2": presettlement species composition (level 2 of presettlement conditions)
- "Sust": maximization of NPV under sustainability criteria

Spectra Vision creates a solution view by mapping the management actions assigned to each analysis unit by a proposed solution. Map 5.7 shows the mapped solution for management scenario "SustenvSC1VQ1Rec1" which, under the sustainability criteria, maximizes the NPV subject to the following constraints: protection of fragile ecosystems, maximization of visual quality (protection of high and medium visual sensitive zones –level one), achievement of ROS's level one (primitive, semi-primitive non-motorized and semi-primitive motorized recreational opportunities) and reaching the presettlement forest's species composition and vertical structure. This

solution accounts for the highest variety of forest uses or goals without prioritizing any of them, and the maximum levels defined within each goal. In ArcView® GIS, the analysis units with the same prescribed management strategies were grouped to create the final management units shown on Map 5.7. This aggregation reduced mapped divisions from 5,787 homogeneous polygons to 16 homogeneous non contiguous spatial polygons (Figure 5.4), making posterior strategic planning and implementation less complex than manipulating the original number of analysis units. Management units with the same management strategies but different schedules were considered differently. In the solution for scenario SustenvSC1VQ1Rec1, even though the objective function was to maximize NPV Spectrum only chose those management actions associated with management intensity three, which represent silvicultural systems where the harvesting removals are individual and group selection cuts with a higher cost than most of the silvicultural systems in management intensity one. In this case, modeling the goal of achieving irregular forest structure as a set of constraints, instead of as a maximization goal, translated into accomplishing this goal before any defined objective function. Although the objective function was to maximize the NPV, this goal came after achieving irregular forest structure because those management goals modeled as constraints (irregular structure) had priority over management goals in the objective function (maximizing NPV).

Management scenario "NPV" maximized the NPV without any other constraints. In this case, management units were different in size and number (Map 5.8) than those corresponding with the SustenvSC1VQ1Rec1 scenario solution. Fewer non contiguous spatial units appeared due to the lower number of management intensities chosen during

the optimization process. For each stand, the management intensities selected provided the maximum net present financial value during the planning horizon, accomplishing no other management goals.

Map 5.9 presents an intermediate management scenario (SustenvSC2VQ2Rec2) solution where the management emphasis matched that defined for the SustenvSC1VQ1Rec1 scenario but with a few different management intensity levels (reach a ROS's level two –semi-primitive motorized and non-motorized uses, protect only high sensitive visual zones, achieve presettlement species composition, and maximize NPV). This scenario solution proposed more management intensities than the previous two, increasing the final number of management units in the future planning process. Even if SustenvSC2VQ2Rec2 scenario had the same emphasis as SustenvSC1VQ1Rec1 (timber harvesting, recreation management, visual impact protection, presettlement conditions, protection of fragile ecosystems and sustainability criteria), which would explain the greater number of intensities compared with the NPV scenario, the level of goal achievement, or intensity, was less restricted. SustenvSC2VQ2Rec2 scenario's goals did not demand an irregular forest structure, primitive recreational use, or protection of medium visual sensitive zones. This translated into increasing the variety of management intensities. The sustainability criteria, which required staggered vegetation removals over time, increased the number of different management intensities in both SustenvSC1VQ1Rec1 and SustenvSC2VQ2Rec2 scenarios. I considered management actions that only differed in their schedules as different management intensities, which translated into a wider array of intensities in the solution map.

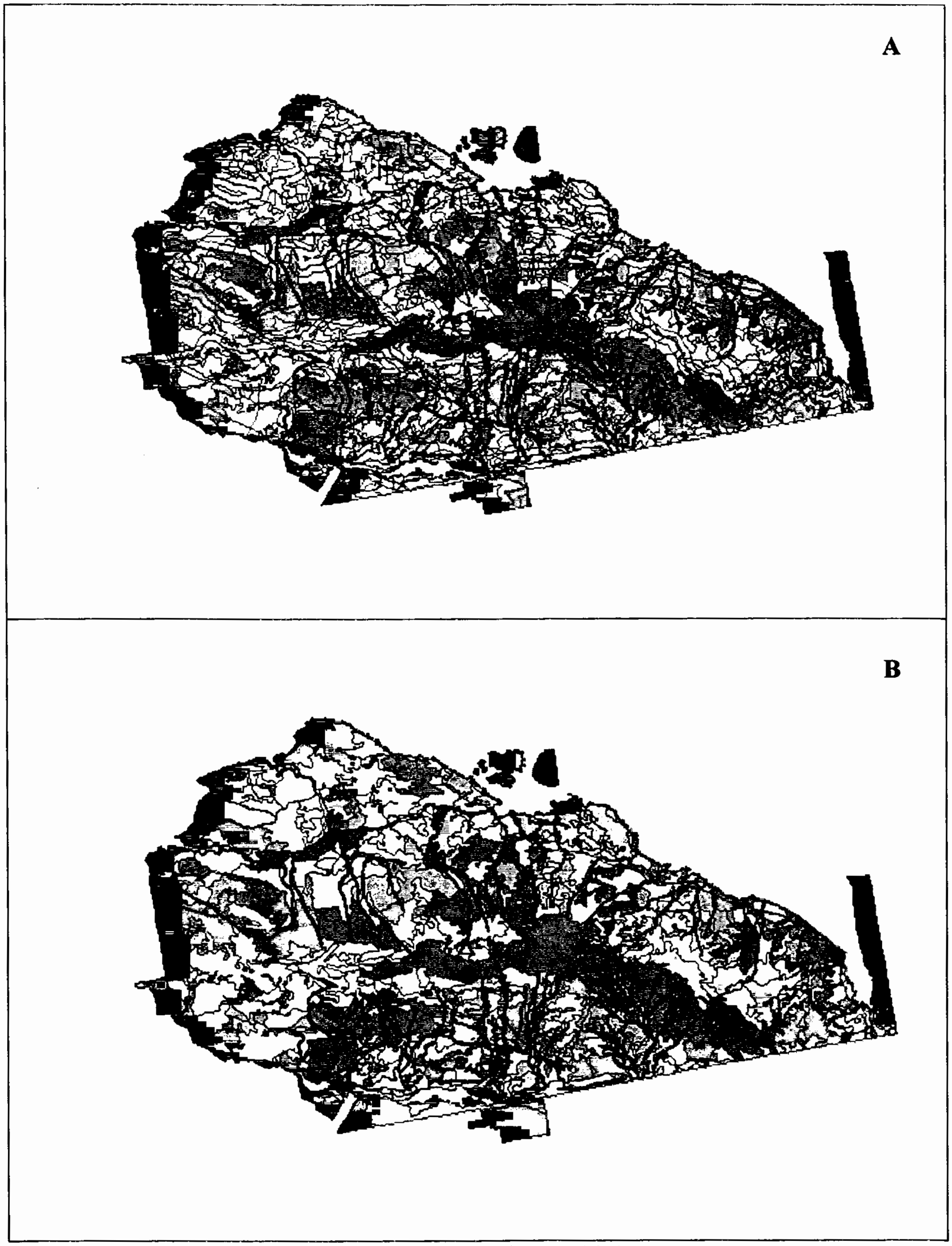
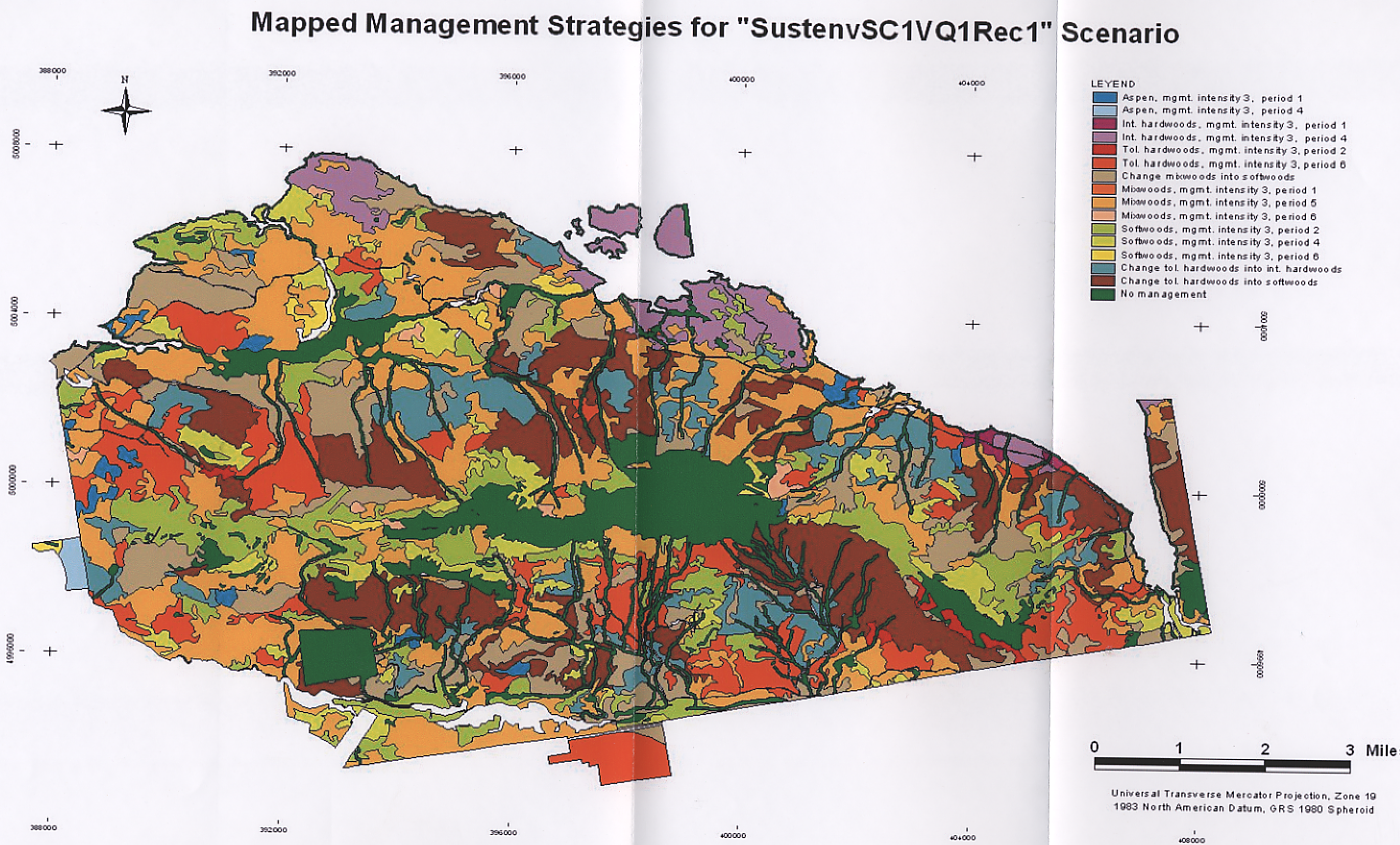
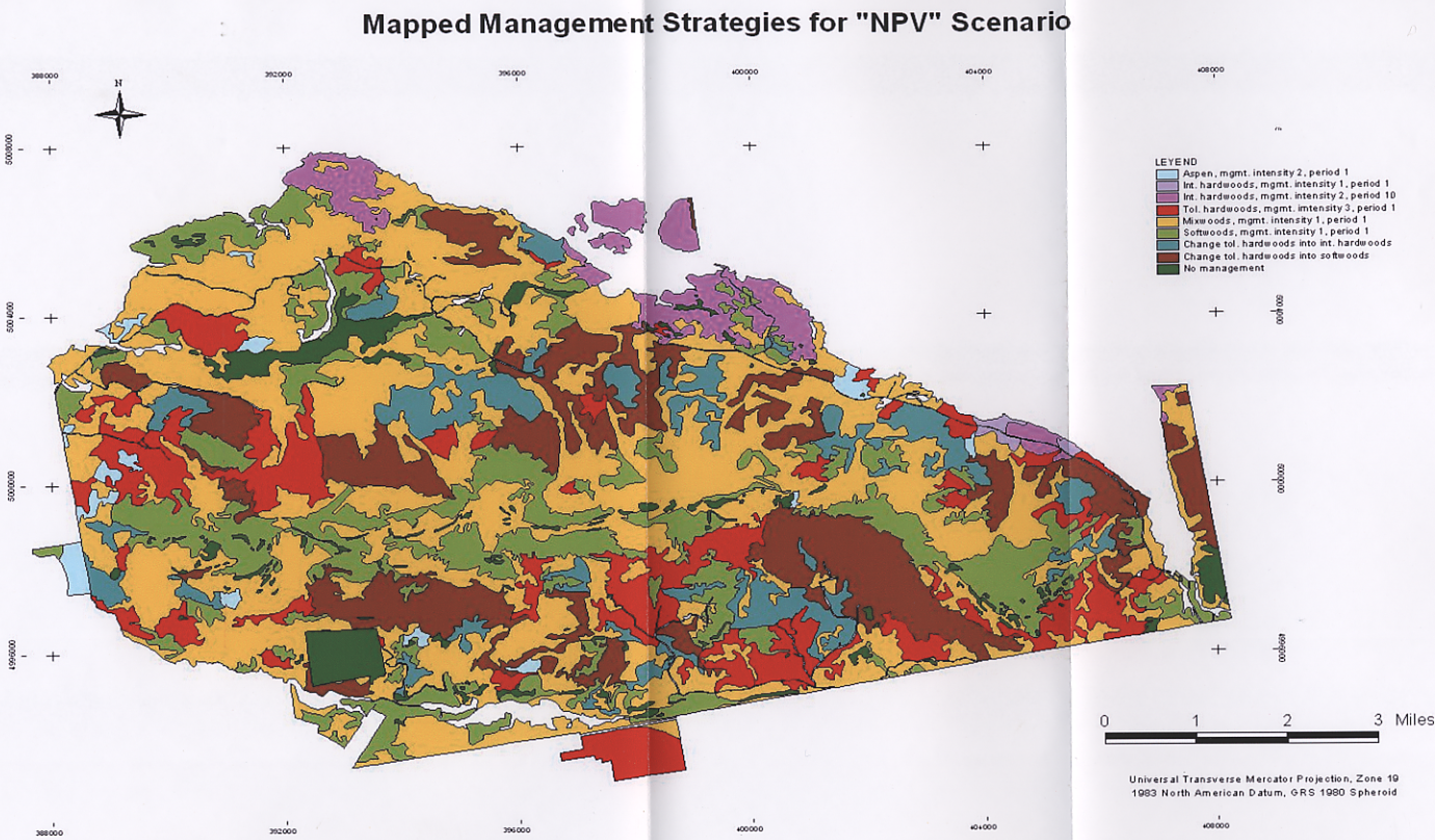


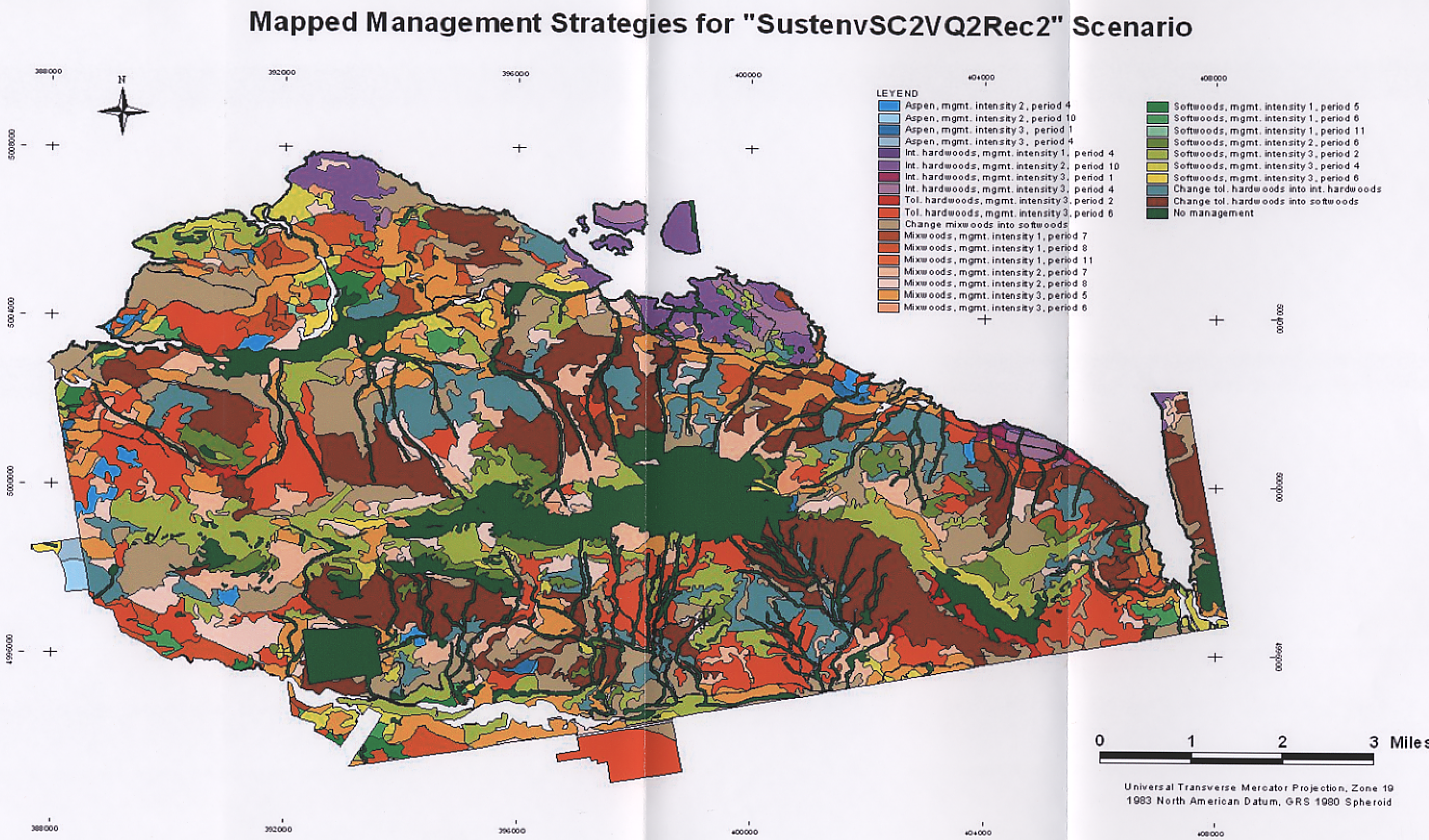
Figure 5.4: Solution map for the most conservative multiple-use management scenario, "SustenvSC1VQ1Rec1", (Table 5.9) before (A) and after (B) aggregating spatial polygons with equal management actions.



Map 5.7: Solution map for the most conservative multiple-use management scenario "SustenvSC1VQ1Rec1" (Table 5.9).



Map 5.8: Solution map for the least conservative management scenario NPV (Table5.9).



Map 5.9: Solution map for an intermediate multiple-use management scenario "SustenvSC2VQ2Rec2" (Table 5.9).

The Spectra Vision software also maps outcome yields over time. These yields quantify activities, outputs and conditions for each analysis unit by creating a dot density map for each simulated period. Figure 5.5 shows the timber removal distribution across the landscape for the NPVenvVQ1Rec1 management scenario during the periods 1, 10, 17 and 21. Within each period, a unique dot density distribution represents the amount of units (cubic feet) per analysis unit for the variable analyzed over time and landscape (timber volume removed). The spatial analysis of forest conditions provides guidance for further analysis of those variables not included in the simulation model and related to them. For the NPVenvVQ1Rec1 management scenario, an analysis of the mature stand acreage distribution across the landscape (Figure 5.6) and over time helps the manager to identify and analyze the forest fragmentation conditions for those wildlife species that require mature forest and how this habitat will change over the planning horizon, determining the optimal and critical periods for these species

Mapping restrictions altered results. I found significant differences (not in the statistical sense) between simulation results where a segment of land subjected to a goal was pre-defined by specific spatial land attributes, and simulation results with the same goal and equal percentage of affected land but not related to any spatial attributes. In this last case, Spectrum allocated the land subject to the goal's management strategies based on other constraints and objectives functions. I assigned 34 percent of the forest to primitive recreational use, 51 percent to semi-primitive non-motorized use and 15 percent to semi-primitive motorized and applied the corresponding restrictions to this area (recreational management level one). The result differences between applying the recreation opportunity mapping criteria (Table 5.5) and not applying it depended on the

other constraints specified within the simulation (Table 5.9). The spatial allocation differences (Figure 5.7) showed how timber management intensity one and two did not occur in those buffer zones located more than two miles away from roads (Map 5.2) when spatial land attributes (distance to roads) were used, otherwise Spectrum chose those areas based on the financial productivity of each analysis unit. For the recreation management level one (two) and in the absence of other constraints, the NPV decreased an average of 14 (24) percent, and the harvested volume increased 6 (8) percent.

Scenario	Change in NPV (%)	Change in harvested volume (%)
NPVenvRec1	-14	6
NPVenvRec2	-24	8
NPVenvSC1Rec1	-1	0
NPVenvSC1Rec2	-1	0
NPVenvSC1VQ1Rec1	-1	0
NPVenvSC1VQ2Rec2	-1	0
NPVenvSC2Rec1	-12	7
NPVenvSC2Rec2	-20	7
NPVenvSC2VQ1Rec1	-11	6
NPVenvSC2VQ2Rec2	-13	4
NPVenvVQ1Rec1	-13	6
NPVenvVQ2Rec2	-15	4
SustenvRec1	-13	-2
SustenvRec2	1	-2
SustenvSC1Rec1	10	-2
SustenvSC1Rec2	10	-2
SustenvSC1VQ1Rec1	10	-2
SustenvSC1VQ2Rec2	10	-2
SustenveSC2Rec1	2	-2
SustenvSC2Rec2	-2	-2
SustenvSC2VQ1Rec1	4	-2
SustenvSC2VQ2Rec2	-2	-2
SustenvVQ1Rec1	18	4
SustenvVQ2Rec2	-5	-3

Table 5.9: Percentage change of harvested volume and NPV when applying the recreation opportunity mapping criteria (Table 5) versus not using spatial attributes that specify which are the suitable areas.

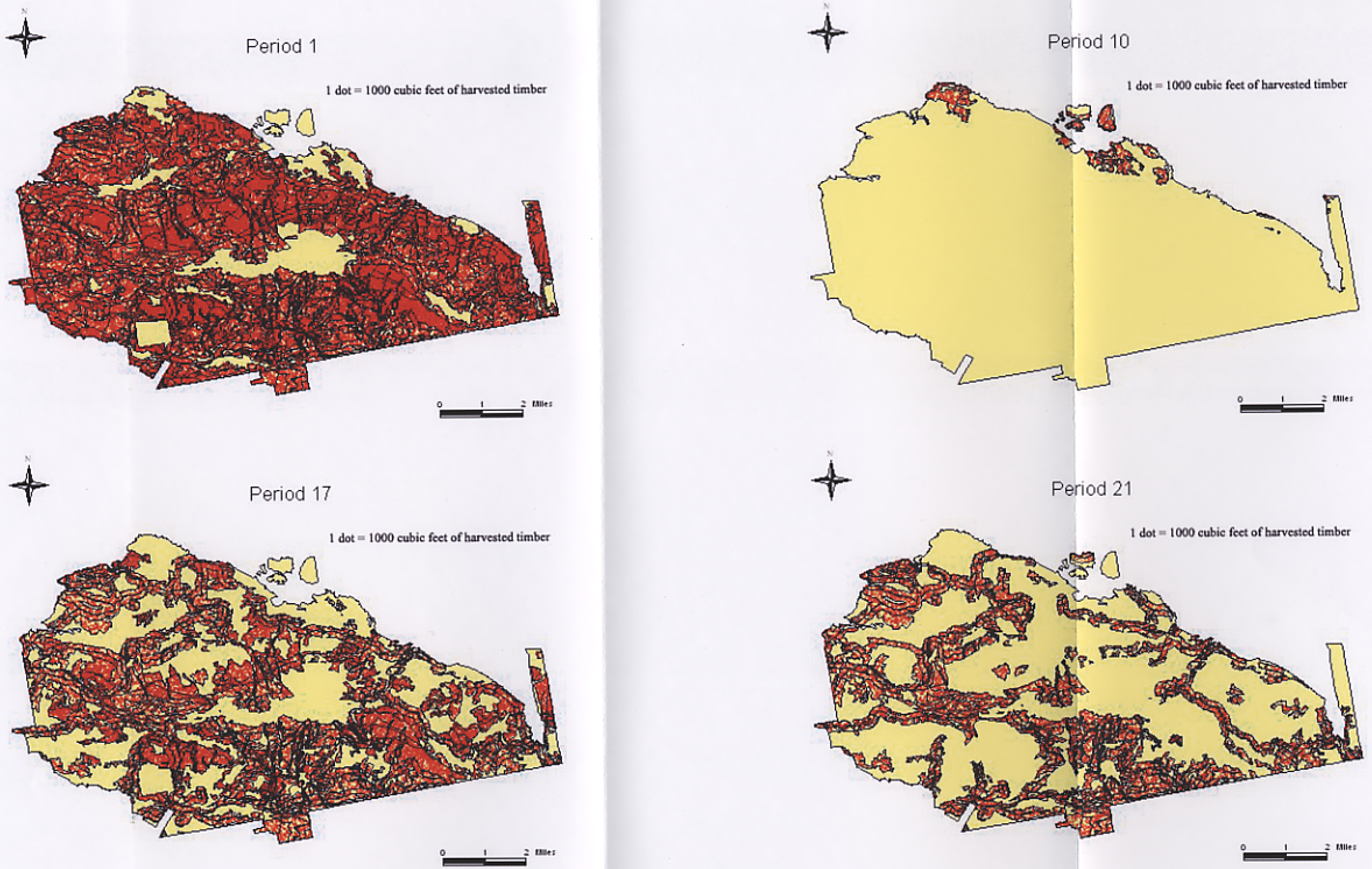


Figure 5.5: Acreage distribution and dot density (in cubic feet) of harvesting removals for simulated periods 1 (2001-2006), 10 (2046-2051), 17 (2081-2086) and 21 (2101-2106) for the intermediate multiple-use management scenario NPVenvVQ1Rec1 (Table 5.9).

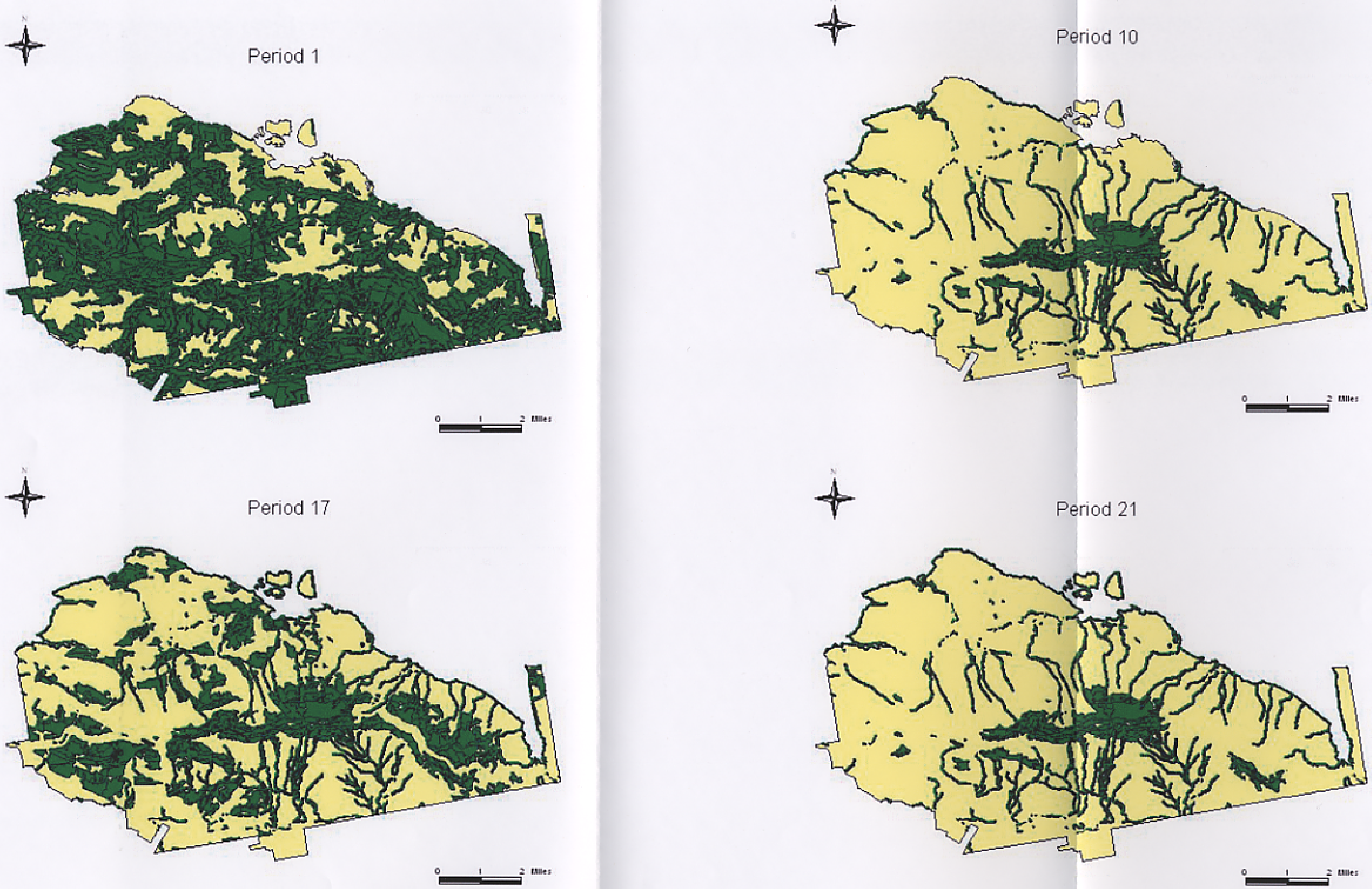
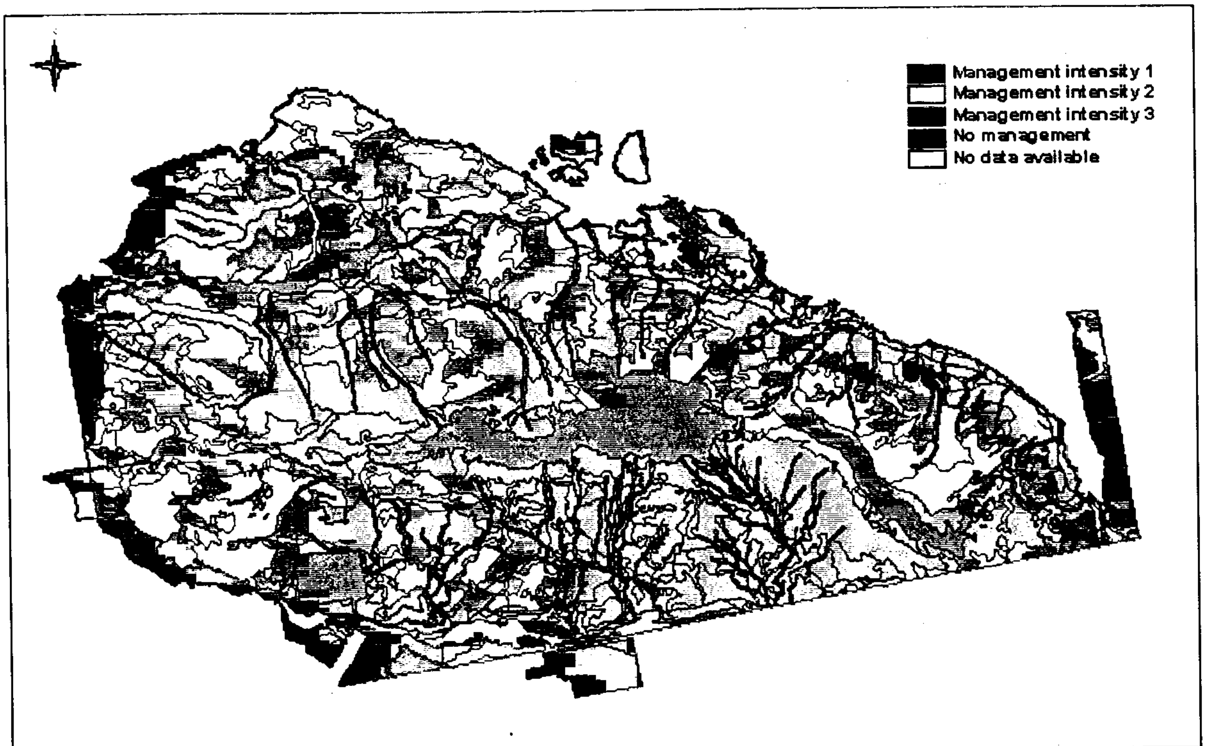


Figure 5.6: Acreage distribution of mature stands across the planning horizon during periods 1 (2001-2006), 10 (2046-2051), 17 (2081-2086) and 21 (2101-2106) for the intermediate multiple-use management scenario NPVenvVQ1Rec1 (Table 5.9).



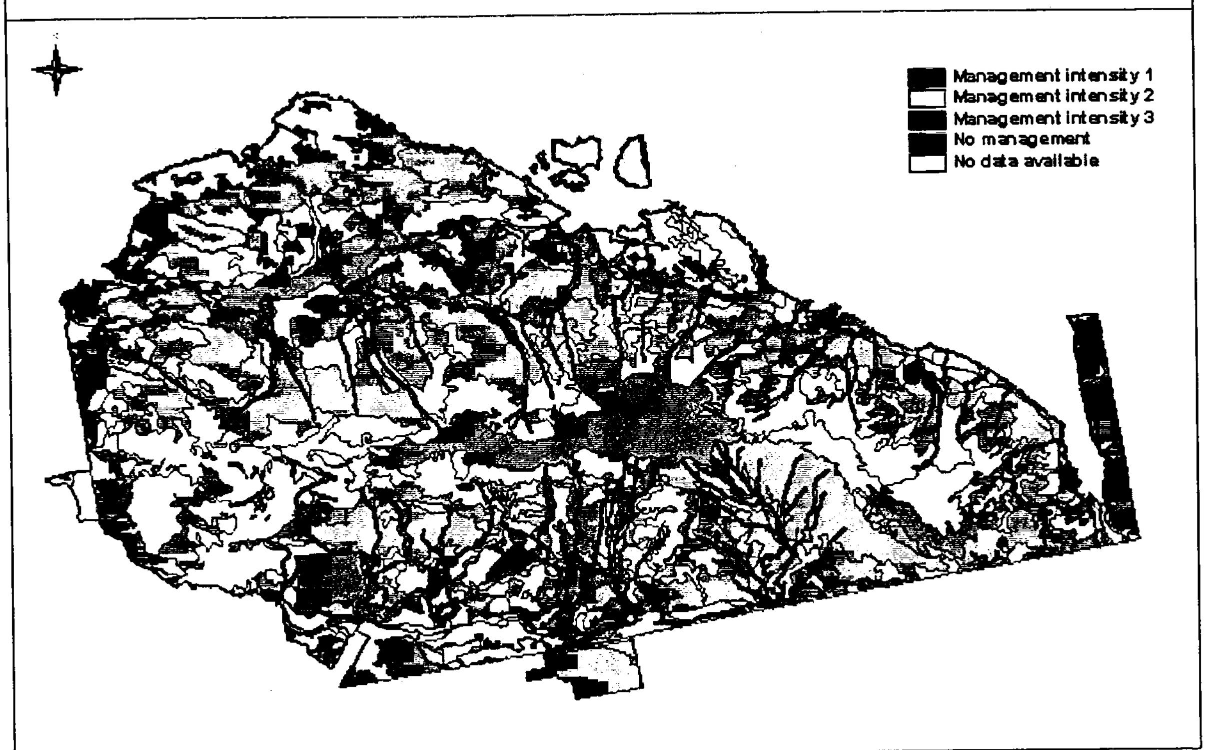


Figure 5.7: Solution map for management scenario NPVenvRec1 (Table 5.9) with (A) and without (B) spatial land attributes for recreational goals.

Each simulated scenario produced its own combination of silvicultural systems for the entire forest. The percentage of land that was managed under management intensities one, two, three and no management varied depending on the set of goals considered (Table 5.10). Protecting fragile ecosystems (alpine and subalpine vegetation, riparian zones and zones with high risk of erosion) required the protection of 15 percent of the land. However, in scenario NPV, which only considered the goal of maximizing NPV, Sprectrum chose the option of no-management for four percent of the land. Achieving an irregular structure of the forest demanded that the only management intensity allowed in the Preserve was either intensity three, which represented individual and group selection harvesting systems, or no management regardless of any other set of goals. Scenario NPV, NPVenv and Sustenv were the only ones where management intensity one applied to half of the land or more (59, 50 and 49 percent respectively). Adding any recreational, visual, and/or ecological goals to these cases translated into an increase in the percent of land managed under intensities two and, mainly, three at a cost of less land managed under management intensity one. There was no case where management intensity two dominated the majority of the land.

Scenarios that accomplished the sustainability criteria presented harvesting schedules that were more complex and less profitable than those scenarios that did not. Within the sustainability criteria, the "time smoothing" effect of the area available for harvesting would certainly have an impact during the implementation phase. The total cost of these criteria represented an average 20 percent decrease of the NPV.

Scenarios	Management 1 (%)	Management 2 (%)	Management 3 (%)	No Management (%)
NPV	59	5	33	4
NPVenv	50	4	30	15
NPVenvRec1	8	20	57	15
NPVenvRec2	8	26	51	15
NPVenvSC1	0	0	85	15
NPVenvSC1Rec1	0	0	85	15
NPVenvSC1Rec2	0	0	85	15
NPVenvSC1VQ1	0	0	85	15
NPVenvSC1VQ1Rec1	0	0	85	15
NPVenvSC1VQ2	0	0	85	15
NPVenvSC1VQ2Rec2	0	0	85	15
NPVenvSC2	39	4	42	15
NPVenvSC2Rec1	8	15	62	15
NPVenvSC2Rec2	8	20	58	15
NPVenvSC2VQ1	14	13	58	15
NPVenvSC2VQ1Rec1	8	15	62	15
NPVenvSC2VQ2	14	13	58	15
NPVenvSC2VQ2Rec2	8	20	58	15
NPVenvVQ1	18	16	51	15
NPVenvVQ1Rec1	8	20	57	15
NPVenvVQ2	18	16	51	15
NPVenvVQ2Rec2	8	26	51	15
Sustenv	49	5	31	15
SustenvRec1	6	17	62	15
SustenvRec2	6	21	58	15
SustenvSC1	0	0	85	15
SustenvSC1Rec1	0	0	85	15
SustenvSC1Rec2	0	0	85	15
SustenvSC1VQ1	0	0	85	15
SustenvSC1VQ1Rec1	0	0	85	15
SustenveSC1VQ2	0	0	85	15
SustenvSC1VQ2Rec2	0	0	85	15
SustenvSC2	37	5	43	15
SustenveSC2Rec1	5	12	67	15
SustenvSC2Rec2	5	15	65	15
SustenvSC2VQ1	12	10	63	15
SustenvSC2VQ1Rec1	5	12	67	15
SustenvSC2VQ2	12	10	63	15
SustenvSC2VQ2Rec2	5	15	65	15
SustenvVQ1	16	12	56	15
SustenvVQ1Rec1	6	17	62	15
SustenvVQ2	16	12	56	15
SustenvVQ2Rec2	6	21	58	15
NoManag	0	0	0	100

Table 5.10: Land percent distribution under management intensities one, two, three and no management for each simulated scenario.

5.5. CONCLUSIONS AND LIMITATIONS

Spectrum represents a powerful decision support tool for forest ecosystem management. The model building process is key to both a successful analysis and flexibility to change management goals. This software package allows working at any spatial scale. The accuracy of the input data, its scale and its manipulation will determine the accuracy of the output data. Nevertheless, the interpretation of outputs should be not taken out of the context of the assumptions under which the model was developed.

Spectrum should be integrated with other GIS and simulation programs to serve as a useful management tool. The integration of Spectrum with ArcView® GIS 3.2, through Spectra Vision, represents a great advantage due to the importance of spatial consideration in strategic planning. In the Bigelow Preserve, the use of mapping criteria related to recreational goals during the modeling process altered NPV results up to 24 percent, and harvested volumes up to 8 percent. In addition, after Spectrum output data are linked to the original spatial information, one can manipulate this information with any GIS tool for further spatial analysis. One of the major advantages that I found in this study was the reduction of the number of spatial units from the model building and solution phases (analysis units) to the definition of the final management strategies (management units).

Spectra Vision provides an accuracy assessment for the constructed model, and a very useful tool during all the phases of ecosystem management: decision-making, strategic planning, implementation and monitoring. Spatial analysis provides us with a visual tool to understand the allocation and evolution of management strategies across the landscape and over time as numeric data does not. The manipulation of hundreds (if not

thousands) of polygons with numeric information associated with each of them can be a complex task. However the interpretation of those results on the geographical space allows a more intuitive analysis and comprehension of them, and in our case served as an accuracy assessment tool.

One of the limitations I found in Spectrum is the difficulty of including new management goals that require physical information not originally included during the analysis unit definition, in which case a new model must be rebuilt. The software's dependency on six layers of information limits the creation of a more complete information system that would allow us to cover unpredicted information requirements associated with new goals defined after the model building process. Therefore, information should be selected carefully. The definition of codes representing different groups of information, such the used inventory codes, might allow more flexibility during the goal-definition modeling process.

Spectrum version 2.5 also has mathematical limitations such as the lack of model II formulations and the manner in which linear equations are defined. Given the following general equation

$$Y = a\,X + b$$

where Y is the dependent variable, X the independent variable and a and b constants, Spectrum only allows a to be different from 1 or 0 if b equals zero; in case b takes a value different from zero, a must be equal to 1 or 0. This program is still an evolutionary tool whose developers move towards the direction of emerging needs.

We conclude that, despite the limitations inherent in modeling natural processes, the benefits that Spectrum provides in searching for solutions to desired multiple goals,

providing precise information for strategic planning, and helping to understand the complex tradeoffs among priced and unpriced forest resource values involved in multiple-purpose decision-making, the benefits of using this technology far exceed the costs.

Chapter 6. TRADEOFF ANALYSIS AND EVALUATION: THE EQUILIBRIUM POINT IN THE MANAGEMENT OF FORESTS FOR MULTIPLE USES.

6.1. CHAPTER ABSTRACT

This paper analyzes tradeoffs among simulated management alternatives for a more than 36-thousand-acre public trust land in the state of Maine. The experimental medium was the USDA Forest Service linear programming-based Spectrum modeling system. Management goals included economic, recreational, visual, and ecological considerations. Outcomes quantified as continuous variables were: net present value; merchantable inventory volume; total harvested volume; sawtimber harvested volume; pulpwood harvested volume; percentage of land classified as sawtimber, pole, and seedling stands; and percentage of land classified as well, adequately, and under stocked. Discontinuous variables accounted for the accomplishment of management goals such as the protection of fragile ecosystems, demand for recreational opportunities, visual quality, presettlement vegetation conditions (species composition and irregular structure), maximizing financial revenues, and accomplishing a sustainability criterion designed to allow stands to exceed conventional maturity criteria while smoothing over time the area available for timber harvesting. Findings revealed that the competition among forest benefits could be reduced through strategic planning. Also, an increase in total forest benefits did not always imply a decrease in financial benefits. The conjoined effect of integrated competitive management goals was significantly[1] different than the sum of these effects considered independently. From all the management goals, reaching an irregular structure of the forest represented the lowest financial return with the exception of the "no management" scenario. However, this goal provided not only ecological benefits, but visual and recreational as well.

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[1] In this study, the term significant is not in the statistical sense; it just implies that the differences are important or considerable.

I tested the hypothesis that forest management directions that favor the greatest variety of conditions and activities lead to a greater aggregate value than do those directions that favor narrower goals. Within the analysis framework, I created a nine-dimension space where each axis represented the percent decrease of each analyzed outcome relative to the maximum capacity of the forest to produce this benefit in the absence of any other competitive uses. The Euclidean distance in the defined nine-dimension space quantified how far each simulated scenario was from the theoretical optimum. This distance was compared to a "variety of benefits" index assigned to each scenario in order to test the original hypothesis. I concluded that the use of Euclidian distances represents a powerful tool in the decision-making processes, which helps managers and decision makers find the right combination of those forest values that match the capacity of the forest, stakeholders' goals and social needs. The main advantage of its use lies in its simplicity and flexibility for adjustment to other cases and decision criteria. The normalization of the different units of measurement that quantify forest values by calculating the percent decrease from the maximum achievable level allows analysts to compare and integrate them together without having to translate these values into a common measurement unit.

6.2. INTRODUCTION

Some of the most difficult tasks that forest managers and decision makers face are the definition, allocation and distribution of sustainable forest management (SFM) practices over time and across landscapes. These difficulties are compounded by the desire to meet present and future demands on forests while conserving important natural

resources. The term 'sustainable forest management' is increasingly well accepted within society and the scientific community and among professionals. The Round Table on Sustainable Forests, a partnership of public and private organizations and individuals, states that "SFM is intended to respect the full range of environmental, social and economic values of the forest, and to integrate the way those values are managed to ensure that none are lost and that the forest remains healthy and vibrant into the future" (USDA Forest Service, 2002). However, this apparently simple idea represents a very challenging task of developing management strategies, implementing plans, and applying adaptive management to account for new social needs and demands. Two months before the World Summit on Sustainable Development (Johannesburg, 2002), the European Union still struggled with the development of an integrated sustainable strategy to propose at the World Summit (Fundación Entorno 2002). The complexity of this task is not just due to the integration and comparison of diverse social, ecological and economic interests, but also to the lack of methodologies that allow us to quantify and compare the value of natural resource amenities (especially non-market priced amenities). In an effort to contribute to solving such a difficult problem, I propose the analysis of values tradeoffs among different management scenarios as a quantifiable tool in the development and evaluation of sustainable management strategies.

The evaluation and analysis of forest resource values helps to identify appropriate management goals, anticipate social reactions, and deal with conflicts over public forest lands (Bengston 1994). However, some forest resources have no well-defined market prices, which make these values hard to quantify and compare among each other and among market-priced values. These resources are largely unmeasured, and even unknown

in some cases. To achieve efficient resource allocation and to use forest resources in a sustainable way, while avoiding conflicts, forest values (both market and non-market) should be analyzed.

Scenario-planning analysis is one of the best methods for comparing the outcomes and value tradeoffs of alternative management plans over time (MacLean 1998). Although, tradeoff analysis does not estimate a value for each forest output, service and condition per se (e.g., the existing value of a landscape view), it estimates the opportunity cost (monetary or non-monetary), or tradeoffs, of maintaining these amenities in a certain status (the implications of keeping that view on other economic, social and ecological variables). Tradeoff analysis breaks down scientific information so that policy makers can understand the implications of their decisions and assists them in making better, more informed decisions. Both forest managers and policy makers need a broader knowledge of the diverse, complex, and multidimensional values associated with forests to develop and successfully implement ecosystem management approaches that are socially and politically acceptable as well as biologically sound (Bengston 1993). Social, political and ecological considerations should be integrated to develop sustainable forest management decisions that achieve specific goals.

Tradeoffs among outputs should be computed from different management scenarios developed for a period of time. In order to simulate a management scenario, I need to develop a modeling environment that allows estimates of outcomes and conditions resulting from an alternative forest management strategy (chapters 5 and 6). Linear programming (LP) based software packages, such as Spectrum, represent a

management tool that allows the user to create models of forests and to simulate forest interactions and responses, across landscapes and through time given a set of goals.

Tradeoff analysis should be carried out considering its own limitations. Connaughton and Fight (1984) presented a outstanding overview of the main limitations and reliability of tradeoff analysis. First, tradeoffs rely on the way outcome objectives are modeled. In LP, the manipulation of inputs through constraints that will ensure reaching a desirable goal might lead to a feasible but not optimal solution. Second, the reliability of tradeoff analysis depends on the planner's confidence in the relationships between management inputs and outputs of the various uses captured in the model. Third, tradeoffs cannot be directly calculated from the differences between management scenarios if they differ in more than one desired outcome. Each scenario represents a set of goals, which translates into a set of constraints and objective functions in linear/goal programming. Therefore, in tradeoff analysis, the set of optimal-output combinations (or the tradeoff curve between two outputs that relates how much of one optimal solution output must be traded off to increase another) changes from one scenario to another. Tradeoffs should be computed within the same curve or set of output combinations. During the development of the "tradeoff" curve between two outputs, the rest of the outputs should remain equal. This limitation increases the number of scenarios to simulate in order to be able to estimate the tradeoffs precisely. Fourth, I should distinguish between marginal and average tradeoffs. According to Connaughton and Fight (1984), there are two reasons that explain how these two variables differ: "First, marginal values are conceptually equivalent to prices for market outputs, whereas average values are generally not. Second, diminishing returns in production mean that as

the objective for goods is increased marginal tradeoffs will be increasing and average tradeoffs will be less than marginal tradeoffs."

The first objective of this paper is to quantify, integrate and compare economic, social and ecological values within different management alternatives, focusing on the analysis of forest value tradeoffs. The second objective is to test the hypothesis that, at the landscape level, management directions that favor the greatest variety of forest products, services and conditions lead to a greater aggregate value, considering the financial, social and ecological aspects of the term "value". That is, forest value is a direct function of forest variety. The analysis framework to test this hypothesis is that, in general, multiple values require coordinating management across the landscape as not every stand should provide all values at all times.

Tradeoffs among management alternatives were calculated from the simulation outputs of a linear programming (LP) model developed for the Bigelow Preserve, a publicly-owned mountain range in western Maine, built to reproduce different management scenarios.

6.3. METHODS

We developed a modeling environment that allowed estimates of outcomes and conditions resulting from alternative forest management strategies. Spectrum, an LP software application developed by the USDA Forest Service (1995a), was used and integrated with geographic information systems (GIS) and forest vegetation simulators to examine alternative resource allocation and evaluation. The outcomes of each

optimization run were sets of forest products, services and conditions for a 105-year planning horizon.

The development of this model structure allowed us to represent a variety of management scenarios, and to estimate the array of forest values and intensities within these values. The 44 simulated scenarios ranged from "no timber management" to "intensive timber management" defining, in between these two extreme cases, several multiple-use management alternatives (including visual, recreational, ecological, and timber benefits) in which no one use dominated and the productivity of the land was not impaired. Simulations occurred in 21 periods of 5 years each, making the Bigelow Preserve model's planning horizon (or total simulated time) 105 years. Based on a close analysis of the geo-physical characteristics of the land, the standing timber inventory, the recreational opportunities offered at the local and state level, and the socioeconomic environment where the Bigelow Preserve is located, I included a total of nine different feasible management goals, each of which had the potential of providing society with economic, ecological or social benefits:

1. "Sust" goal: Application of a sustainability criteria based on extending harvesting rotations to ensure that the stand would exceed a mature state, and enforcing an equal distribution of the number of acres of mature forest that can be accessed for merchantable volume removal among all the simulated periods. I assumed that the capacity of a forest to absorb disturbances, also called "forest resilience", is directly related to the size of the impacted area. So if a large percent of the forest was ready to be harvested in the first period I divided this number of acres among following periods until new stands exceeded maturity.

2. "Env" goal: Protection of fragile ecosystems (alpine and subalpine vegetation, zones with high risk of soil erosion, and riparian corridors along the water bodies).
3. "SC1" goal: Achievement of presettlement species composition and forest vertical structure.
4. "SC2" goal: Achievement of presettlement species composition only.
5. "Rec1" goal: Promotion of a recreational opportunity spectrum (ROS) that includes primitive, semi-primitive non-motorized and semi-primitive motorized, modified from Douglass classification (1993).
6. "Rec2" goal: Promotion of a ROS that includes semi-primitive non-motorized and semi-primitive motorized opportunities.
7. "VQ1" goal: Visual protection of high and medium visually sensitive zones.
8. "VQ2" goal: Visual protection of high visually sensitive zones.
9. "NPV" goal: Maximization of net present financial value.

The Spectrum software does not simulate natural processes. This information must be provided during the model building process. Growth and yield information was independently simulated in the Northern TWIGS variant of the Forest Vegetation Simulator, an individual-tree, distance-independent growth model developed by the USDA Forest Service (Bush 1995). The results were imported into Spectrum as part of the forest responses to four silvicultural systems developed for each vegetation cover type and the forest growth response to no management within the Bigelow model (see chapter 4). I calculated average growth and yield outputs for each type of forest cover type.

After importing FVS growth and yield values into Spectrum, I developed grouping criteria within this LP software to facilitate the final analysis of output

variables. Based on the basal area values obtained as FVS outputs, I developed four stocking classifications: well stocked, adequately stocked, partially stocked and under stocked. Basal area values within each category varied by species composition (Table 6.1).

Cover type	Under stocked	Partially stocked	Adequately stocked	Well stocked
Hardwood	≤ 30	31 - 55	56 - 90	≥ 91
Mixwood	≤ 30	31 - 80	81 – 126	≥ 126
Softwood	≤ 30	31 - 90	91 - 140	≥ 141

Table 6.1: Stand basal area (ft^2/acre) classification for hardwood, mixwood and softwood species.

In order to analyze simulation results, I defined discrete and continuous variables. Discrete variables (Table 6.2) accounted for those management goals that provided a specific forest condition. They were modeled as constraint sets in Spectrum. Continuous variables represented the Spectrum simulation outputs. Discrete variables remained constant through the planning horizon, but continuous variables did not. Continuous variables accounted for the percentage of land classified as well stocked, adequately stocked, partially stocked or under stocked forest; the percentage of land classified as sapling/seedlings, pole or sawtimber stands; the merchantable inventory volume; the merchantable harvested volume; the sawlog volume within the total harvested volume; the pulpwood volume within the total harvested volume; and the net revenues or costs within each period.

Sustainability criteria	Yes No
Fragile ecosystem and soil erosion protection	Yes No
Presettlement conditions	Level 1: presettlement species composition and forest irregular vertical structure Level 2: presettlement species composition Level 3: no
Recreational opportunities	Level 1: primitive, semi-primitive non-motorized and semi-primitive motorized Level 2: semi-primitive non-motorized and semi-primitive motorized Level 3: no
Visual quality	Level 1: high and medium visual sensitive zones Level 2: high visual sensitive zones Level 3: no

Table 6.2: Discrete variables accounting for management goals.

The analysis process had two phases: 1) a scenario analysis where simulation results were analyzed both individually across time and also averaged for the entire planning horizon (in the case of the net financial value I used the net present value (NPV) index instead of an average value across time) and 2) an analysis of the tradeoffs among different management goals, and the estimation of the relationships among continuous variables across all scenarios. Because tradeoffs cannot be directly calculated from the differences between management scenarios if they differ in more than one desired outcome, some of the 44 management scenarios (Table 6.3) were intermediate cases that were needed to be able to estimate tradeoffs accurately. To facilitate the analysis, scenarios were grouped under two categories: those that achieved sustainability criteria and those that did not achieve this goal. Scenarios that achieved sustainability criteria used yield curves with longer rotations, in some cases, and time schedules that evenly distributed, across time, the number of acres where vegetation removal occurred.

Tradeoff curves were adjusted using a one-dimension interpolation function based on piecewise cubic Hermite interpolating polynomials. Hermite curves are used to smoothly interpolate between key points. The advantage of using these curves is that it maintains the shape and monotonicity of the underlying data (MatLab 2002), without creating non-existing maximum or minimum points as some of the quadratic, cubic, or other n^{th} degree polynomials do. The data used to create these curves were the time-averaged values of the analyzed variables expressed in percentage of decrease relative to scenario NPV.

Sensitivity Analysis (SA) quantified how the variation of model outputs can be assigned, qualitatively or quantitatively, to different sources of variation. The use of SA increases the confidence in the model and its predictions because it offers insight into how model outcomes vary when inputs change. I conducted SA on the assumed four percent real discount rate used with economic information in the LP model.

	Sustainab. criteria		Fragile ecosystems		Presettlement conditions			Recreational opportunities			Visual quality		
Scenarios	**yes**	**no**	**yes**	**no**	**SC1**	**SC2**	**no**	**Rec1**	**Rec2**	**no**	**VQ1**	**VQ2**	**no**
NPV		✓		✓			✓			✓			✓
NPVenv		✓	✓				✓			✓			✓
NPVenvRec1		✓	✓				✓	✓					✓
NPVenvRec2		✓	✓				✓		✓				✓
NPVenvSC1		✓	✓		✓					✓			✓
NPVenvSC1Rec1		✓	✓		✓			✓					✓
NPVenvSC1Rec2		✓	✓		✓				✓				✓
NPVenvSC1VQ1		✓	✓		✓					✓	✓		
NPVenvSC1VQ1Rec1		✓	✓		✓			✓			✓		
NPVenvSC1VQ2		✓	✓		✓					✓		✓	
NPVenvSC1VQ2Rec2		✓	✓		✓				✓			✓	
NPVenvSC2		✓	✓			✓				✓			✓
NPVenvSC2Rec1		✓	✓			✓		✓					✓
NPVenvSC2Rec2		✓	✓			✓			✓				✓
NPVenvSC2VQ1		✓	✓			✓				✓	✓		
NPVenvSC2VQ1Rec1		✓	✓			✓		✓			✓		
NPVenvSC2VQ2		✓	✓			✓				✓		✓	
NPVenvSC2VQ2Rec2		✓	✓			✓			✓			✓	
NPVenvVQ1		✓	✓				✓			✓	✓		
NPVenvVQ1Rec1		✓	✓				✓	✓			✓		
NPVenvVQ2		✓	✓				✓			✓		✓	
NPVenvVQ2Rec2		✓	✓				✓		✓			✓	
Sustenv	✓		✓				✓			✓			✓
SustenvRec1	✓		✓				✓	✓					✓
SustenvRec2	✓		✓				✓		✓				✓
SustenvSC1	✓		✓		✓					✓			✓
SustenvSC1Rec1	✓		✓		✓			✓					✓
SustenvSC1Rec2	✓		✓		✓				✓				✓
SustenvSC1VQ1	✓		✓		✓					✓	✓		
SustenvSC1VQ1Rec1	✓		✓		✓			✓			✓		
SustenvSC1VQ2	✓		✓		✓					✓		✓	
SustenvSC1VQ2Rec2	✓		✓		✓				✓			✓	
SustenvSC2	✓		✓			✓				✓			✓
SustenvSC2Rec1	✓		✓			✓		✓					✓
SustenvSC2Rec2	✓		✓			✓			✓				✓
SustenvSC2VQ1	✓		✓			✓				✓	✓		
SustenvSC2VQ1Rec1	✓		✓			✓		✓			✓		
SustenvSC2VQ2	✓		✓			✓				✓		✓	
SustenvSC2VQ2Rec2	✓		✓			✓			✓			✓	
SustenvVQ1	✓		✓				✓			✓	✓		
SustenvVQ1Rec1	✓		✓				✓	✓			✓		
SustenvVQ2	✓		✓				✓			✓		✓	
SustenvVQ2Rec2	✓		✓				✓		✓			✓	
NoManag	✓		✓		✓					✓	✓		

Table 6.3: Management goals within each simulated management scenario, in addition to Net Present Value maximization goal.

To test my hypothesis[2], I created a value comparison indicator, the Euclidean distance, which measured how far the results of each analyzed scenario were from a

[2] Not in the statistical sense

maximum threshold, beyond which the forest capacity could not provide higher values for the analyzed outcomes. To define this maximum threshold, I considered the theoretical situation where forest uses did not compete and all proposed economic, social and ecological goals could be achieved together at their most restrictive level (goals 1, 2, 3, 5, 7, and 9). This "ideal", though unreachable, optimum scenario was created by a combination of the maximum levels of outputs and conditions found in the 44 simulated scenarios. Each scenario was compared to the ideal by estimating the percentage of decrease, or deviations, of each output from the ideal

In order to develop a value comparison indicator that accounted for all the output deviations and allowed us to compare scenarios, I created a nine-dimension space where each axis measured the deviations of outputs and conditions (in percentages) from the ideal optima. The Euclidean distance from the results of any simulated scenario, with coordinates (δ_i) representing deviations, to the ideal one was defined by the formula:

$$\sqrt{\left(\delta_1^{\,2} + \delta_2^{\,2} + \delta_3^{\,2} + \delta_4^{\,2} + \delta_5^{\,2} + \delta_6^{\,2} + \delta_7^{\,2} + \delta_8^{\,2} + \delta_9^{\,2}\right)}.$$

This represented a comparison index of the values offered by a forest managed under a specific plan or scenario. The Euclidean distance expressed how far away a real management scenario (where uses compete) was from achieving all benefits that the forest could possibly provide grouped together. In general, if I included stakeholders' interests and values as management goals, one could explore how far away any management plan is from the ideal situation in an *n*-dimension space. The *n*-dimension would be given by the number of considered values or benefits. Each axis would represent a beneficial forest outcome, and each point coordinate (deviation) would be a quantitative measure of each forest value loss from its potential optimum due to

competition among other values. If we considered economic, social and ecological goals to have equal weight, this index could be used as a powerful tool in sustainable management and decision making processes.

Figure 6.1 offers a visualization of this idea in a three-dimension (3-D) space. Imagine that we want to accomplish three management goals: 1) an economic goal, to get the maximum financial benefit from the forest; 2) a social goal, to provide a specific ROS; and 3) an ecological goal, to obtain an irregular vertical structure of the forest. Although these goals are not mutually exclusive, they certainly compete. If one only considered one of the three management goals, for example to obtain the maximum financial benefit from the forest, there would be no competition and the output (financial value) would be given by the capacity of the forest to produce market-priced outcomes. Considering the financial, the social, and the ecological goals together, one cannot obtain the same outputs and condition levels as when considering each of them individually. To eliminate the competition factor, we can simulate three management scenarios, one for each management goal considered individually, and aggregate all the simulation results together to create the theoretical ideal optimum. In a 3-D space (Figure 1), each axis would represent the percentage of decrease (deviation) for each goal with respect to the optimum. The theoretical optimum would be located at the axis origin as it represents the maximum threshold whereby the scenarios are compared, and any other scenario would be located in the space defined by the positive segments of each axis (point A). The comparison value index (Euclidean distance) would be represented on the space by the straight line between the axis origin and the point that represents the scenario. The same idea was applied to a nine-dimension space.

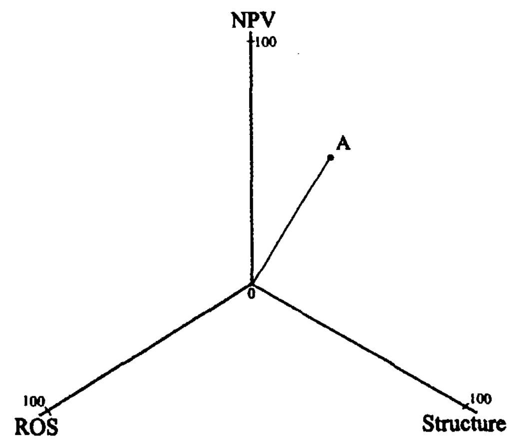

Figure 6.1: Euclidean distance from management scenario A to ideal scenario (origin vertex) in a 3-dimension space. Each axis represents the percentage of decrease within the management goals.

The Euclidean distance helps to find the combination of management goals and goal intensities that satisfies value demands and that reduces the competition among them. The more forest uses compete in a given management scenario, the higher the Euclidean distance. I used the Euclidean distance as a forest value comparison index, considering the ideal optimum as the reference point. The smaller the distance from the ideal, the closer the analyzed scenario was to providing the maximum desired benefits. Giving all goals equal weight, the smaller the deviation from the ideal optimum, the greater the forest value that a management scenario offers to society.

We developed a variability index to estimate the diversity of uses and amenities that each scenario provided. I considered not only the quantity of uses and amenities but also their quality. Each amenity and use was given equal weight. The uses and amenities considered are summarized in Table 6.4.

Management goal	Amenities
Sustainability	Timber rotations allow stands to over-reach mature stages and an even-time distribution of the land ready for timber removals, which cause smaller size impacts
Environmental protection	Soil erosion prevention of steep zones. Protection of fragile ecosystems (alpine, subalpine and riparian ecosystems)
Presettlement conditions	Presettlement species composition Irregular vertical structure
Recreational opportunities	Primitive recreational use Semi-primitive non-motorized, and motorized recreational uses
Visual quality	Protection of high visual sensitive zones Protection of medium visual sensitive zones
Timber production	Profitable timber management Non profitable timber management

Table 6.4: Uses and amenities that define the variability index.

6.4. RESULTS

6.4.1. Scenario analysis.

6.4.1.1. Scenario analysis over time.

Forest inventory conditions, harvested volumes, and net revenues differed according to the set of management goals considered, and these differences did not remain constant through time and did not have the same rate of change. Figure 6.2 shows the variation of the stand class distribution when adding to the NPV scenario, the management goals for sustainability criteria (goal Sust) and protection of fragile ecosystems (goal Env), which represented scenario Sustenv; goal Env, the achievement of providing primitive and semi-primitive opportunities (goal Rec1), and the protection of high and medium visually sensitive zones (goal VQ1), which represented scenario NPVenvRec1VQ1; goal Sust, goal Env, goal Rec1 and goal VQ1, which represented scenario SustenvRec1VQ1; goal Env, the achievement of presettlement species composition and vertical structure (goal SC1), Rec1 and VQ1, which represented scenario NPVenvSC1Rec1VQ1; and goal Sust, Env, SC1, Rec1 and VQ1 (scenario

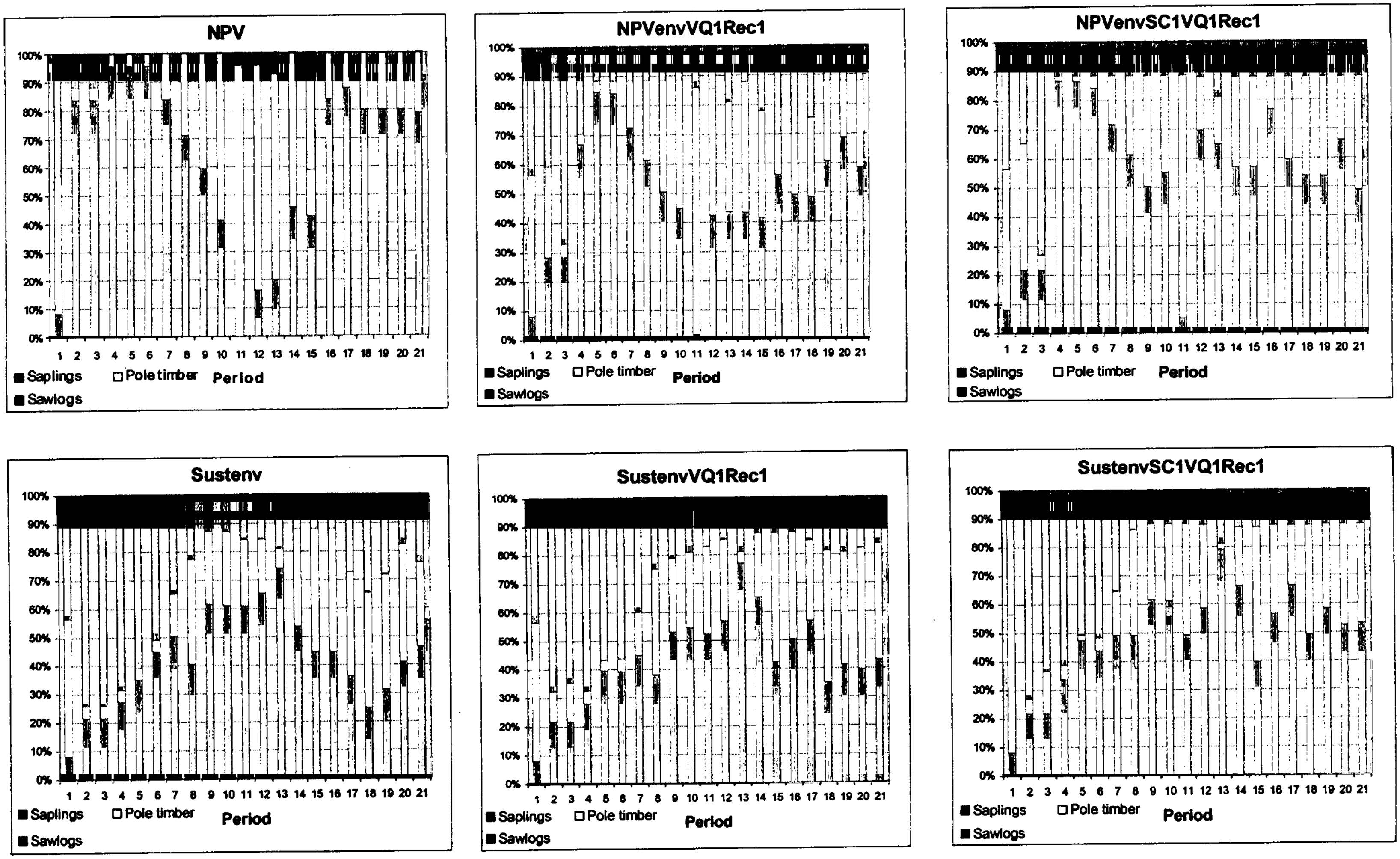

Figure 6.2: Land percentage distribution of stand classes in the Bigelow Preserve forest under management scenarios NPV, NPVenvVQ2Rec2, NPVenvSC1VQ1Rec1, Sustenv, SustenvVQ2Rec2, and SusenvSC1Rec1.

SustenvRec1VQ1SC1). Management goals related to visual and recreational aspects required silvicultural treatments with low visual impact. This condition excluded high intensity timber management, such as clearcuts and short rotations, and translated into an increase of sawtimber in the forest for almost every period.

Although management goal SC1 (achieving presettlement species composition and vertical structure) increased the distribution of sawtimber stands in the landscape by six percent, the cumulative effect of SC1 over recreational and visual management goals had a decreasing impact on the percent distribution of sawtimber stands over time. An explanation for this result relies on the fact that the only vegetation removals allowed under SC1 were individual and groups selection cuts (depending on the shade tolerance of the primary species composition of the stand) in order to achieve an irregular structure in the entire forest. In the absence of other goals, selection cuts did not significantly increase the stand quadratic mean diameter, (an indicator used to classify the average tree diameter size of the stand) averaged over the simulation time. Although selection cuts left a minimum of five large-diameter (at least 28 inches) trees per acre in the forest, they also heavily targeted sawlogs and veneers because of their higher market value. The species composition change goal had no effect on the percentage of land classified as sawtimber stands and averaged for the planning horizon. However, during the early periods, when the species composition change occurred, there was a small decrease in the percentage of sawtimber stands. The removal and/or suppression of the undesired species (in some cases a total removal and planting was necessary) affected about 30 percent of the land. In those areas with new species composition, I carried out earlier thinnings to promote new regeneration and to start a multiple-layer forest structure. This high

intensity management, applied to a third of the forest, resulted in a small decrease of sawtimber stands at the forest level during the earlier periods compared to the same management scenarios without the presettlement species composition goal.

The sustainability criteria (Sust) accounted for a significant increase in the percentage of sawtimber stands in the forest over time, and ensured a forest stand distribution with a minimum of 12.5 percent of the land classified as sawtimber stands over all simulated periods, regardless of other management goals (see Appendix B, the percent distribution of stand classes across the area, for all management scenarios). In addition, the Sustenv and SustenvVQ2Rec2 scenarios presented the longest time stage (24 percent of the periods) with more than 50 percent of the land classified as sawtimber.

The stocking distribution of the forest also varied through time and across scenarios (Appendix C). Presettlement, visual and recreational management goals tended to increase stocking levels (Figure 6.3). The sustainability criteria also increased the stocking levels over time, however their cumulative effects decreased when other management goals were considered. Unlike stand class distribution, stocking levels were very sensitive to those goals that restricted the maximization of the NPV. Restrictions with low opportunity costs, such as protecting fragile ecosystems and achieving presettlement species composition (NPVenvSC2), translated into large increases in the percentages of time (from 28 to 81) in which at least 50 percent of the forest fell under the adequately stocked or well stocked categories. Under management scenario NPV, at least 50 percent of the forest was adequately stocked or well stocked over 28 percent of the planning horizon, while scenarios Sustenv, and NPVenvVQ1Rec1 achieved these

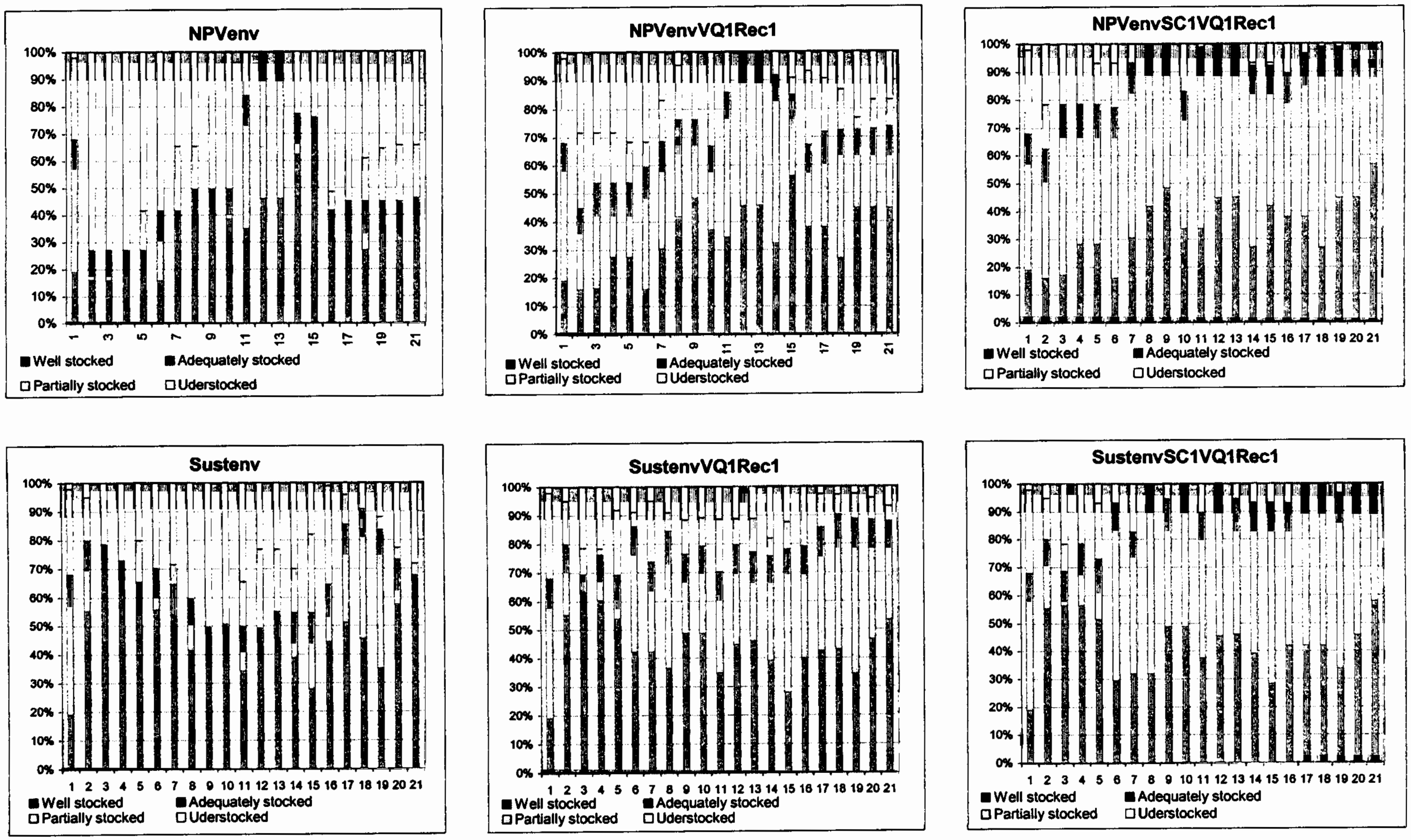

Figure 6.3: Land percentage distribution of forest stocking levels in the Bigelow Preserve under management scenarios NPV, NPVenvVQ2Rec2, NPVenvSC1VQ1Rec1, Sustenv, SustenvVQ2Rec2, and SusenvSC1Rec1.

levels 85 and 95 percent of the time respectively; and scenarios NPVenvSC1VQ1Rec1, SustenvVQ1Rec1 and SustenvSC1VQ1Rec1 were 100 percent. These results changed when considering at least three quarters of the forest instead of half (Table 6.5).

An analysis of all scenarios revealed that the influence of the sustainability criteria on the stand quadratic mean diameter was higher in the absence of other management goals. When included with other goals, the cumulative effect of the sustainability criteria showed a significant increase of the well stocked category, sometimes at the expense of the adequately stocked category. For scenarios NPVenv and Sustenv, the time interval during which at least 50 percent of the land was classified as well or adequately stocked varied from 33 to 85 percent of the planning horizon, respectively, while the time percent associated with at least 70 percent of the land under those two categories did not change. The sustainability criteria increased the well stocked category entirely at the expense of the adequately stocked, so the sum of both categories explained the "no change" for the 70 percent threshold. Analyzing the well stocked category individually I found that for the 50 (70) percent of land threshold, scenario NPVenv fell into this category 10 (0) percent of the time, while scenario Sustenv fell 48 (5) percent.

SCENARIO	At least 50 %	At least 75%
NPV	28	14
NPVenv	33	24
NPVenvRec1	95	33
NPVenvRec2	81	24
NPVenvSC1	100	90
NPVenvSC1Rec1	100	90
NPVenvSC1Rec2	100	90
NPVenvSC1VQ1	100	90
NPVenvSC1VQ1Rec1	100	90
NPVenvSC1VQ2	100	90
NPVenvSC1VQ2Rec2	100	90
NPVenvSC2	81	24
NPVenvSC2Rec1	95	62
NPVenvSC2Rec2	95	33
NPVenvSC2VQ1	95	33
NPVenvSC2VQ1Rec1	95	62
NPVenvSC2VQ2	95	33
NPVenvSC2VQ2Rec2	95	33
NPVenvVQ1	81	24
NPVenvVQ1Rec1	95	33
NPVenvVQ2	81	24
NPVenvVQ2Rec2	81	24
Sustenv	85	24
SustenvRec1	100	71
SustenvRec2	100	57
SustenvSC1	100	85
SustenvSC1Rec1	100	85
SustenvSC1Rec2	100	85
SustenvSC1VQ1	100	85
SustenvSC1VQ1Rec1	100	85
SustenvSC1VQ2	100	85
SustenvSC1VQ2Rec2	100	85
SustenvSC2	100	52
SustenveSC2Rec1	100	85
SustenvSC2Rec2	100	76
SustenvSC2VQ1	100	76
SustenvSC2VQ1Rec1	100	85
SustenvSC2VQ2	100	76
SustenvSC2VQ2Rec2	100	80
SustenvVQ1	100	76
SustenvVQ1Rec1	100	76
SustenvVQ2	100	38
SustenvVQ2Rec2	100	43

Table 6.5: Percentage of time when a minimum of 50 and 75 percent of the forest land fell under the well or adequately stocked categories.

In general, the sustainability criteria goals provided a more homogeneous distribution of the forest inventory volumes across time and a higher volume for two thirds of all periods in the absence of other goals (Figure 6.4). Figure 6.5 shows the inventory volume evolution through time for different scenarios grouped in four charts. The visual and recreational goals in groups one and three were more restrictive than in groups two and four. In the first group, the order in which scenarios provided inventory volumes for every period was the following (from lower to higher): NPV, NPVenv, NPVenvVQ1, NPVenvRec1 and NPVenvVQ1Rec1, NPVenvSC1 and NPVenvSC1VQ1Rec1. The same scenarios under sustainability criteria (group three) did not show this order until they reached period eight. The sustainability criteria accounted for similar inventory volumes during the first eight periods for these scenarios, becoming the differences in volume more significant from period eight to twenty one.

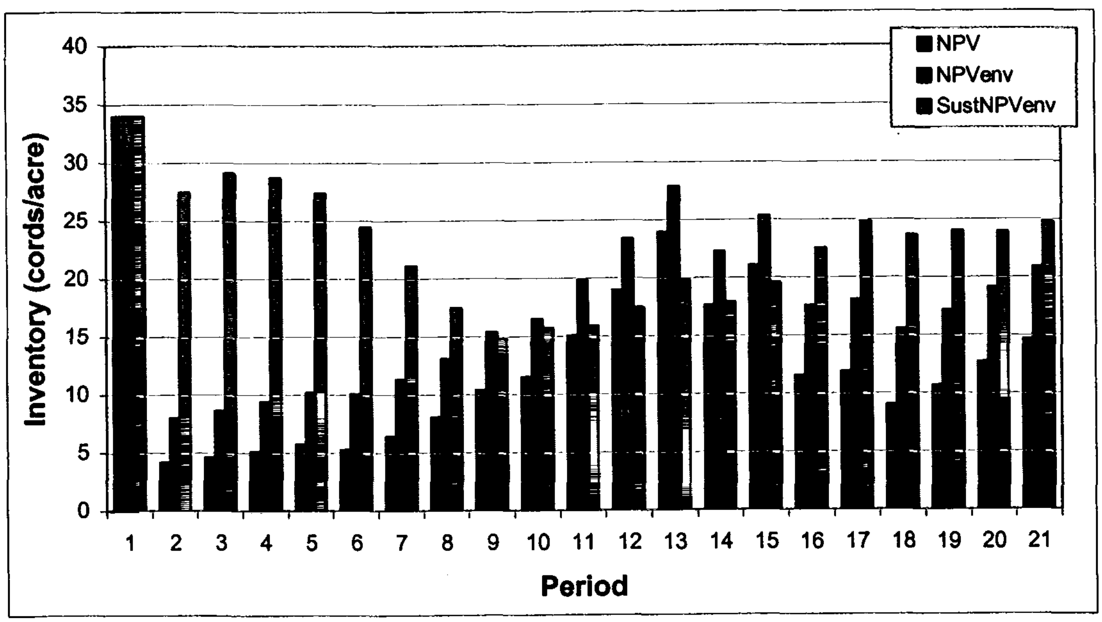

Figure 6.4: Time distribution of the forest inventory volume for management scenarios NPV, NPVenv, and SustNPVenv.

Management goals Rec1 and VQ1 had no inventory volume cumulative effect in the presence of goal SC1, nor did goal VQ1 in the presence of goal Rec1 within both sustainability and non-sustainability criteria scenario groups. However, these values under sustainability criteria and under non-sustainability criteria groups differed for each simulated period, having sustainable scenarios with a higher average value over time. Each of the scenario pairs NPVenvSC1-NPVenvSC1VQ1Rec1 and SustenvSC-SustenvSC1VQ1Rec1 presented the same number of cords per acre for each one of the 21 simulated periods. The inclusion of management goals VQ1 and Rec1 did not seem to change the inventory volume once the goal SC1 was accomplished, with and without sustainability criteria (see groups one and three in Figure 6.5). At the same time, scenarios NPVenvRec1 and NPVenvVQ1Rec1 presented the same inventory response although goal VQ1 did not present a cumulative effect on the inventory volume if goal Rec1 had already been accomplished. In both cases, this pattern was not reciprocal. Achieving goal VQ1 (NPVenvVQ1 or SustenvVQ1) did not provide the same inventory volume as achieving goal VQ1 and Rec1 (NPVenvVQ1Rec1 or SustenvVQ1Rec1) and achieving goals VQ1 and Rec1 (NPVenvVQ1Rec1 or SustenvVQ1Rec1) did not produce the same response as achieving goal SC1 (NPVenvSC1 or SustenvSC1). However, even if NPVenvSC1 and NPVenvSC1VQ1Rec1 had the same inventory values for each period (group one), these values differed from SustenvSC1 and SustenvSC1VQ1Rec1 (group three). Therefore the impact of the sustainability criteria on the SC1 goal had an increasing average effect. One can deduce the same conclusion by analyzing the effect of sustainability on the Rec1 goal.

Comparison of scenarios associated with less restrictive visual and recreational goals (groups two and four in Figure 6.5) presented a different order in terms of inventory volume. From lower to higher inventory levels, these scenarios were: NPV, NPVenv, NPVenvVQ2, NPVenvSC2, NPVenvRec2, NPVenvVQ2Rec2, and NPVenvSC2VQ2Rec2. The added effect of the sustainability criteria on these scenarios (group four) was the same as in the scenarios considered under group three. Before period eight, the inventory values across scenarios remained similar. After period eight, differences became relevant. Like group three, the sequential order found in group two did not happen in group four until reaching period eight. Scenarios NPVenvSC2 and NPVenvSC2VQ2Rec2 presented different inventory values, unlike the equivalent and more restricted scenarios in group one (NPVenvSC1 and NPVenvSC2VQ2Rec2). Therefore, there is a cumulative effect when achieving goals VQ2 and Rec2 in addition to goal SC2. However, the effect of goal VQ2 after accomplishing goal Rec2 is null under non-sustainable criteria, and significant under sustainability criteria.

The interpretation of these results showed that achieving and maintaining an irregular vertical structure of the forest (the difference between accomplishing SC1 and SC2) additionally provided the highest visual quality level (VQ1) defined in this study and the most desired recreational level (Rec1) for all simulated periods. Vertical structure also provided a higher inventory volume in all cases, and all periods with the exception of periods three, four, five and six in group four.

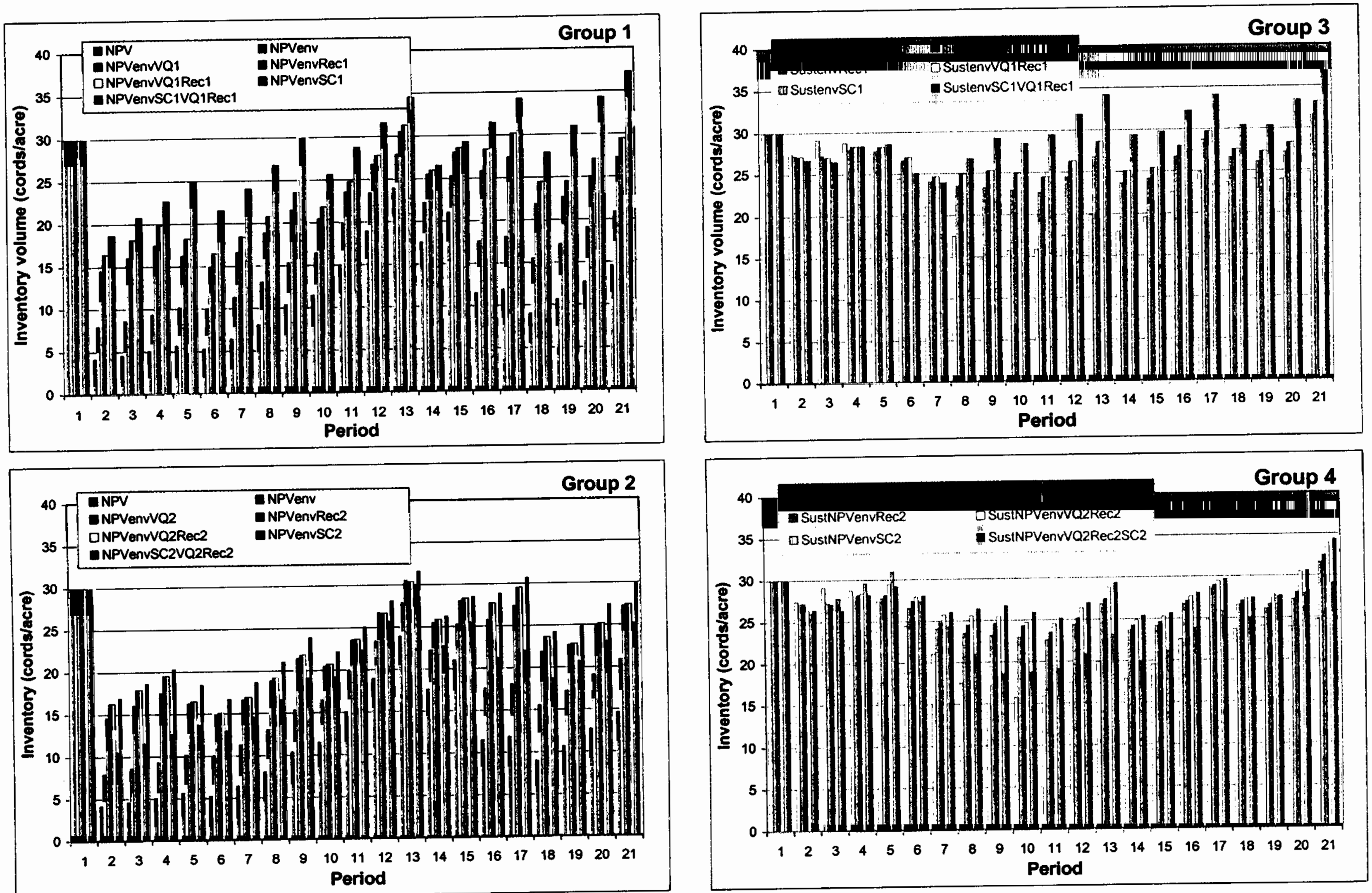

Figure 6.5: Time distribution of inventory volume (cords per acre) for different management scenarios simulated over the planning horizon.

Pair comparisons among all management scenarios under non-sustainability criteria and the one that presented the minimum standing inventory volume (NPV), revealed that NPVenvSC1VQ1Rec1 and NPVSC1 showed the widest range of change and the highest change values for all the periods, while NPVenv presented the narrowest rate of change and the lowest values. Figure 6.6 shows the inventory volume change among 11 of the 22 scenarios without sustainability criteria and NPV. The equivalent scenarios under sustainability criteria revealed the same pattern after period eight. Figure 6.7 shows the comparisons of ten of the 21 sustainable scenarios against NPV, where the time threshold (vertical white discontinuous line) represents the point in time where differences among scenario inventories became significant.

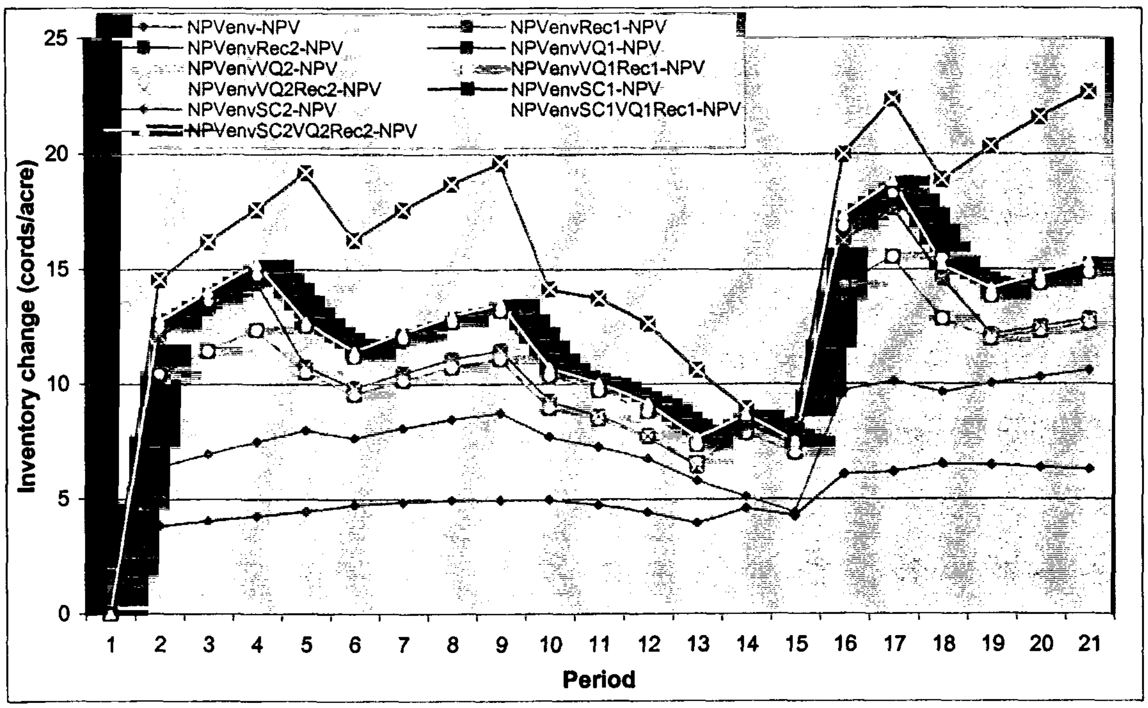

Figure 6.6: Inventory change of pair comparison between one of the 11 considered management scenarios under non-sustainable criteria and scenario NPV.

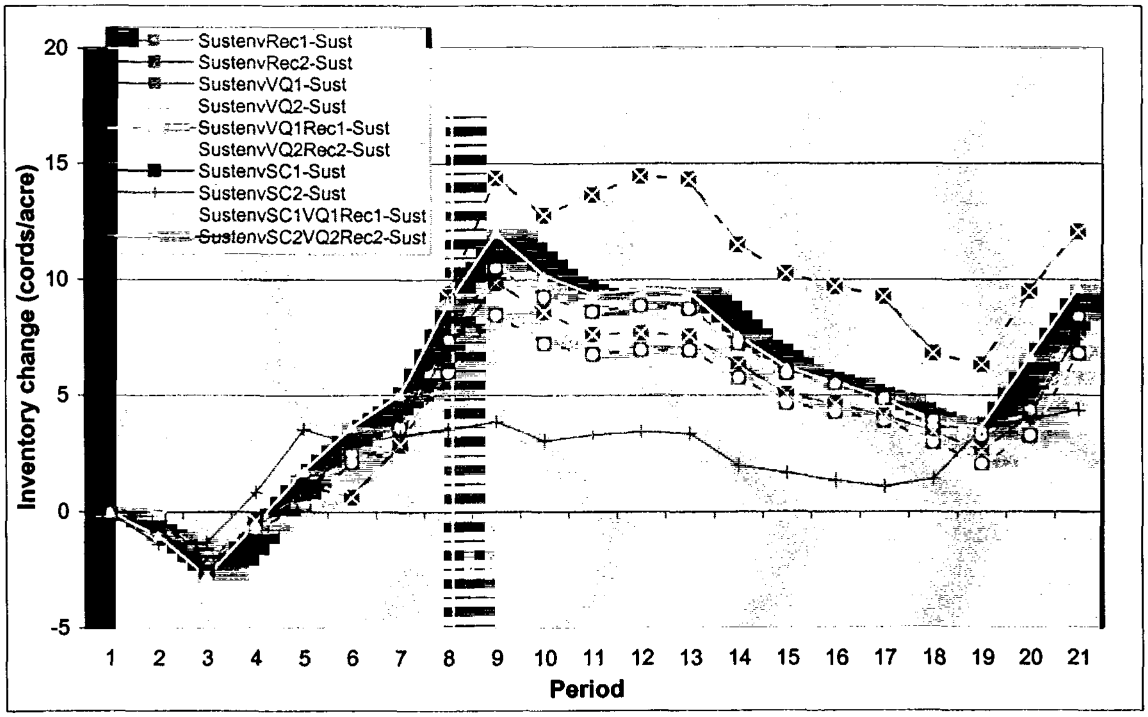

Figure 6.7: Inventory change of pair comparison between one of the ten considered management scenarios under sustainable criteria and scenario Sustenv.

As expected, the "area control" constraint under sustainability criteria translated into a more even distribution of the merchantable harvested volume over time (Figure 6.8). However, the volume distribution between periods was more regular for sawtimber than for pulpwood products. Under non-sustainability criteria, neither sawtimber nor pulpwood presented an even distribution of their volumes across those periods when timber removal occurred (Figures 6.9 and 6.10).

The distribution of the harvested volume across periods had an impact on the net present value (NPV). Given the same merchantable harvested volume averaged over the planning horizon, those scenarios that removed large volumes during the first periods had a greater NPV than those scenarios with a similar harvested volume for each period. The time average harvested volume between scenarios NPVenv and Sustenv differed just one percent, but the different volume distribution over time accounted for the 35 percent NPV

decrease of scenario Sustenv compared to scenario NPVenv. In this last scenario, the liquidation of the forest in period one and shorter rotations produced a significant financial impact. The higher the harvested volume in early periods, the greater the NPV values. A comparison of scenario SustenvRec1 to scenario NPVenvRec1 revealed an 8.5 percent decrease of average harvested volume and a 21 percent decrease in NPV. The ratio of change did not stay constant among scenarios, it was a function of the set of considered goals.

Both under sustainability criteria and non-sustainability criteria, scenarios that achieved goals Env and SC1 all presented the same harvested volume with the same products composition (sawtimber and pulpwood) for every period. Likewise, the inclusion of any of the two visual quality goals to those scenarios that provided recreational opportunities did not have a cumulative effect on the harvested volume, nor a change on the products composition. In period 16 and in all scenarios with the exception of those that accomplished an irregular structure of the forest, the amount of pulpwood supplied was significantly large in comparison with the rest of the periods. During this period, many acres were ready for regeneration cuts of a two-cut shelterwood system, commercial thinnings in addition to the final removals, which explains the large amount of pulpwood obtained. For the same period, the amount of sawtimber was low; non-sustainable scenarios presented less than 12 thousand board feet for the entire forest. This increase of pulpwood during period 16 was maximized in scenario NPV. In the absence of other management goals, maximizing NPV liquidated as much mature forest as existed in the first period. Seventy five years later, the forest presented a large percent of mature, fast-growth species and ready-to-thin slow growth species.

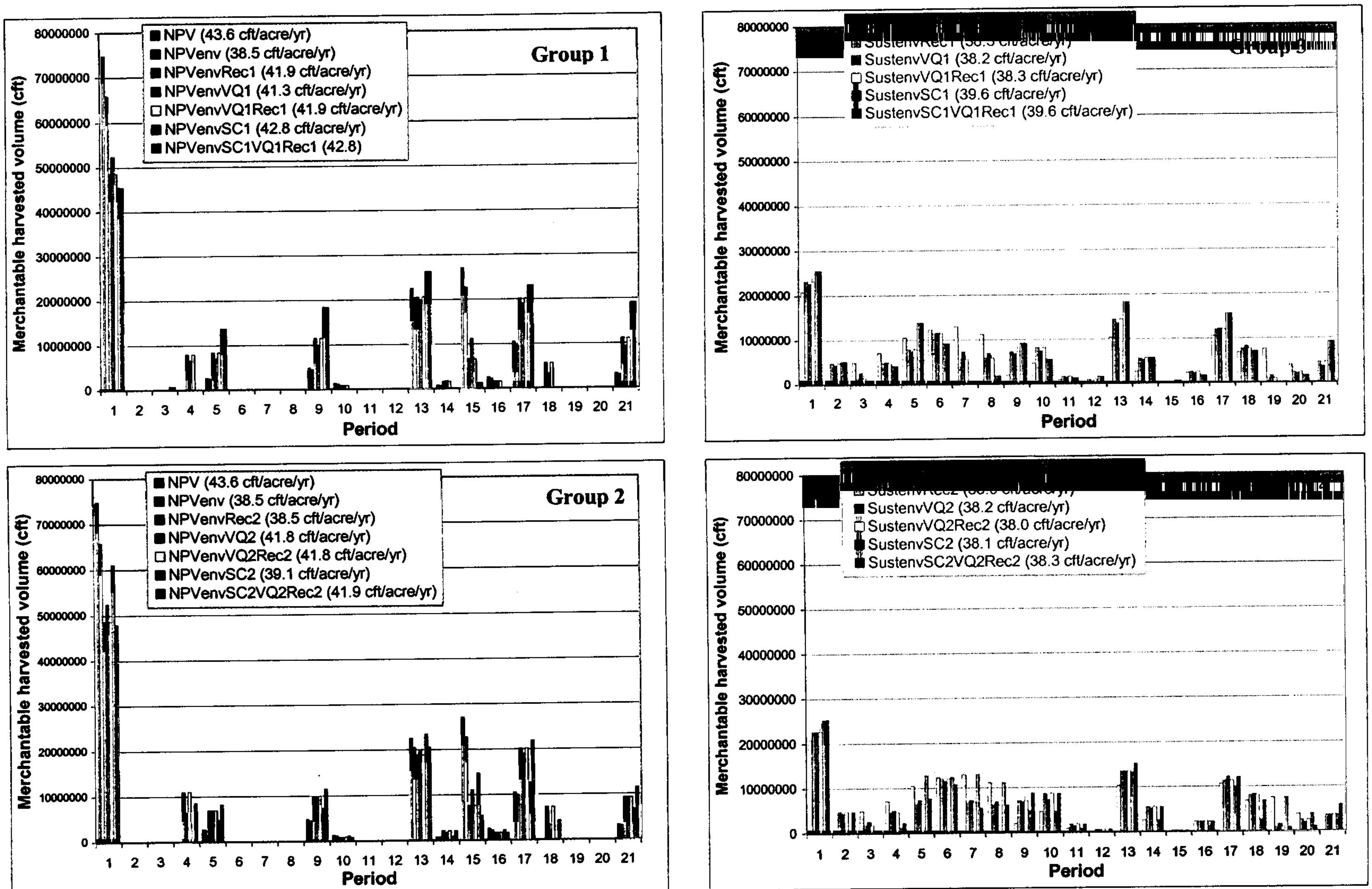

Figure 6.8: Merchantable harvested volume distribution (cubic feet) over time and averaged values (cubic feet per acre per year) for four groups of simulated management scenarios.

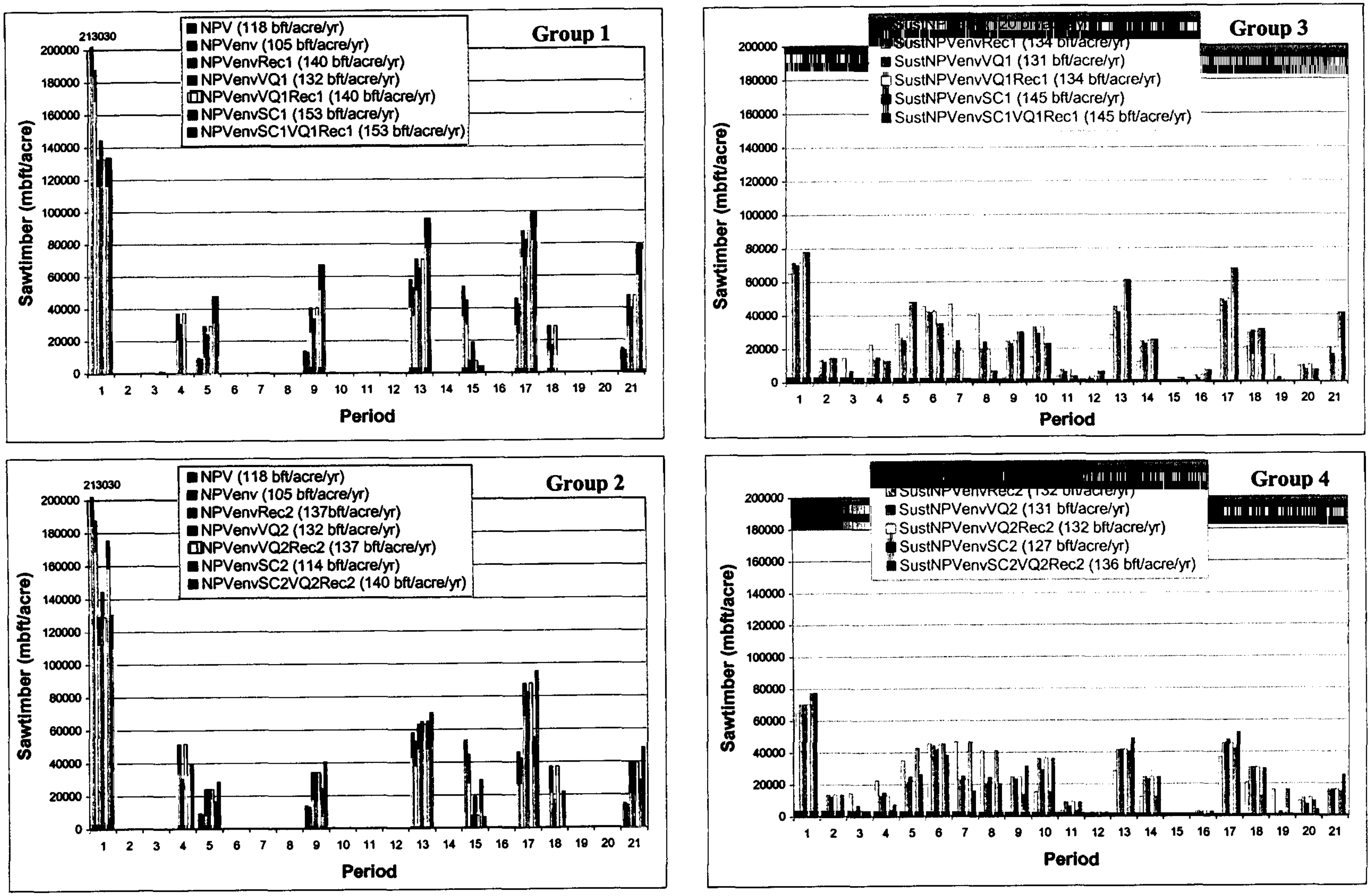

Figure 6.9: Sawtimber volume distribution (in thousand of board feet) over time and averaged values (cubic feet per acre per year) for four groups of simulated management scenarios.

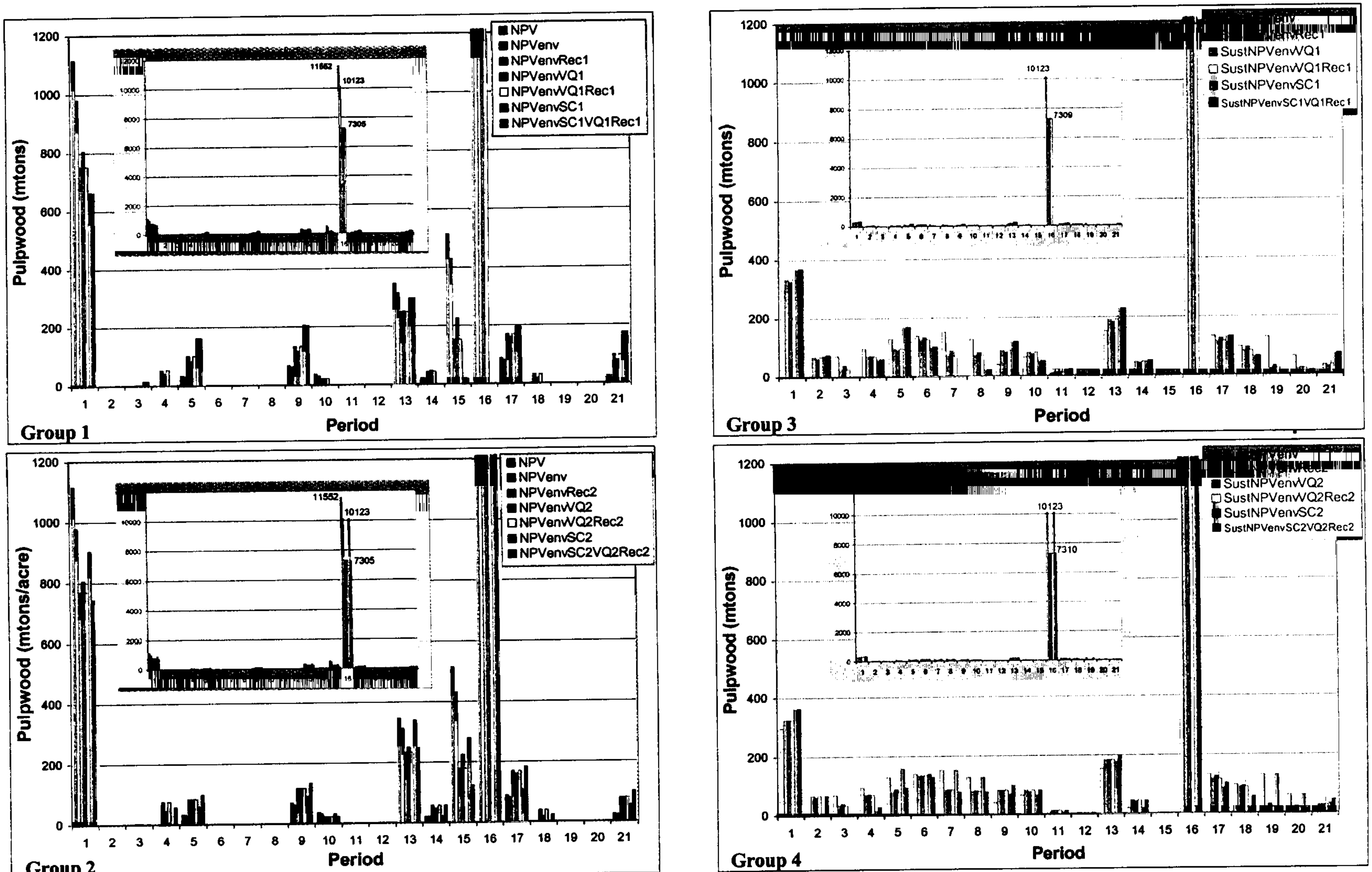

Figure 6.10: Pulpwood volume distribution (in thousand of tons) over time for four groups of simulated management scenarios. Two scales represented to emphasize detail.

<u>6.4.1.2. Scenario analysis by time-averaged variables.</u>

Taking the maximum financial value that forest capacity can provide as the reference point for comparing scenario results, scenario NPV presented the upper threshold for the analysis of variables NPV, average merchantable harvested volume, and average sawlog and pulpwood volumes over time. In general, adding other management goals to the maximization of the financial revenue had a negative impact on the NPV. The size of the impact depended on the set of goals considered and did not represent a cumulative effect in some cases. Including the more competitive goals did not necessarily imply a higher NPV loss.

An analysis of the NPV across all management scenarios revealed that the sustainability criteria decreased NPV an average of 20 percent, varying from 17 to 27 percent (Figure 6.11), excluding the "no-management" scenario. While scenario NPV presented the highest NPV ($300 per acre), all those scenarios that met the sustainability criteria and the presettlement forest structure and species composition at the same time presented the lowest NPV ($134 per acre) after the no-management scenario, despite whether other goals were accomplished. Scenario SustenvSC1VQ1Rec1, which accounted for the most restrictive management goals, also presented a NPV of 134 dollars per acre (The scenario NPV with sustainability criteria was not simulated). The no-management scenario had a low administration cost of a few dollars per acre per year. Because the Bigelow Preserve is public land, taxes were not relevant.

Different goal combinations had different responses in terms of benefits and costs and their distribution over time. Under both sustainability and non-sustainability scenario groups, achieving irregular structure represented the lowest threshold beyond which the

inclusion of another goal could not decrease the NPV (with the exception of not managing). Management actions associated with producing an irregular forest structure also met the requirements needed to achieve visual quality and recreational restrictions, so the inclusion of these other goals did not alter the financial output.

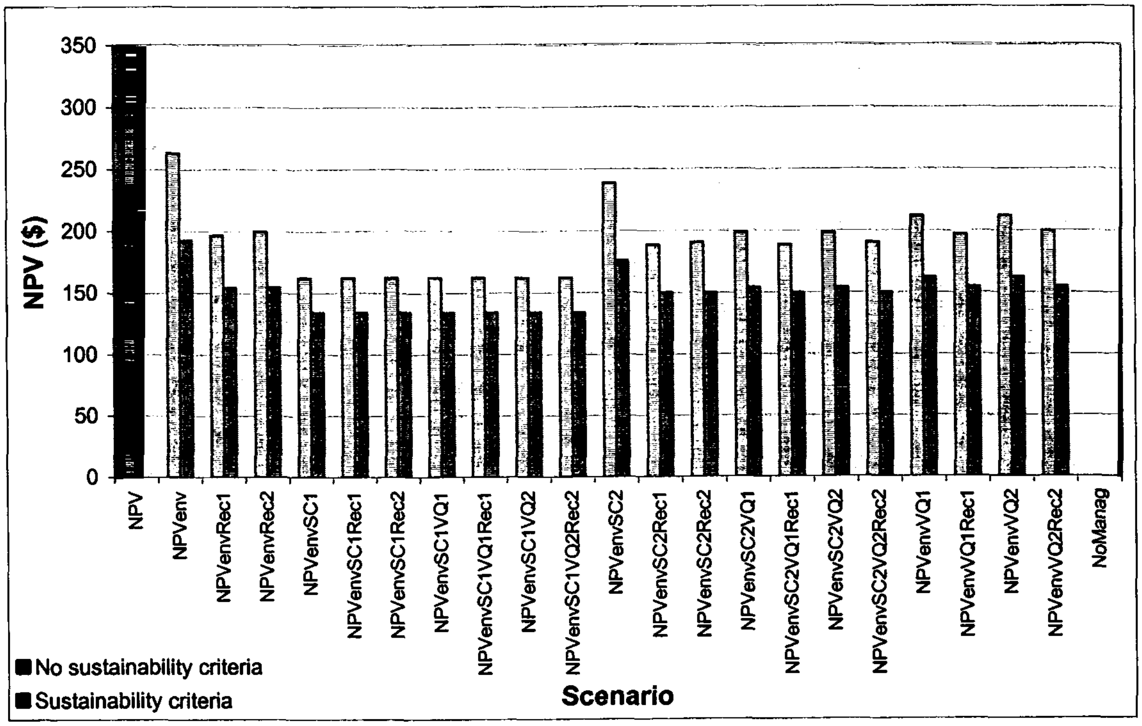

Figure 6.11: Net present value (in dollars) for all management scenarios.

The sum of the effects of each goal considered independently had a different impact than when they were integrated together. In all cases, the cumulative effect of a set of goals was lower than the sum of each of them considered independently. Table 6.6 shows the financial impact of each management goal considered independently on the study area. Fragile ecosystems accounted for 14 percent of the land, and their protection decreased NPV by 12 percent. Achieving vertical structure presented the highest individual decrease (32 percent) while achieving species composition had an eight percent decrease. However, the combination of both ecological goals showed a 38

percent NPV decrease, a number slightly lower than the sum (40 percent) of both effects individually considered. Because it was not an objective to provide just one recreational opportunity class, I did not simulate scenarios for each recreational opportunity but, rather, for groups of them. Therefore, I could not isolate the impact of each individual class on the NPV. Results showed that providing primitive opportunities in addition to semi-primitive non-motorized and semi-primitive motorized, only decreased the NPV by one percent. The same results were found when comparing the protection of high and medium visually sensitive areas with just high visually sensitive areas.

Management Goal	**NPV decrease (%)**
Sustainability criteria	20
Fragile ecosystems protection	12
Irregular structure	32
Presettlement species composition	8
ROS: primitive, semi-primitive non-motorized and semi-primitive motorized	22
ROS: semi-primitive non-motorized and semi-primitive motorized.	21
High and medium visual sensitive zones protection.	17
High visual sensitive zones protection	16

Table 6.6: NPV decrease (in percentage) of each management goal considered independently with respect to the NPV scenario.

The only factors that had a significant impact on the amount of harvested volume were the sustainability criteria, with an average decrease of 7.5 percent and a range from nine to one percent for all scenarios (Figure 6.12). Average volume distribution across scenarios was very similar for most of the scenarios, with a maximum variability of 11 percent. While the inclusion of the fragile ecosystem goal reduced the harvested volume 11 percent relative to the maximum volume produced by scenario NPV, the addition of other goal(s) to this one increased this amount to a total maximum decrease of five percent (with the exception of including just presettlement species composition, which

scored a total decrease of ten percent). Therefore, scenarios NPVenv and NPVenvSC2, offered some of the lowest harvested volumes and, in addition to scenario NPV, the highest NPV. However, NPV depended not only on the amount of harvested volume, but also on the distribution of the volume over time, the product composition of the total harvested volume (pulpwood and sawtimber), the costs associated with the applied silvicultural treatments, and rotation lengths used to obtain that amount of harvested volume. A comparison of scenarios NPVenv and Sustenv with scenario NPV showed that scenario NPVenv led to a decrease of 12 percent in average harvested volume and 12 percent in NPV, while the same scenario under sustainability criteria, Sustenv, caused a decrease of 13 percent in average harvested volume and 35 percent in NPV. The different distributions of harvested volume over time between scenario NPVenv and Sustenv accounted for the big difference in NPV decrease (Figure 6.13).

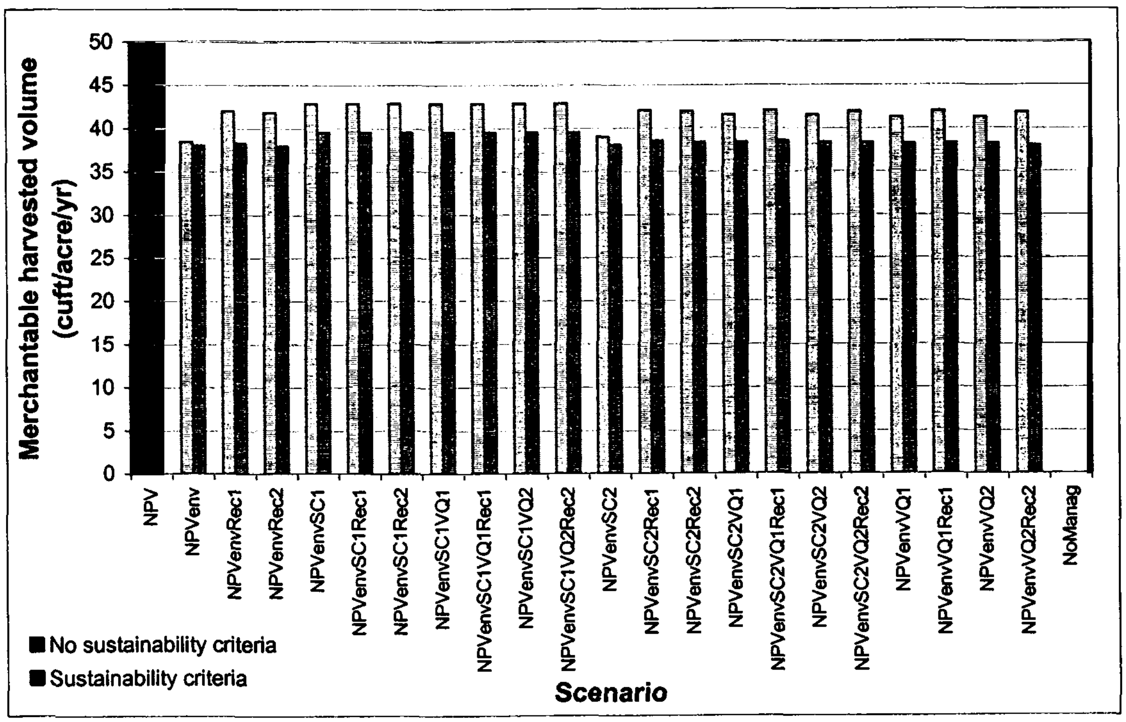

Figure 6.12: Average across periods of merchantable harvested timber volume (cubic feet per acre per year) for all management scenarios.

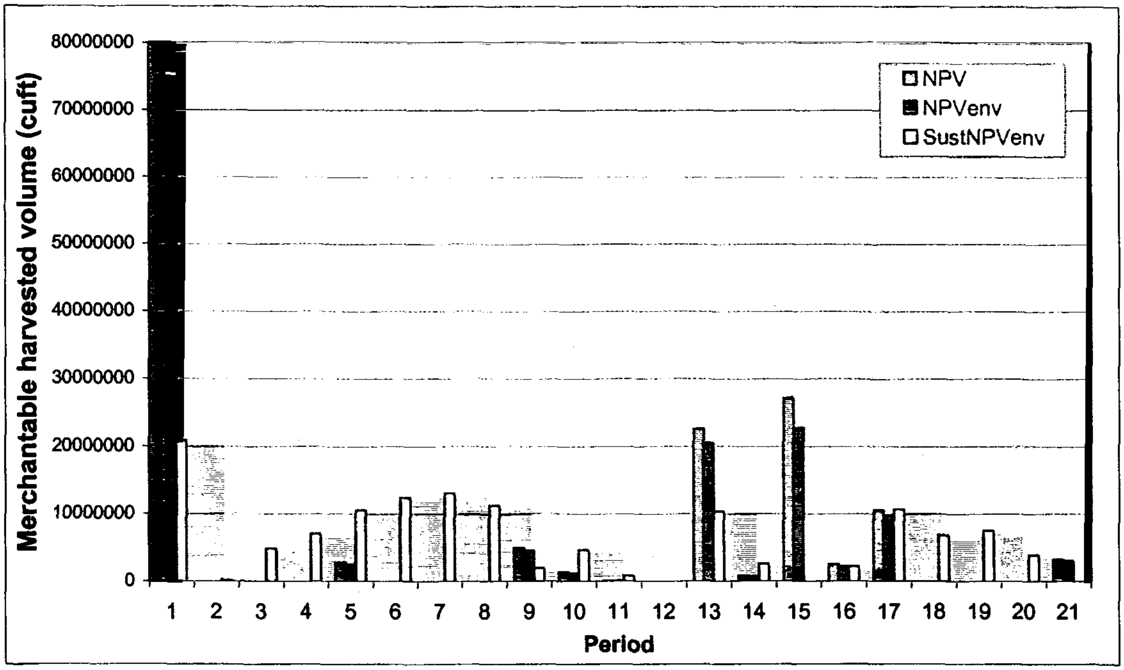

Figure 6.13: Merchantable harvested volume distribution (cubic feet) over time for scenarios NPV, NPVenv and SustNPVenv.

Scenarios NPV, NPVenv, NPVenvSC2, Sustenv and SustenvSC2 provided the lowest sawtimber volume (Figure 6.14) and the highest pulpwood volume (Figure 6.15). Even if sawtimber market prices are higher than pulpwood prices, the mentioned influencing factors accounted for the higher NPV associated with the scenarios NPVenv and NPVenvSC2 compared to the others. In these cases, the decrease in volume occurred more at the expense of sawtimber than pulpwood, which translated into lower revenues (the harvested volume is lower with a larger pulpwood representation than other scenarios). Consequently, the costs were lower and the harvest of a large part of the forest occurred in earlier periods than in the rest of the scenarios in order to have a high NPV. Because the sustainability criteria were not applied in these two cases, there was no time restriction, letting the optimization process decide which schedules were more profitable. The lack of time, recreational, visual and forest structure restrictions translated into

decreasing costs, making timber management more profitable. However, removing less volume did not necessarily imply that more inventory volume remained in the forest as the effect of applying the sustainability criteria did, where the harvested volume decreased and inventory volume increased. In fact, Figure 6.16 shows how scenarios NPVenv and NPVenvSC2, in addition to scenario NPV, presented the lowest average inventory volumes.

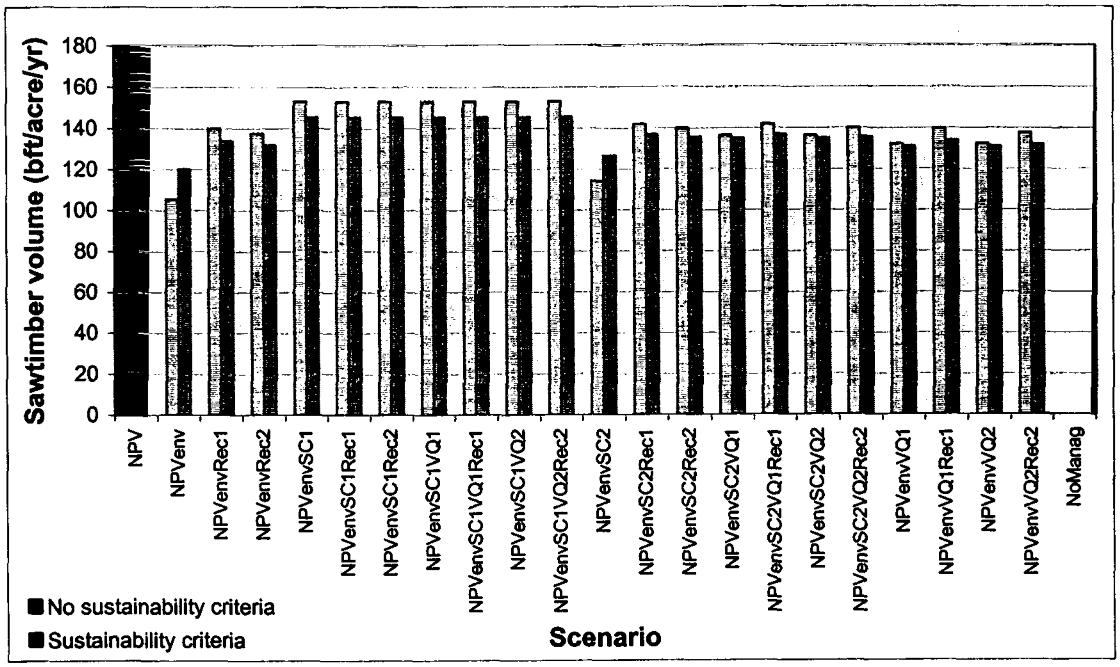

Figure 6.14: Average across periods of sawlog volume (board feet per acre per year) for all management scenarios.

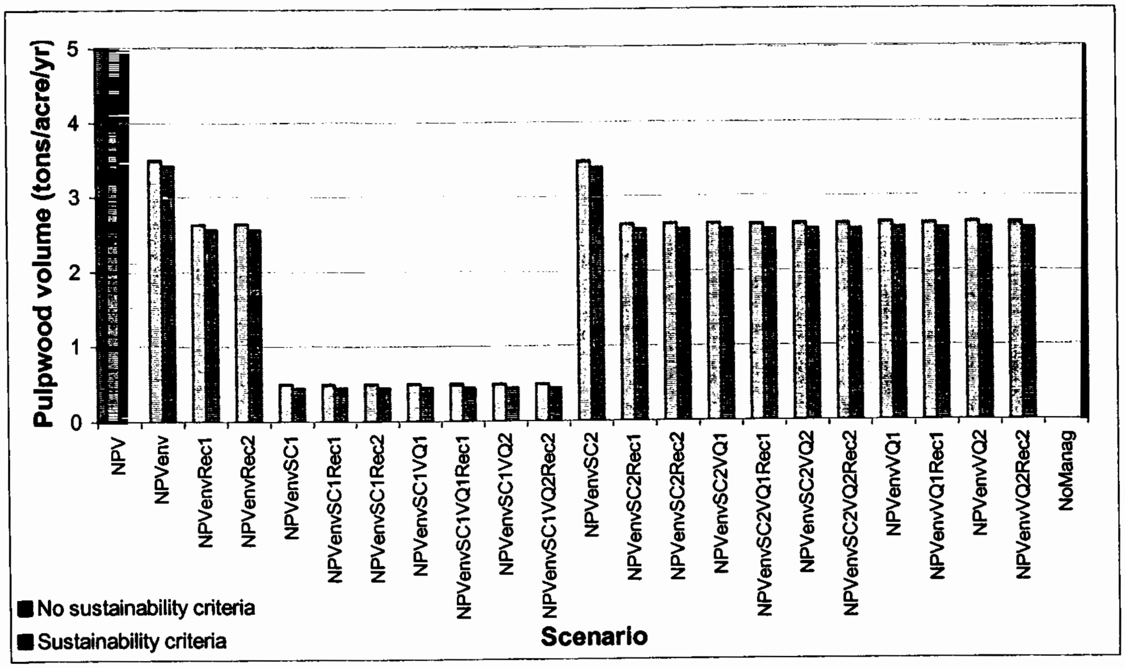

Figure 6.15: Average across periods of pulpwood volume (tons per acre per year) for all management scenarios.

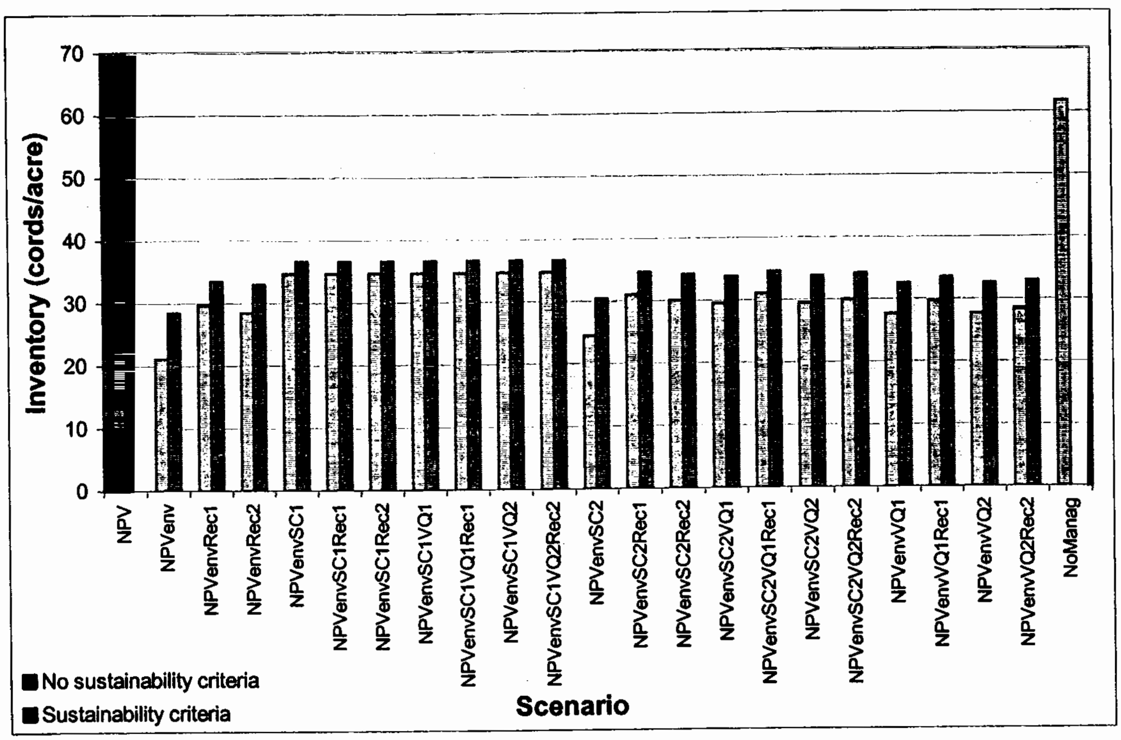

Figure 6.16: Average inventory volume (cords per acre) for all management scenarios.

The average value of pulpwood volumes presented broader variations than sawtimber volumes across all scenarios. The sustainability criteria averaged a two percent decrease in sawtimber with a range of change varying from -4 to 15 percent, and a six percent decrease in pulpwood with a 2 to 13 percent range. Only scenarios Sustenv and SustenvSC2 showed an increase in sawtimber volume when sustainability criteria were applied. The rest of the cases showed a sawtimber decrease no higher than five percent, mainly due to the total harvested volume decrease.

Under both sustainability and non-sustainability criteria, achieving an irregular forest structure increased the amount of harvested sawtimber to the maximum levels for all scenarios, reaching 153.0 and 145.4 board feet per acre per year respectively. This approach also significantly decreased the amount of pulpwood, reducing values within the range 2.64-3.99 tons per acre per year to values of 0.45 tons per acre per year. The silvicultural harvesting methods to achieve irregular structure included individual tree selection cuts for shade tolerant species and small group selection cuts for shade intolerant species. Both harvesting practices allowed the selection of those tree diameters that have a higher market value. Although, for ecological reasons, large diameters trees were also left in the standing forest, selection cuts removed a higher time-average proportion of sawtimber trees than did shelterwood cuts. Excluding scenarios that achieved irregular vertical structure, the rest presented equal volumes of pulpwood with an approximately three percent variation between sustainable and non-sustainable scenarios and very similar, though not equal, sawtimber volumes.

Inventory volumes rated higher for those scenarios that achieved the sustainability criteria and the irregular structure goals. Taking scenario NPV as the comparative

reference point, the inventory volume increase when achieving both goals was 138 percent (Figure 6.16). The increase due to the sustainability criteria across scenarios averaged 13 percent, with a range varying from six to 35 percent.

Comparing results to the outcomes of the no management scenario instead of scenario NPV, scenarios that achieved the sustainability criteria and the irregular structure goals showed a 40 percent decrease in inventory volume. However, 36.6 cords per acre represented a high density for a managed forest and, although it is true that this amount was significantly lower than the 61.7 cords per acre present in the no-management scenario, if we compare this number to the densities of a high-intensity timber management forest (15 cords per acre and lower), this number could be considered high. With the exception of scenario NPV, all scenarios scored average inventory volumes higher than 20 cords per acre, which represented good stocking levels (Figure 6.17).

All the scenarios had more than 62 percent of the forestland classified under the well or adequately stocked categories (except scenarios NPV and NPVenv). In those scenarios that achieved the sustainable and vertical structure goals, almost 90 percent of the forest could be classified in one of these two categories, which represented a 5 percent decrease over stocking levels of the no management scenario. The sustainability criteria did not have a significant impact (only one percent increase) in the percentage of land classified in the well and adequately stocked categories for those scenarios that reached an irregular vertical structure. However, for the rest of the scenarios the sustainability criteria averaged a 14 percent increase.

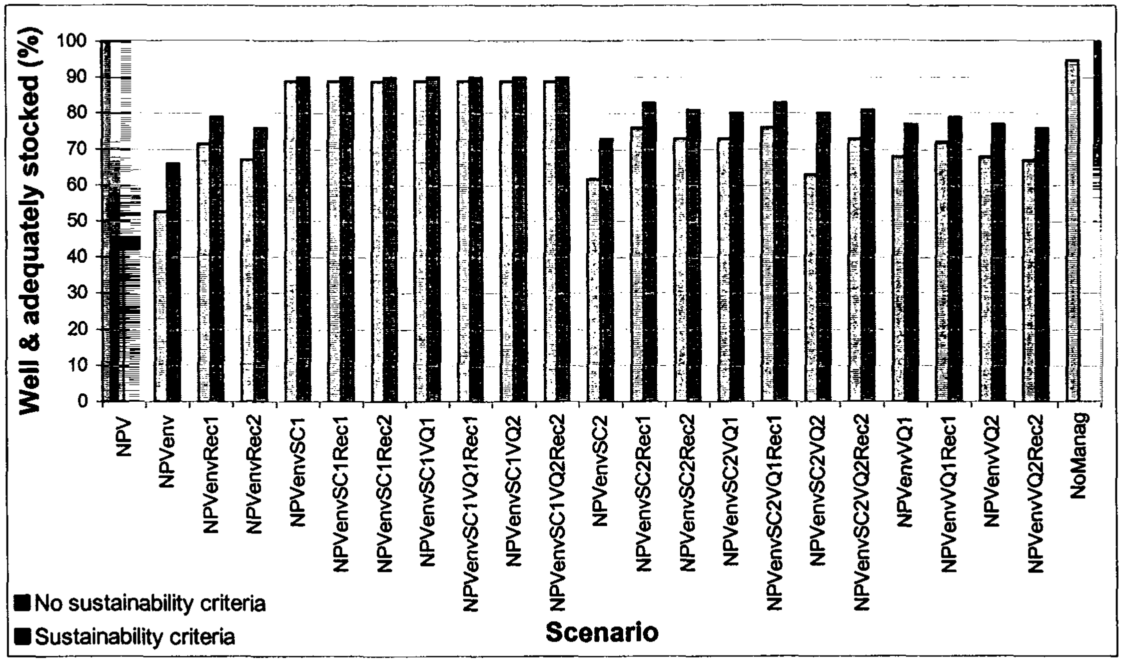

Figure 6.17: Percentage of land classified as well or adequately stocked within each management scenario.

The percentage of forestland classified as sawtimber stands was sensitive to the sustainability criteria. Sawtimber stand representation increased an average of 47 percent across all scenarios with a variability range of 35 to 88 percent (Figure 6.18). The variability range within each of the two scenario groups that met sustainable and non-sustainable criteria was smaller in the first one. Each group presented a percentage of forestland classified as sawtimber that varied from 27 to 32 percent, and from 6 to 23 percent respectively. This represented an average 67 percent decrease for the sustainable group, and an average 80 percent decrease for the non-sustainable group with respect to the no-management scenario. Scenarios that achieved a forest irregular structure and the sustainability criteria SustenvSC1, SustenvSC1Rec1, SustenvSC1Rec2, SustenvSC1VQ1, SustenvSC1VQ1Rec1, SustenvSC1VQ2 and SC1VQ2Rec2 had 27 percent of the forestland classified as sawtimber, which represented a ten percent

decrease over the average of the rest of the scenarios that did not meet the irregular structure goal but met at least one more goal than the protection of fragile ecosystems within that group. The same scenarios under the non-sustainable group doubled the difference, with a 20 percent decrease. This phenomenon was due to the silvicultural treatments used to create an irregular structure in the forest. Considering average values over time (the Y axis of Figure 6.18 represents the average over time of the percentage of forest that classified under the sawtimber stand type), selection cuts targeted higher diameters more than did shelterwood cuts. Shelterwood cuts retained higher diameters during longer periods. In addition, goal SC1 not only accounted for achieving an irregular structure, but also for achieving presettlement species composition. Species composition change had a smaller impact on the average percentage of land classified as sawtimber than did the irregular structure, since it only affected 35 percent of the land (instead of the entire forest), and it just decreased stand ages in those cases where the establishment of the new communities was through plantations.

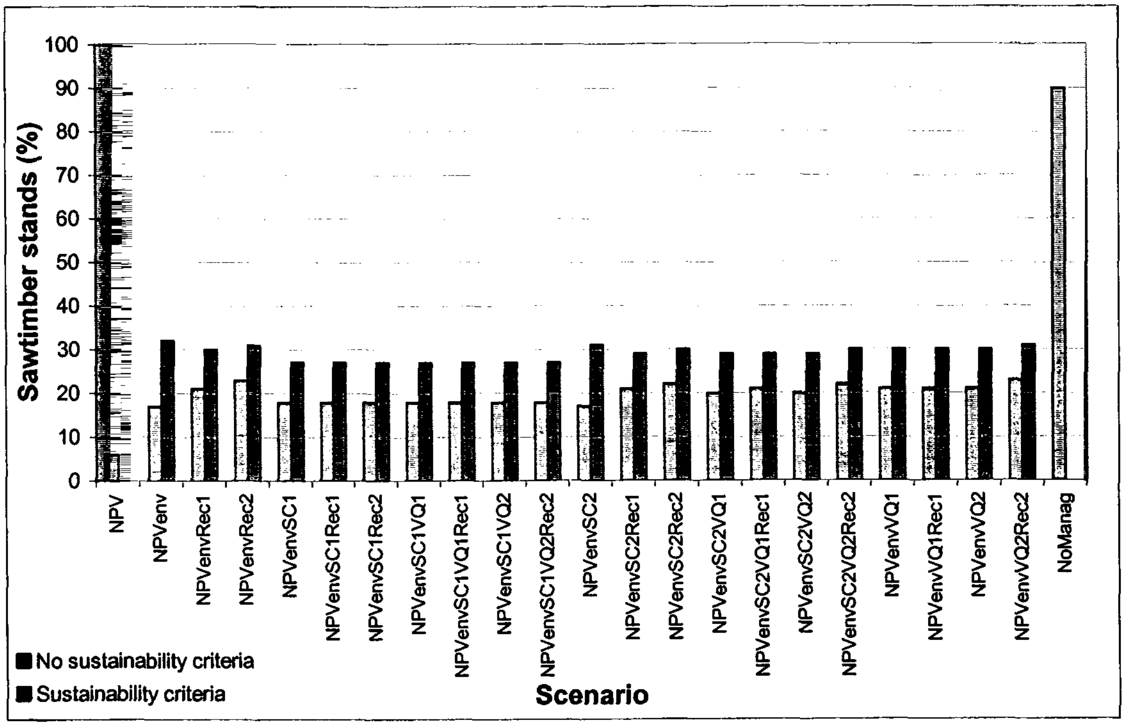

Figure 6.18: Percentage of land classified as sawtimber stands within each management scenario.

6.4.2. Tradeoff analysis

6.4.2.1. Tradeoff analysis between management goals.

We analyzed the impact of the different management goals on forest outcomes, defining hypothetical transformations curves that related continuous variables (forest outcomes) with discontinuous variables (management goals). These tradeoff curves were adjusted to piecewise cubic Hermite interpolating polynomials.

In order to facilitate the analysis, I defined three management levels depending on the goals achieved: 1) management level zero meant not achieving a specific goal; 2) management level one implied achieving management goal Rec2 for the recreational curve, goal VQ2 for the visual quality curve, or SC2 for the presettlement conditions curve; 3) management level two entailed achieving management goal Rec1 for the recreational curve, goal VQ1 for the visual quality curve, and SC1 for the presettlement

conditions curve. Basically, management level two represented the most restrictive management goals, level one the less restrictive, and management zero a failure to accomplish all goals except NPV. Tradeoff curves associated with the protection of fragile ecosystems and the sustainability criteria were horizontal functions defined only for the segment between management levels one and two. Data were manipulated as percentages of change with respect to the NPV scenario.

Figure 6.19-A shows the hypothetical transformation curves for the NPV change (in percent) given the three management levels. Percent change was relative to scenario NPV for all variables. Recreational and visual quality goals had almost identical transformation curves in regard to the NPV change. Both curves maintained a constant value (about 20 percent decrease) for management level one and two. Hence, the financial loss of including a primitive recreational opportunity in addition to the semi-primitive non-motorized and semi-primitive motorized was null. Visual quality showed the same result, the financial loss of protecting highly visually sensitive areas did not increase when including medium visually sensitive areas as well. Sustainability criteria also decreased the NPV by 20 percent. The convexity of the transformation curve fitted for presettlement conditions changed with respect to the recreational and visual curves. While achieving species composition change decreased the NPV by eight percent, adding the irregular structure decreased the NPV by 30 percent more. The presettlement conditions curve presented the highest NPV loss (or minimum curve value) among all curves. Fragile ecosystem protection led to a 12 percent NPV decrease. Figure 6.19-B demonstrates how the total impact on NPV of all management goals integrated within the same scenario (black continuous line) was significantly lower than the arithmetic sum of

each impact considered individually (black discontinuous line). For any of these curves, the slope of the tangent at a given point equals the marginal tradeoff between NPV and any of the other management goals, and the slope of the chord between any two points on the curve estimates the average tradeoff.

Harvested volume tradeoffs exhibited a different behavior (Figure 6.20-A). While recreational, visual, and presettlement conditions had an increasing impact on the amount of merchantable volume, the sustainability criteria and the protection of fragile ecosystems caused decreases of 8 and 12 percent respectively. Volume transformation curves for recreational and visual goals behaved like the NPV curves; once level one was reached the value remained almost constant in level two. However, they did not have identical values. As in the NPV case, the recreational curve almost stabilized within the 8.6 (level one) to 9.1 (level two) range of percent increase and the visual curve remained constant at a seven percent increase. The conjoint effect of all management goals not only increased the percentage of harvested volume compared to the sum of each effect considered individually, but it reached the maximum value at level one and slightly decreased in level two. This behavior did not occur with the curve associated with the sum of each effect considered individually (discontinuous black line), in which case the maximum value was achieved in level two instead of one. The conjoint effect of more restricted constraints in management level two had a decreasing effect on the volume of harvested timber (Figure 6.20-B).

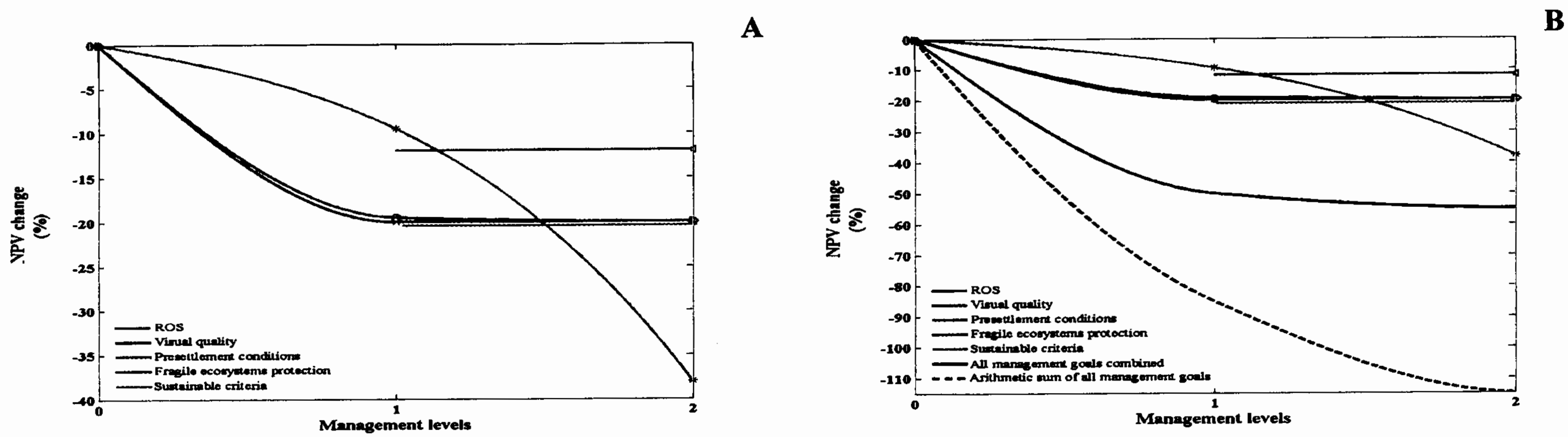

Figure 6.19: Tradeoff values of the NPV change (in percentage) for hypothetical transformation curves (A analyzes goals individually, B also includes the cumulative effect of all goals considered together and the arithmetic sum of each effect considered individually).

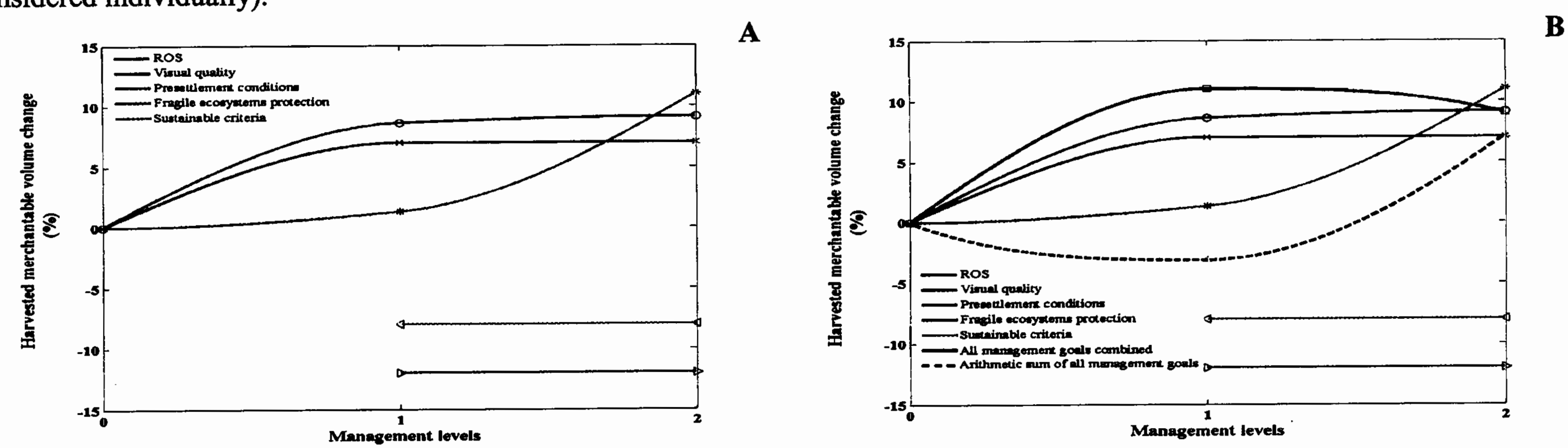

Figure 6.20: Tradeoff values of the harvested merchantable change (in percentage) for hypothetical transformation curves (A analyzes goals individually, B also includes the cumulative effect of all goals considered together and the arithmetic sum of each effect considered individually).

Inventory volume reached maximum levels under management goal SC1 (management level 2 for presettlement conditions curve, Figure 6.21-A). The sustainability criteria accounted for a 13 percent inventory volume increase. With respect to scenario NPV, the fragile ecosystem protection accounted for a 37 percent increase. Protection of high visual sensitive zones added 31 percent, keeping this value constant when including medium sensitive zones. Consideration of semi-primitives opportunities led to a 35 percent increase with a five percent increase added when including primitive opportunities as well. Meeting the presettlement species composition goal added 16 percent, reaching 64 percent when including irregular structure. The cumulative effect on the inventory volume of all management goals considered together did not differ much from the sum of the impacts of each goal individually. The conjoint effect was slightly higher for management level one and slightly lower for management level 2 (Figure 6.21-B). This was the only variable for which the conjoint effect of management goals was close to the sum of each effect considerably individually.

The increase of inventory volumes due to management goals other than maximizing the NPV impacted on the percentage of land classified as sawtimber stands in different ways (Figure 6.22-A). Even though the presettlement conditions curve reached the maximum inventory volume increase for management level two, this curve scored the lowest levels of the percentage of land classified as sawtimber stands compared to the rest of the management goals. Achieving presettlement species composition had no impact on the stand quadratic mean diameter, as expected. However, the irregular structure of the forest only increased by six percent the percentage of land classified as sawtimber stands across the landscape. The protection of fragile ecosystems

had the highest impact, with a 183 percent increase, followed by the sustainability criteria, with a 48 percent increase. Visual quality presented a constant 19 percent increase for management levels one and two. The recreational curve peaked at management level one with a 35 percent increase, which decreased to a 24 percent increase for management level two. Adding primitive recreational opportunities to semi-primitive opportunities made the percentage of sawtimber decrease by ten percent in the study area, due to timber management restrictions associated with primitive recreation. In primitive recreational areas, only selection cuts were allowed during winter, keeping a 600-foot buffer corridor along trails and campsites with no timber harvesting of any type. Selection cuts created an irregular forest structure. However, as has been explained before, selection cuts did not increase the stand quadratic mean diameter averaged through time. The cumulative effect of all management goals remained constant for management level one and two; however, the sum of the effects considered individually showed increasingly higher values (Figure 6.22-B).

The impact of management goals on the percentage of land classified under the well or adequately stocked categories differed from the impact on the sawtimber stand distribution (Figure 6.23-A). The vertical structure goal (presettlement conditions) presented the maximum percent increase in stocking levels, reaching a 70 percent increase in the percentage of land classified as well or adequately stocked. Next in order, the recreational curve (ROS) scored a 27 percent increase for semi-primitive (motorized and non-motorized) opportunities and a 36 percent increase for semi-primitive and primitive opportunities. Visual quality impacts stayed constant for management levels one and two, with a 23 percent decrease, followed by species composition change with an

18 percent increase. Fragile ecosystem protection presented a 16 percent increase and the sustainability goal a 10 percent increase. The highest impact on stocking levels came from including the primitive recreational opportunity in addition to semi-primitive opportunities. Achieving an irregular structure showed the same behavior, which can be explained by the harvesting methods associated with both goals. Selection cuts boosted forest regeneration and increased stocking levels to the point that, in the case of being used as the only harvesting tool, 90 percent of the forest reached well or adequately stocked-level categories (Figure 6.16). The conjoint effect of all management goals integrated within the same scenario was significantly lower than the sum effect of all management goals considered individually. However, the value for management levels one and two did not remain constant, but increased in level two (Figure 6.23-B). Table 6.7 summarizes the individual effect of management goals on the variables analyzed.

Mgmt. Goal	NPV	Harvested Volume	Inventory Volume	Well & Adequately Stocked	Sawtimber Stands
Rec1	-25.0	9.1	40.0	36.0	24.0
Rec2	-24.0	8.6	35.0	27.0	35.0
VQ1	-20.0	7.0	31.0	23.0	19.0
VQ2	-20.0	7.0	31.0	23.0	19.0
SC1	-38.0	11.0	64.0	70.0	6.0
SC2	-8.0	1.3	16.0	18.0	0.0
Env	-12.0	-12.0	37.0	16.0	183.0
Sust	-20.0	-8.0	13.0	10.0	48.0

Table 6.7: Percent change on continuous variables due to the effect of management goals considered individually.

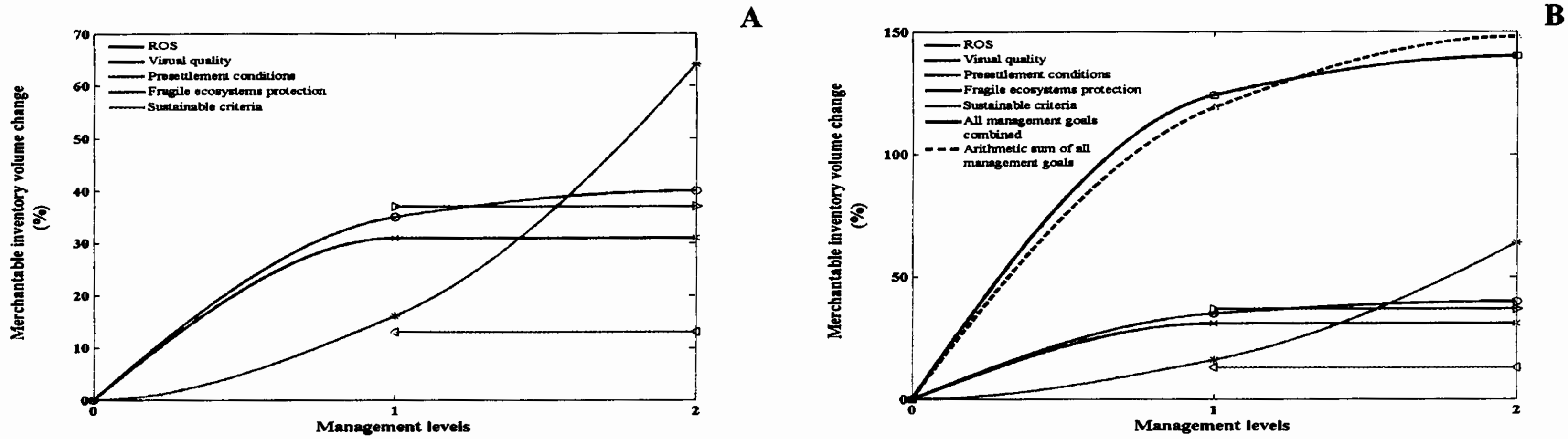

Figure 6.21: Tradeoff values of the inventory volume change (in percentage) for hypothetical transformation curves (A analyzes goals individually, B also includes the cumulative effect of all goals considered together and the arithmetic sum of each effect considered individually).

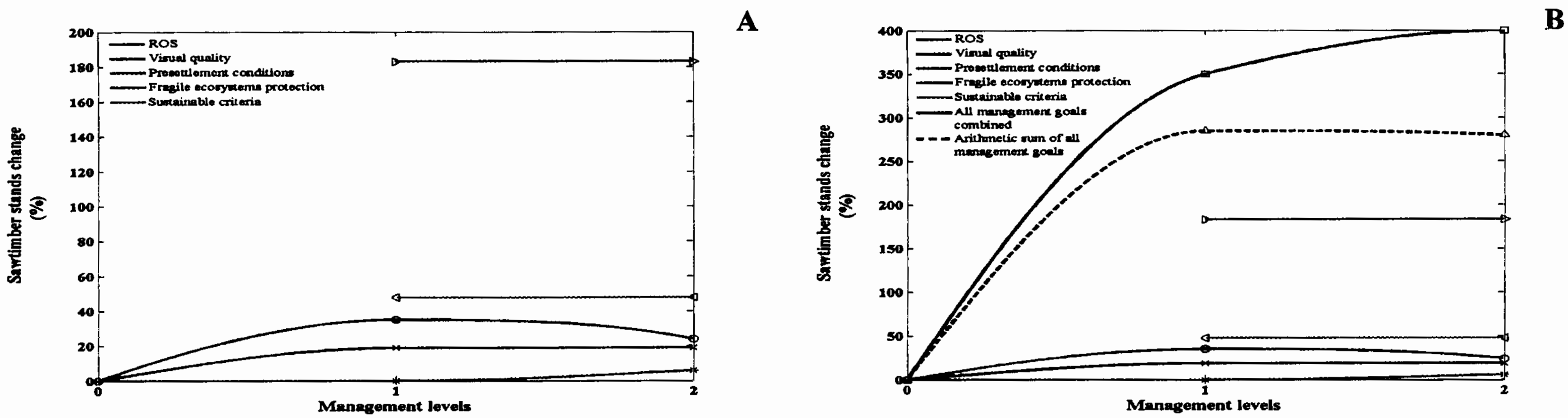

Figure 6.22: Tradeoff values of the change percent of land classified as sawtimber stands for hypothetical transformation curves (A analyzes goals individually, B also includes the cumulative effect of all goals considered together and the arithmetic sum of each effect considered individually).

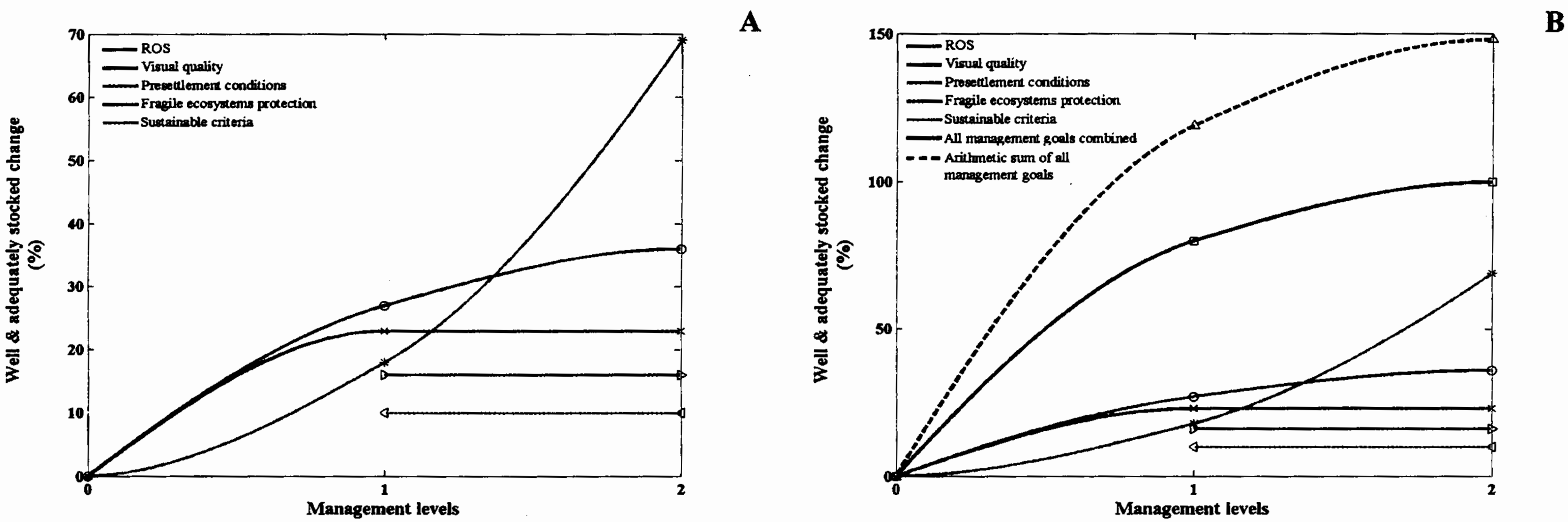

Figure 6.23: Tradeoff values of the change percent of land classified as well or adequately stocked for hypothetical transformation curves (A analyzes goals individually, B also includes the cumulative effect of all goals considered together and the arithmetic sum of each effect considered individually).

6.4.2.2. Relationships among tree-related continuous outcome variables.

An analysis of the NPV and the time-averaged outcomes across scenarios revealed a linear relationship among continuous variables under both sustainability and non-sustainability criteria (Figures 6.24 through 6.27). The estimated regression equations presented very high coefficients of determination, or *R-square* (R^2), with the exception of the regression equation between variables NPV and the percentage of land classified as sawtimber stands for scenarios under non-sustainability. The smaller the variability of the residual values around the regression line relative to the overall variability (the higher R^2 value), the better the regression equation fits the data.

Harvested volume, inventory volume and percentage of land classified as well or adequately well stocked were indirect linear functions of the NPV, the higher the NPV the lower these variables scored. The percentage of land classified as sawtimber stands revealed a direct linear relationship with respect to the NPV (the higher NPV the higher the percentage of land classified as sawtimber stands). However, although the regression curve of those scenarios within the sustainability criteria group was a good data fit (R^2 value was 0.802), this was not the case for scenarios that did not achieve the sustainability criteria (R^2 value was 0.018). Therefore, the accuracy of this regression was not sufficient. The slope of the regression curve represented the change ratio between the two compared variables, which did not remain constant among variable-pair comparisons. Within each pair comparison, the curve slopes for the two analyzed scenario groups, those that achieved sustainability criteria and those scenarios that did not, were not identical in value though they were relatively close and presented the same orientation. The comparison between the regression curves for those scenarios that did

not achieve the sustainability criteria and those that did revealed that the slope of the regression curves was steeper for the harvested volume and inventory volume variables and flatter for the percentages of land classified as well or adequately stocked and classified as sawtimber stands.

For scenarios that did not achieve the sustainability criteria, for every unit of NPV that increased, 0.041 units of harvested volume decreased, 0.156 units of inventory volume decreased, 0.389 percent of land classified as well or adequately stocked decreased, and 0.010 percent of the land classified as sawtimber stands increased. For scenarios that achieved the sustainability criteria, the ratio for every unit of NPV increase was 0.034 decrease for harvested volume, 0.146 for inventory volume, 0.939 for the percentage of land classified as well or adequately stocked, and 0.097 for the percentage of land classified as sawtimber stands (Table 6.8).

Variables compared	**No sustainability criteria**		**Sustainability criteria**	
	Ratio	**R^2**	**Ratio**	**R^2**
NPV - harvested volume	- 0.041	(0.931)	- 0.034	(0.705)
NPV - inventory volume	- 0.156	(0.992)	- 0.146	(0.987)
NPV - % of land classified as well or adequately stocked	- 0.389	(0.895)	- 0.435	(0.939)
NPV - % of land classified as sawtimber stands	0.010	(0.018)	0.097	(0.802)

Table 6.8: Regression coefficients (slope of regression curve and R^2) for variable-pair comparisons.

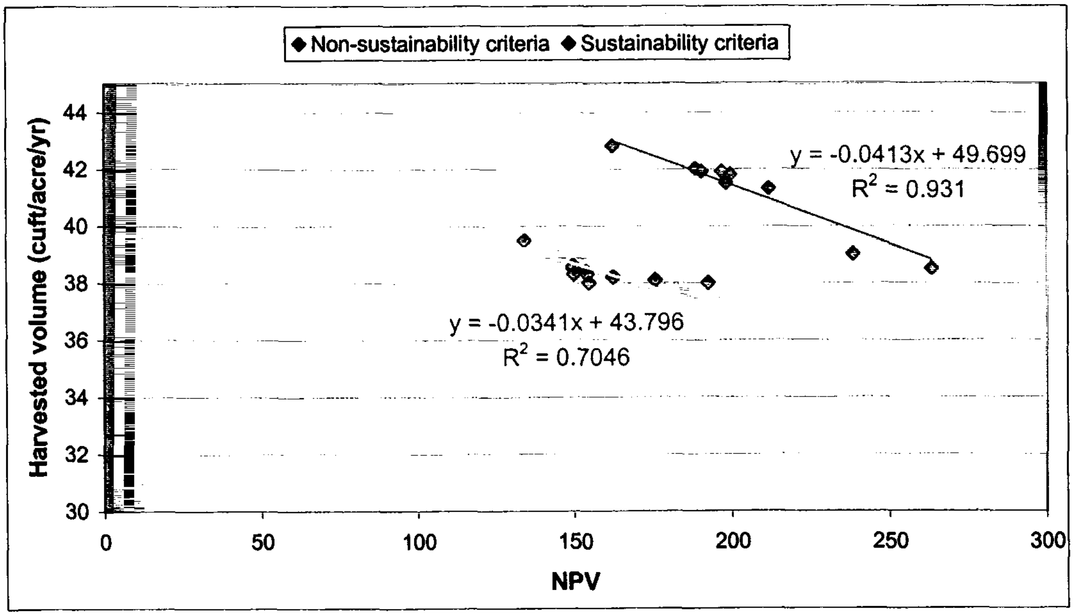

Figure 6.24: Relationships between harvested volume (cubic feet per acre per year) and NPV (dollars per acre) for scenarios under both sustainability and non-sustainability criteria.

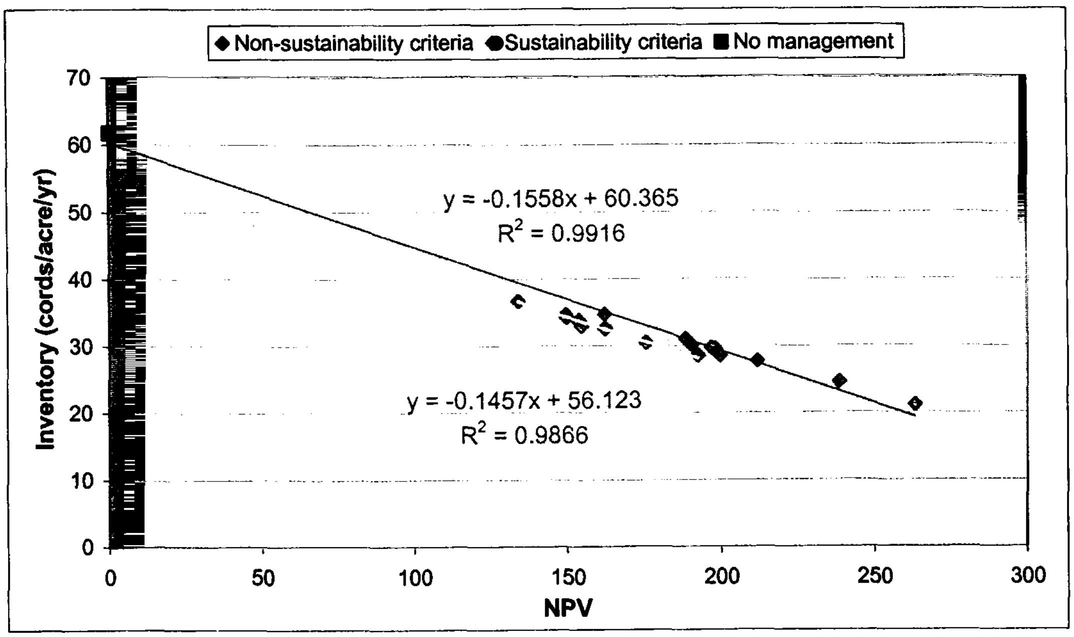

Figure 6.25: Relationships between inventory volume (cords per acre per year) and NPV (dollars per acre) for scenarios under sustainability, non-sustainability criteria and no management.

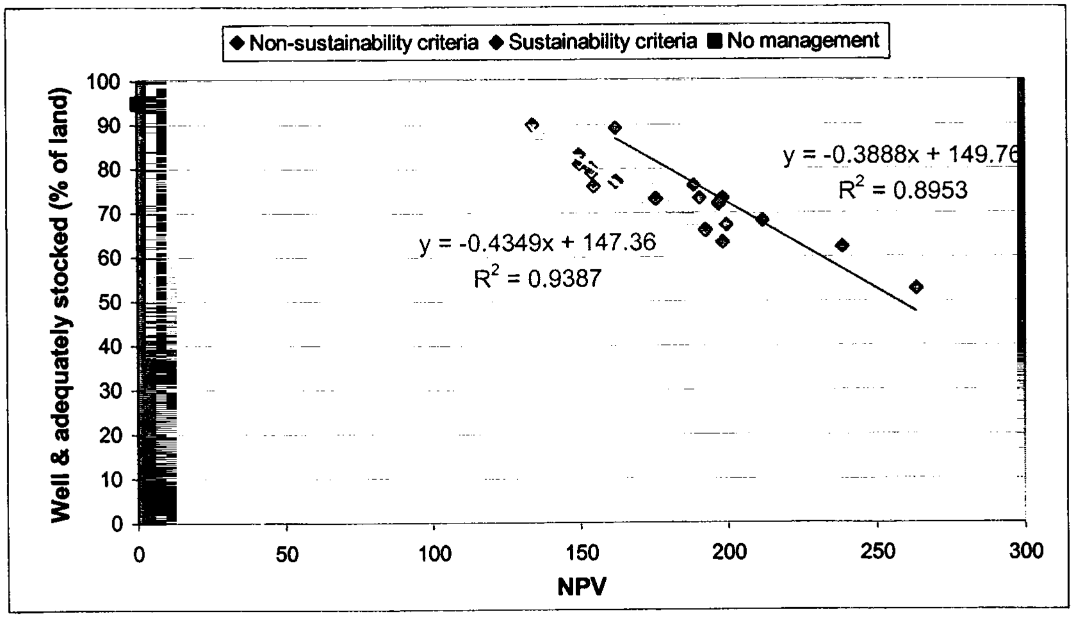

Figure 6.26: Relationships between the percentage of land classified as well or adequately stocked and NPV (dollars per acre) for scenarios under sustainability, non-sustainability criteria and no management.

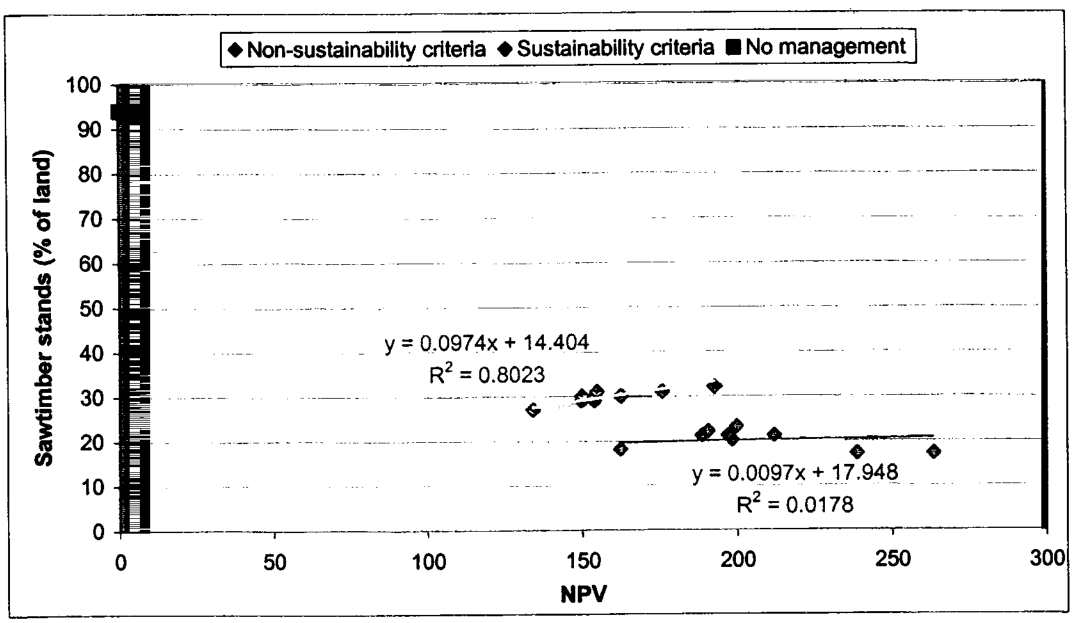

Figure 6.27: Relationships between the percentage of land classified as sawtimber stands and NPV (dollars per acre) for scenarios under sustainability, non-sustainability criteria and no management.

6.5. SENSITIVITY ANALYSIS

To understand how "sensitive" the LP model was to assumption variations, I calculated the changes in NPV and in the financial costs and benefits distribution over time when the assumed discount rate varied from three to six percent real (assuming that the rate of change in all dollar values was equal to the rate of change of the purchasing power of the dollar for the planning horizon). Changing the discount rate value had a different impact depending on the analyzed scenario. These impacts accounted for a change in the scenario's NPV and a change in the amount of costs and revenues within some periods and in their distribution over time.

Results showed two trends (Table 6.9). In scenarios that supplied several forest benefits, the higher the discount rate the lower the NPV. In scenarios NPV and NPVenv, NPV peaked at the four percent discount rate. The results for the three percent discount rate were significantly lower compared to the other two (five and six percent). The NPV differences between the three and four rates varied from 3.1 dollars per acre for scenario NPV, to 2.7 for scenario NPVenv. Scenario Sustenv was the exception to these two trends, with a direct relationship between the NPV and the discount rate. However, the variance between the rates was very low (0.008), while the rest of the scenarios presented a variance higher than 0.4, reaching a maximum variability with the scenarios NPV and NPVenv. The variance represented an indicator about the sensitivity of each scenario to the change of the discount rate. Sustainable scenarios presented lower variances than those scenarios that did not meet the sustainability criteria.

The discount rate change affected the optimal solution of every scenario and accounted for a different distribution of benefits and costs over time. I found no consistent pattern regarding to these changes, and they only occurred in very few periods.

Scenario	Discount rate	NPV ($/acre)	Percentage of NPV change	Variance
NPV	3%	296.99	0.00	1.898
	4%	299.87	0.96	
	5%	299.70	0.91	
	6%	299.63	0.89	
NPVenv	3%	260.70	0.00	1.662
	4%	263.40	1.04	
	5%	263.24	0.97	
	6%	263.18	0.95	
Sustenv	3%	192.54	0.00	0.008
	4%	192.70	0.08	
	5%	192.71	0.09	
	6%	192.73	0.10	
NPVenvSC2VQ2Rec2	3%	191.51	0.00	0.437
	4%	190.63	-0.46	
	5%	190.20	-0.69	
	6%	190.04	-0.77	
SustenvSC2VQ2Rec2	3%	150.43	0.00	0.412
	4%	150.04	-0.26	
	5%	149.77	-0.44	
	6%	148.91	-1.00	
NPVenvSC1VQ1Rec1	3%	164.30	0.00	1.560
	4%	162.47	-1.12	
	5%	161.79	-1.53	
	6%	161.54	-1.68	
SustenvSC1VQ1Rec1	3%	135.11	0.00	0.334
	4%	134.26	-0.63	
	5%	133.95	-0.86	
	6%	133.83	-0.95	

Table 6.9: NPV variation for discount rates three, four, five and six percent when simulating scenarios NPV, NPVenv, NPVenvSC1VQ1Rec1, and Sustenv SC1VQ1Rec1. Percentage of NPV change is relative to the value of NPV with a three percent discount rate.

6.6. HYPOTHESIS TESTING

We defined a theoretically optimum scenario for the management of the Bigelow Preserve forest, by grouping the maximum outcome values (simulated independently) that the forest can provide. The Euclidean distance between this optimum and each simulated scenario provided a quantitative measure of the deviation of each scenario from the theoretical optimum. Figures 6.28 and 6.29 show the relationship between deviations and the variety of uses provided for each scenario, which were grouped under sustainable and non-sustainable criteria for easier analysis. In both groups, the trend line showed that the higher the Euclidean distance, the lower the variety of uses. There was a correlation between the variety of uses and the value that the forest can provide to society: the higher the variety, the closer we are to the ideal optimum. One could argue that this ideal optimum is unreal and unfeasible because it was defined under a non-competitive framework. However, although this is true, it represents a reference point that integrates forest values and to which all management scenarios can be compared.

Giving equal consideration to ecological, social and economic values, the Euclidean distance represents a quantitative indicator of the value of a management plan. The distance between the closest scenario, or group of scenarios, and the ideal optimum (axis origin) reflects competition among uses.

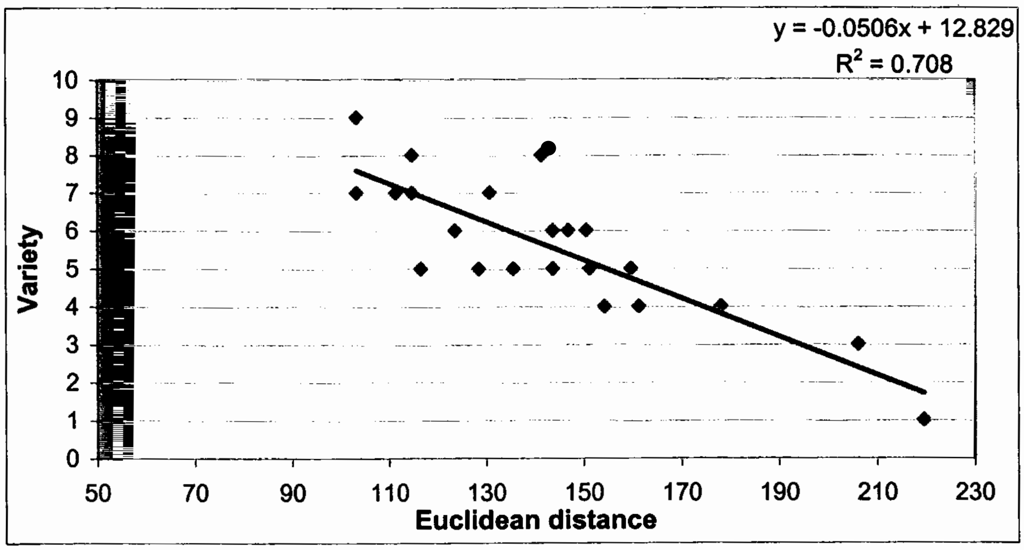

Figure 6.28: Relationship between the variety index and deviation from the ideal optimum solution (Euclidean distance in a nine dimension space) for scenarios under non-sustainable criteria.

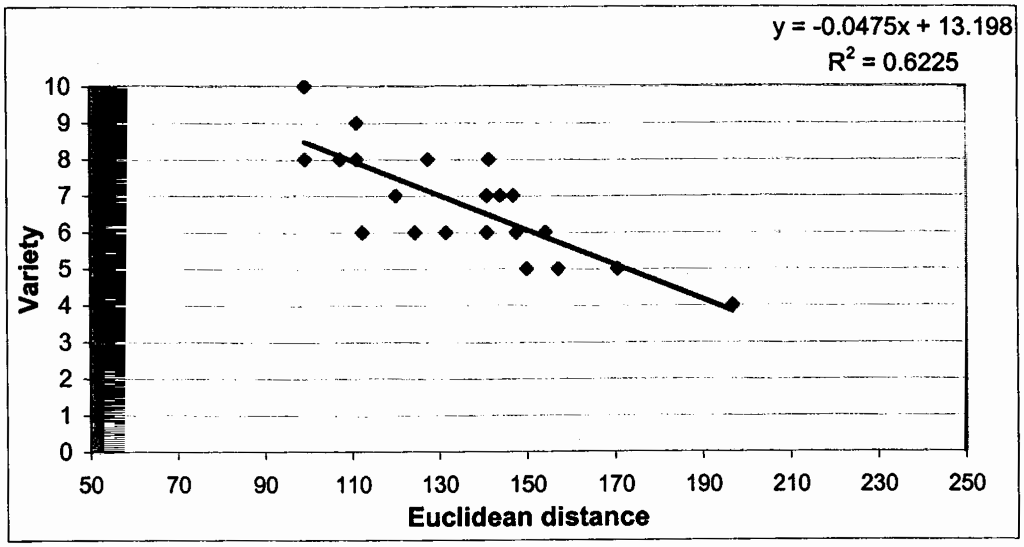

Figure 6.29: Relationship between the variety index and deviation from the ideal optimum solution (Euclidean distance in a nine dimension space) for scenarios under sustainable criteria.

A vector in a nine-dimension space represented each management scenario. The coordinates that located each point in the space were the percent decrease with respect to the theoretical optimum of the following variable values: NPV, harvested volume, visually sensitive land that was protected, ROS, standing inventory volume, land with

well and adequately stocked levels, land classified as sawtimber stands, land with presettlement species composition, and land with irregular structure. By using percentages instead of real variable scores, I normalized the data and created an equal scale to compare different units of measurement, as well as continuous and discrete variables (e.g. dollars and forest structure). Depending on the particular needs and forest characteristics the defined nine-dimension space could be modified in order to consider a different set of values that the decision maker desires to consider. This method represents a flexible tool that allows adapting the number of dimensions to any particular case.

Table 6.10 shows the vector values for each management scenario. Forest values not only competed among each other, but some management goals also had a residual positive effect on other variables that were not the goal's target (providing a primitive recreational use in the forest and protecting the visual quality contributed to achieving an irregular structure in those areas affected, although this was not the reason why they were developed).

In the definition of vector coordinates, I accounted for the impacts of each goal on all variables. However, I found that none of the management goals helped to achieve recreational opportunities except for those specifically defined for that purpose. Even if visual protection created areas suitable for primitive and semi-primitive categories, these areas were discontinuously scattered over the area and did not meet the size and trail buffer requirements needed to provide these opportunities. I considered not only a quantitative analysis, but also spatial considerations when analyzing the effect of each goal on each variable.

Scenarios	NPV	Harvested volume	Visual quality	ROS	Inventory volume	Well & adequately stocked	Sawtimber stands	Presettlement species composition	Irregular structure
NPV	0	0	100	100	75	52	94	32	100
NPVenv	12	12	95	100	66	45	82	32	88
NPVenvRec1	34	4	49	0	52	25	78	32	50
NPVenvRec2	33	4	67	50	54	29	76	32	65
NPVenvSC1	46	2	0	100	44	6	81	0	0
NPVenvSC1Rec1	55	9	0	0	41	5	71	0	0
NPVenvSC1Rec2	55	9	0	50	41	5	71	0	0
NPVenvSC1VQ1	55	9	0	100	41	5	71	0	0
NPVenvSC1VQ1Rec1	55	9	0	0	41	5	71	0	0
NPVenvSC1VQ2	46	2	0	100	44	6	81	0	0
NPVenvSC1VQ2Rec2	46	2	0	50	44	6	81	0	0
NPVenvSC2	20	11	71	100	60	35	82	0	68
NPVenvSC2Rec1	37	4	49	0	50	20	78	0	50
NPVenvSC2Rec2	36	4	67	50	51	23	77	0	65
NPVenvSC2VQ1	34	5	0	100	52	23	79	0	45
NPVenvSC2VQ1Rec1	37	4	0	0	50	20	78	0	45
NPVenvSC2VQ2	34	5	25	100	52	34	79	0	60
NPVenvSC2VQ2Rec2	36	4	25	50	51	23	77	0	60
NPVenvVQ1	29	5	0	100	55	28	78	32	45
NPVenvVQ1Rec1	34	4	0	0	52	24	78	32	45
NPVenvVQ2	29	5	25	100	55	28	78	32	60
NPVenvVQ2Rec2	33	4	25	50	54	29	76	32	60
Sustenviro	36	13	95	100	54	31	66	32	88
SustenvRec1	49	12	49	0	46	17	68	32	50
SustenvRec2	48	13	67	50	47	20	67	32	65
SustenvSC1	55	9	0	100	41	5	71	0	0
SustenvSC1Rec1	55	9	0	0	41	5	71	0	0
SustenvSC1Rec2	55	9	0	50	41	5	71	0	0
SustenvSC1VQ1	55	9	0	100	41	5	71	0	0
SustenvSC1VQ1Rec1	55	9	0	0	41	5	71	0	0
SustenveSC1VQ2	55	9	0	100	41	5	71	0	0
SustenvSC1VQ2Rec2	55	9	0	50	41	5	71	0	0
SustenvSC2	41	13	71	100	51	23	67	0	68
SustenveSC2Rec1	50	12	49	0	44	13	69	0	50
SustenvSC2Rec2	50	12	67	50	45	15	68	0	65
SustenvSC2VQ1	49	12	0	100	45	16	69	0	45
SustenvSC2VQ1Rec1	50	11	0	0	44	13	69	0	45
SustenvSC2VQ2	49	12	25	100	45	16	69	0	60
SustenvSC2VQ2Rec2	50	12	25	50	45	15	68	0	60
SustenvVQ1	46	12	0	100	47	19	68	32	45
SustenvVQ1Rec1	49	12	0	0	46	17	68	32	45
SustenvVQ2	46	12	25	100	47	19	68	32	60
SustenvVQ2Rec2	48	13	25	50	47	20	67	32	60
NoManag	100	100	0	0	0	0	0	0	0

Table 6.10: Percentage decrease of considered variables relative to the theoretical optimum for each scenario.

The inventory volume, the percentage of land classified into the well and adequately stocked category, the percentage of land classified as sawtimber stands, the species composition, and the irregular vertical structure are all ecological indicators. One could argue that having a nine-dimension space with five of its nine axes being ecological indicators, and giving each axis equal weight when calculating Euclidean distances, does

not totally support the concept of sustainability because none of the economic, social and ecological values should be prioritized. Due to the difficulty of choosing which variables should be considered and which should be left out, I averaged all coordinate values within the economic, social and ecological categories and displayed the new vectors (this time defined by three coordinates) in a three dimension space (Figure 6.30). Results showed that there were no changes in the order in which management scenarios ranked in terms of the Euclidean distance to the theoretical optimum except for the position of the no-management scenario. The distances between scenarios were smaller while the variety index remained constant, which translated into a higher slope for the regression line and a lower R^2 value for both sustainable and non-sustainable criteria scenario groups (Figures 6.31 and 6.32). Data presented a better fit (higher R^2) when adjusted to an exponential function (scenarios not meeting sustainability criteria) and to a power function (scenarios meeting sustainability criteria). In this evaluation framework, the no management scenario (orange dot in Figures 6.31 and 6.32) presented the highest Euclidean distance, being in the farthest position from the regression curve due to the lack of revenues, which accounted for a third of the distance. The new location of the no management scenario was responsible for the lower coefficient of determination. Removing the no management scenario from the data set increased R^2 reaching the value of 0.75 for scenarios not meeting sustainability criteria and 0.70 for scenarios meeting sustainability criteria. Whereas data was adjusted to a linear, exponential, or power function the trend lines showed that the higher the variety of conditions in the forest, the closer we are to the ideal optimum and therefore the higher the value that the forest provide (testing hypothesis).

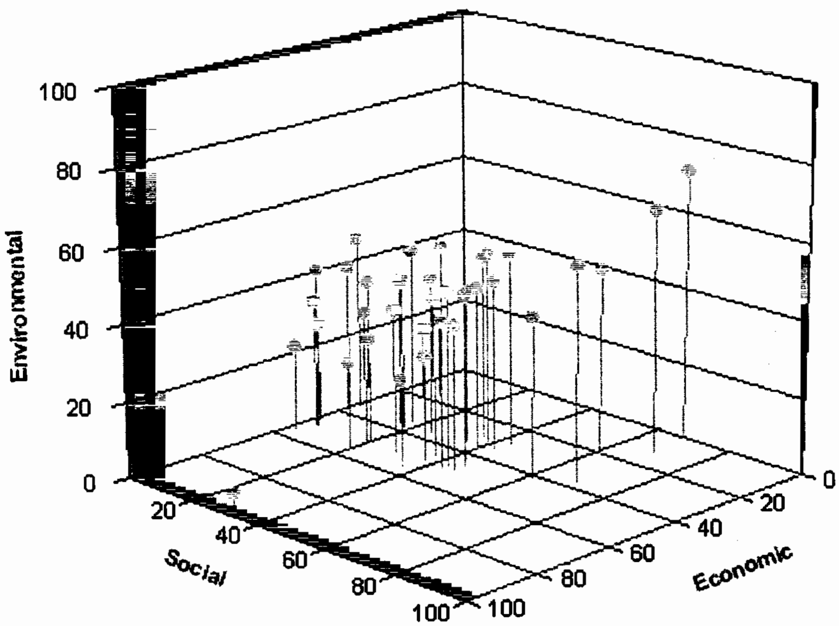

Figure 6.30: Spatial distribution (in three dimension) of simulated management goals.

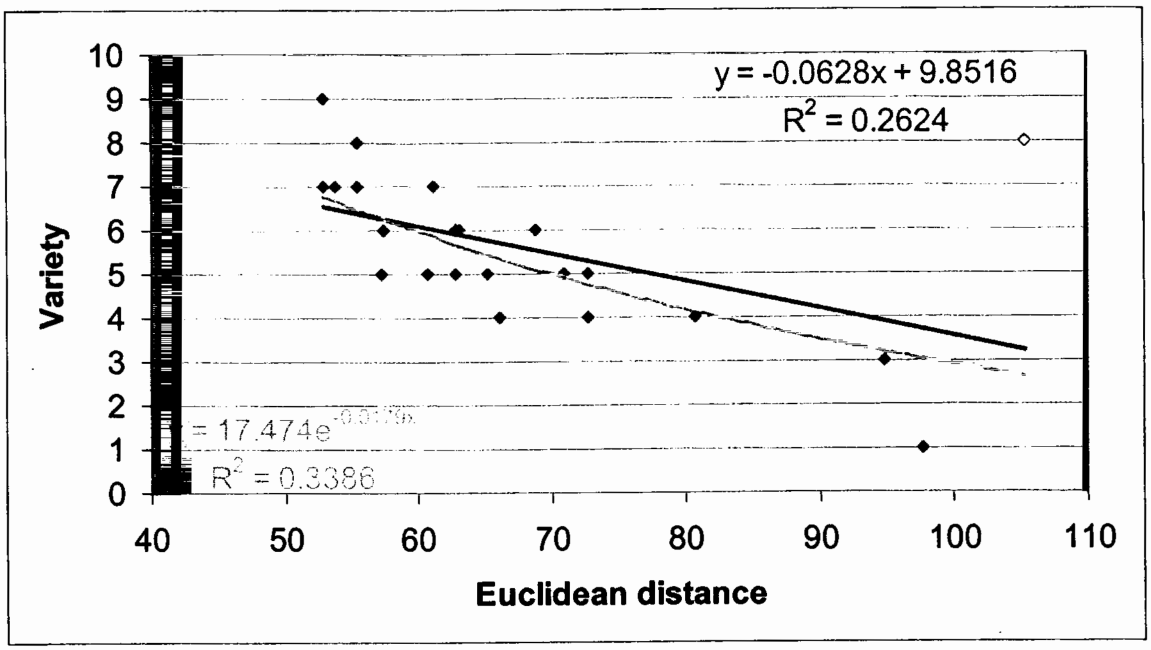

Figure 6.31: Relationship between the variety index and deviation to the ideal optimum solution (Euclidean distance in a three dimension space) for scenarios under non-sustainable criteria.

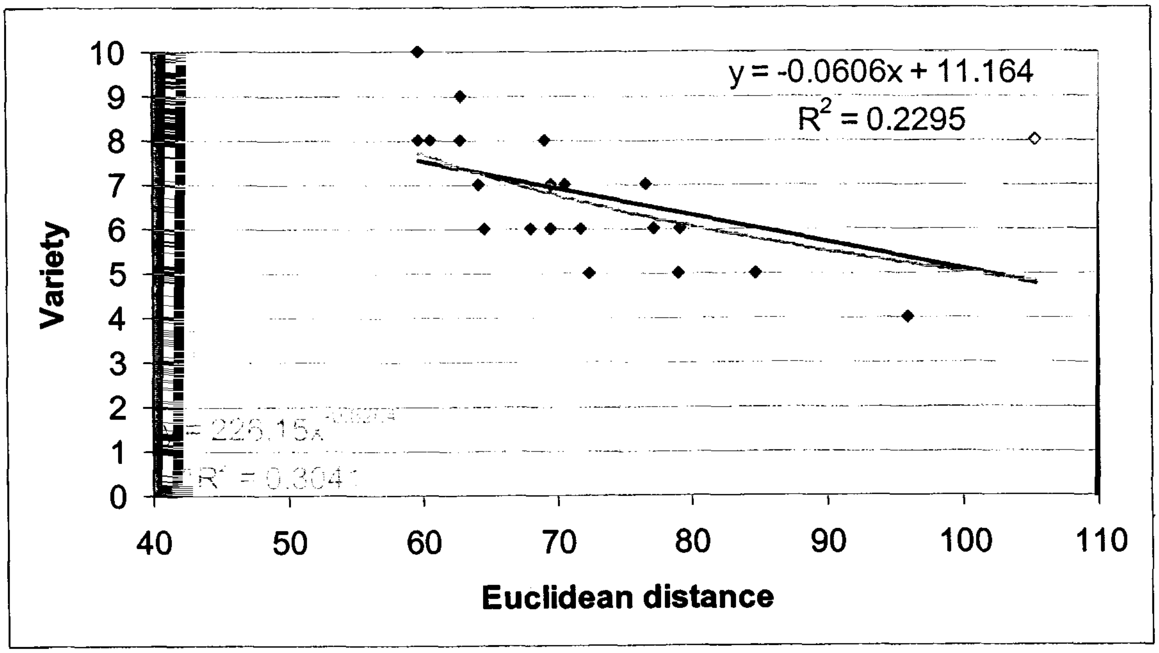

Figure 6.32: Relationship between the variety index and deviation to the ideal optimum solution (Euclidean distance in a three dimension space) for scenarios under sustainability criteria.

Scenario SustenvSC1VQ1Rec1, which accounted for all of the most restricted management goals (Table 6.11), scored the highest variety of values and the closest distance to the ideal optimum. This scenario reached the presettlement species distribution and vertical structure, provided semi-primitive (motorized and non-motorized) and primitive recreational opportunities, protected the visual quality of high and medium visual sensitive zones, protected fragile forest fragile ecosystems (alpine and subalpine vegetation, zones with high risk of soil erosion, and riparian ecosystems), ensured that harvesting rotations exceeded mature states, enforced an even distribution of the number of acres of mature forest that were accessed for vegetation removal among the simulated periods, and produced a NPV of $134 per acre over the 105-year simulated planning horizon. The other extreme scenario, NPV, presented the lowest variety of

values and the highest distance to the ideal optimum. Although this scenario presented the highest financial return, 300 dollars per acre, it did not accomplish any of the other goals. However, even if these goals were not accomplished, one could argue that this scenario still provided other values, such as more developed recreational opportunities that do not require remoteness or a natural-look environment. Nevertheless, it is not only the number of values that the forest provides but also the quality of these values and uses, their frequency of availability at a global scale, and the integrity and resilience of the ecosystem for future use and enjoyment that matters. The definition of proposed management goals considered the supply of the same values from other areas as well as the unique and fragile ecological characteristics of the Bigelow Preserve. The financial difference between these two scenarios, NPV and SustenvSC1VQ1Rec1, represented a 55 percent NPV decrease.

Scenario	Euclidean distance	Variety index	Scenario	Euclidean distance	Variety index
NPV	219.5	1	NoManag	141.4	8
NPVenv	206.1	3	Sustenv	196.9	4
NPVenvRec1	128.5	5	SustenvRec1	124.5	6
NPVenvRec2	151.2	5	SustenvRec2	147.7	6
NPVenvSC1	143.7	5	SustenvSC1	140.9	6
NPVenvSC1Rec1	103.2	7	SustenvSC1Rec1	99.3	8
NPVenvSC1Rec2	114.7	7	SustenvSC1Rec2	111.1	8
NPVenvSC1VQ1	143.7	6	SustenvSC1VQ1	140.9	7
NPVenvSC1VQ1Rec1	103.2	9	SustenvSC1VQ1Rec1	99.3	10
NPVenvSC1VQ2	143.7	6	SustenvSC1VQ2	140.9	7
NPVenvSC1VQ2Rec2	114.7	8	SustenvSC1VQ2Rec2	111.1	9
NPVenvSC2	178.1	4	SustenvSC2	170.7	5
NPVenvSC2Rec1	123.6	6	SustenvSC2Rec1	120.0	7
NPVenvSC2Rec2	146.9	6	SustenvSC2Rec2	144.0	7
NPVenvSC2VQ1	150.6	6	SustenvSC2VQ1	147.0	7
NPVenvSC2VQ1Rec1	111.3	7	SustenvSC2VQ1Rec1	107.3	8
NPVenvSC2VQ2	159.7	5	SustenvSC2VQ2	154.3	6
NPVenvSC2VQ2Rec2	130.8	7	SustenvSC2VQ2Rec2	127.4	8
NPVenvVQ1	154.3	4	SustenvVQ1	150.0	5
NPVenvVQ1Rec1	116.6	5	SustenvVQ1Rec1	112.4	6
NPVenvVQ2	161.3	4	SustenvVQ2	157.2	5
NPVenvVQ2Rec2	135.6	5	SustenvVQ2Rec2	131.6	6

Table 6.11: Euclidean distance and variety index scores for all simulated management scenarios.

Scenarios in between these two distance-variety extremes represented a wide array of options, giving decision makers a spectrum for comparing alternatives and outputs. Three dimension visualizations resulted a very useful way to present information. However, as an analysis tool, recognizing all variables individually without averaging them in categories was more advantageous. Figure 6.33 shows the vector comparison of scenarios NPV, SustenvSC1VQ1Rec1, NPVenvSC2VQ2Rec2, and NoManag in a three-dimension space where each axis represents the percent decrease from the ideal optimum within the economic, ecological and environmental categories.

The no-management scenario scored the highest ecological values, while it did not produce any financial benefit. Social benefits, such as visual quality and recreation remained high as long as trail access and campsites were maintained, but the sense of "order" and "see through" (resulting from timber management) in the forest would disappear and the levels of combustible material would increase in the future. Although it is true that forest fires are not frequent and do not represent a major threat in the state of Maine, they are still a risk, and are a significant factor in other forest situations where one may want to use these techniques.

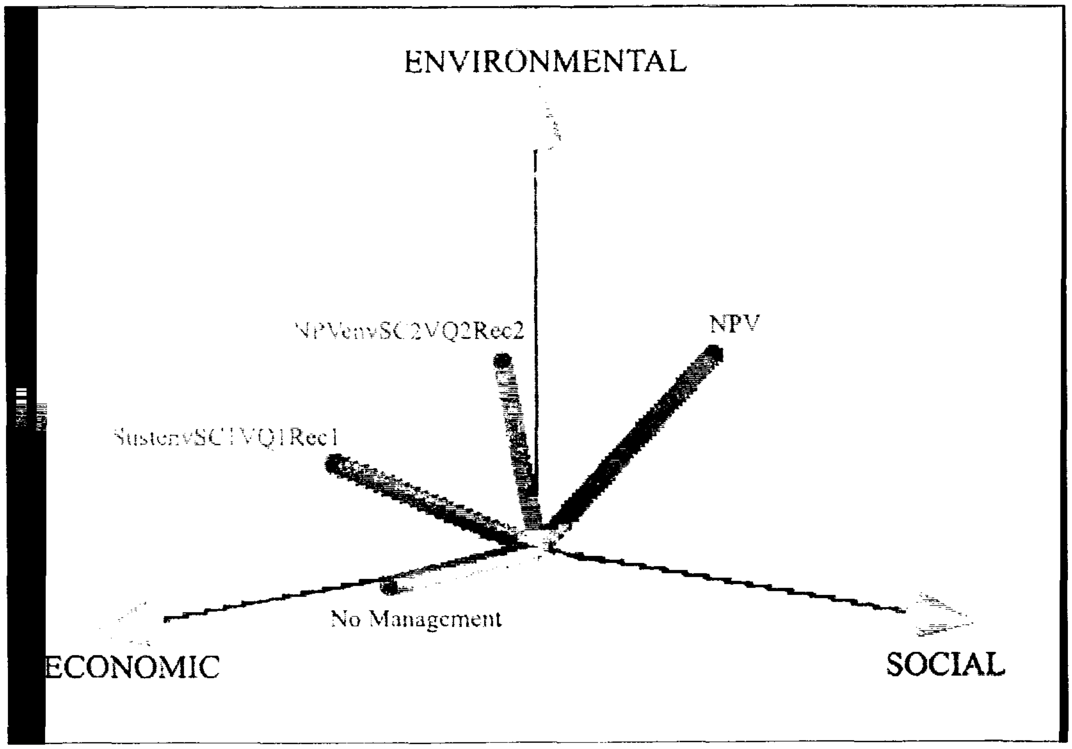

Figure 6.33: Vector comparison for scenarios NPV, SustenvSC1VQ1Rec1, NPVenvSC2VQ2Rec2, and NoManag in a three-dimension space. Each axis represents the percentage of decrease from the ideal optimum within the economic, ecological and environmental categories.

Although forest values competed with each other, management strategies played an important role in the level of competition. Consider a case where economic forces drive the decision makers. Scenarios that produce the same revenues can provide different sets of non-priced forest benefits depending of the management plan designed. Figure 6.34 shows how plans with the same NPV can provide additional different value sets. Among all simulated scenarios, six of them (SustenvSC1, SustenvSC1VQ1, SustenvSC1Rec1, SustenvSC1VQ1Rec1, SustenvSC1Rec2, SustSC1VQ2, SustSC1VQ2Rec2) presented the same $134-per-acre NPV and different combinations of recreation and visual quality, from none to the most restrictive cases.

An increase in total forest benefits did not always imply a decrease in financial benefits. Even though the scenarios with the shorter distance to the optimum (SustenvSC1VQ1Rec1, SustenvSC1Rec1, and SutenvSC1VQ2Rec2) presented the lowest NPV and the scenario with the longest distance (NPV) presented the highest, a shorter distance was not necessarily related to a loss in NPV. Scenarios in between provided different value combinations with a different NPV loss. For example, scenario NPVenvSC2VQ1Rec1 offered a 189-dollar-per-acre NPV while achieving presettlement species composition, protecting fragile ecosystems and high and medium visually sensitive areas, and providing primitive and semi-primitive (motorized and non-motorized) recreational opportunities. In contrast, scenario SustenvSC2Rec2 provided a lower NPV, 150 dollars per acre and achieved the sustainability criteria, but did not offer semi-primitive and/or primitive recreational opportunities, nor did it protect medium visually sensitive areas.

An analysis of the relationship between the Euclidean distance, the variety index and the inventory volume showed the same behavior as NPV (Figure 6.35). Although most of the scenarios with shorter distances and higher variety indexes presented higher inventory volumes, and the scenarios with longer distances and lower variety indexes supplied lower inventory volumes, there were scenarios that did not follow this rule. For example, scenario SustenvSC1 presented the highest inventory volume (37 cords per acre), after no management, and scored a medium value for both the variety index and the Euclidean distance. Within the multiple-uses scenarios, scenario NPVenvSC2VQ1Rec1 fell within the group of high variety and short distance while its inventory volume (31 cords per acre) was slightly lower than the rest of the scenarios in that group. On the

other hand, scenario NPVenvSC1 presented a higher inventory (35 cords per acre) volume while both the diversity index and the distance were lower.

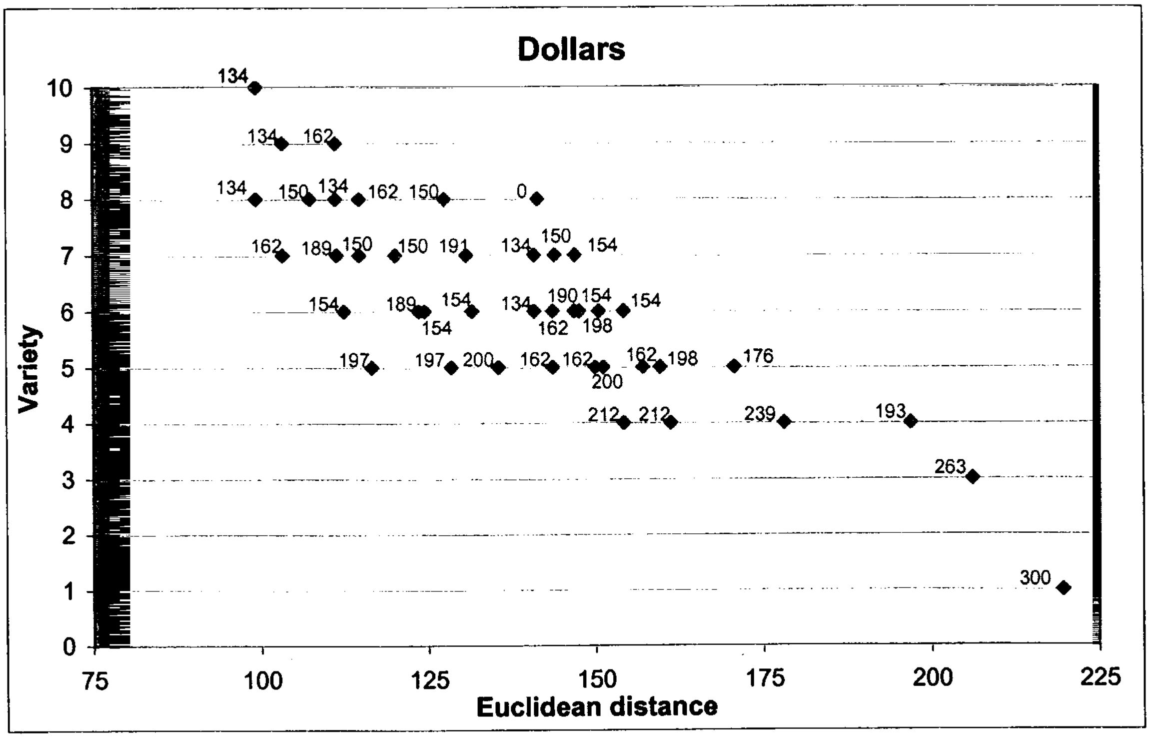

Figure 6.34: Scenario comparison of variety index, Euclidean distance and NPV (dollars per acre).

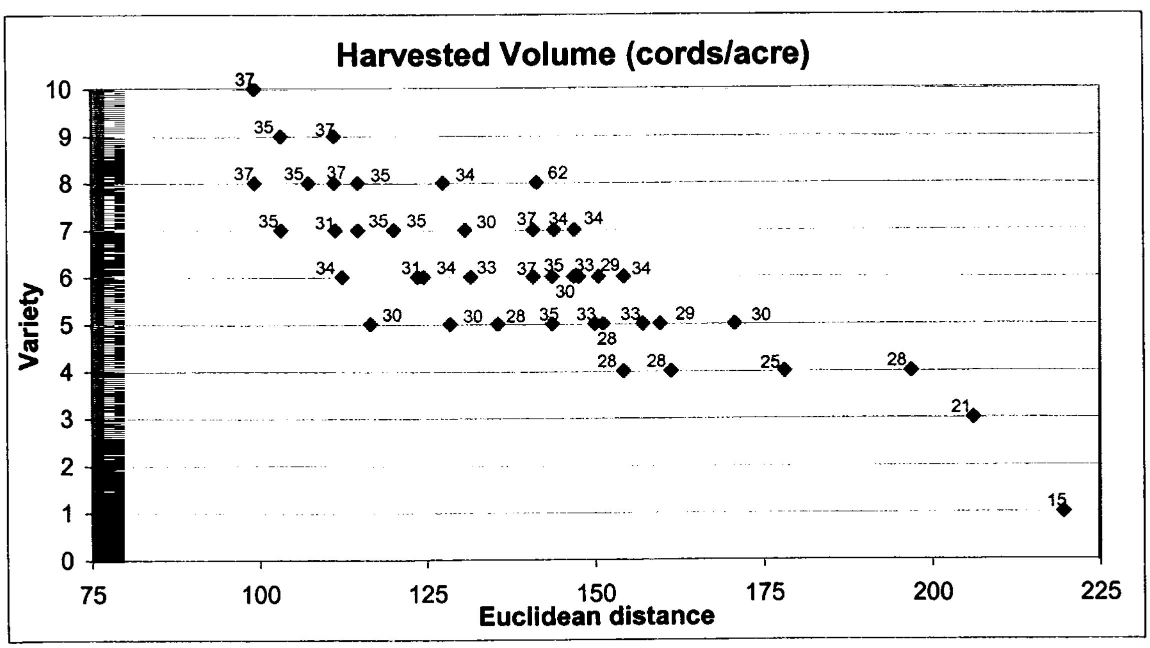

Figure 6.35: Scenario comparison of variety index, Euclidean distance and inventory volume (cords per acre).

6.7. CONCLUSIONS

In this study, the effect of management goals on forest outcomes depended not only on the goal objectives but also on when, where and how strategic plans were carried out. Spatial and temporal factors became as important as the management actions themselves. The right combination of forest management practices at the right time and in the right way reduced the competition of uses in the forest and, at the same time, provided a wide array of values without jeopardizing ecosystem integrity. While it is true that financial timber revenues competed with other forest values such as forest protection, recreation, and visual quality, and in the short term these competing values translated into a financial loss, the loss could be significantly reduced by the design of strategic plans. Even in the case where all the most restricted goals were met (SustenvSC1VQ1Rec1), there was still room for financial profit. This scenario presented a NPV of $134 dollars per acre, or 55 percent less than the maximum that the capacity of the forest could provide. A good integration of desired uses resulted in a smaller or, depending on the goals considered, no financial loss. There was no fixed formula that could be applied to all cases. Forests, due to high variability in space and time, must be analyzed individually. The methodology presented in this study can help managers and decision makers to find that combination of forest values that matches the capacity of the forest, landowner goals, and social needs.

Sustainable management involves an authoritative allocation of values, so is a concept that links politics and natural resources. It is difficult for a decision maker who is not an expert in forest management to choose among competing forest values and make

the best decision to most short and long term needs. This study's methodology breaks down and presents scientific information in a way that should help policy makers to understand the implications of their decisions by allowing them to see how different forest values interact in a finite way. Results showed the relationships among uses in a simple quantitative way. Final results in Table 6.11, where all data were expressed as percentage decreases relative to the maximum capacity of the forest, represent an easy and simple way to analyze options with little need of technical knowledge. The presented analysis framework provides with a decision support tool where the decision maker can find the best management alternative(s) based on: 1) a specific level of a desired outcome (or groups of them), 2) a desired level of variability of uses, or 3) within a certain distance from the theoretical optimum.

Scenario analysis is a useful tool for comparing alternatives within the same forest by estimating tradeoffs. However, considerations such as "existence" value were not quantified in the way the model for the Bigelow Preserve was designed, though the forest integrity and future existence was ensured in the strategic plans of each scenario. Existence values could have been included as such if data from contingent valuation surveys would have been available.

The achievement of some management goals inhibited the cumulative effect of other goals on some of the outcomes. Reaching an irregular structure of the forest not only provided visual and recreational benefits, but also represented the lowest financial return with the exception of the no management scenario.

In general, the sum of the effects of each goal considered individually had a different impact than the total impact of the same goals integrated together:

- the conjoint effect on NPV loss was lower than the sum of the goals effects considered independently,
- the conjoint effect on harvested volume was higher than the sum,
- the conjoint effect on merchantable inventory was relatively similar to the sum,
- the conjoint effect on the percentage of land classified as sawtimber stands was higher than the sum, and
- the conjoint effect on the percentage of land classified as well or adequately stocked was lower than the sum.

As could be expected, raising the stand quadratic mean diameter and keeping it at high levels through the planning horizon resulted in one of the most competitive benefits against financial revenues. However, retaining some large diameter trees in the stand did not significantly interfere (no in a statistical sense) with timber profitability.

From an industrial point, of view where the main goal is to maximize the revenues while ensuring the health and resilience of the forest ecosystem, scenario NPVenv represented one of the ideal candidates for choice. This scenario protected alpine and subalpine forests, riparian ecosystems, and areas at high risk of erosion. Although the opportunity cost associated with the protection of these fragile ecosystems reduced the maximum NPV that the capacity of the forest could provide by 12 percent, it ensured the continuation of the ecosystem in the future.

If the decision maker is more concerned about increasing wood consumption levels, and producing the highest harvested volumes becomes a priority at the same time that we protect fragile ecosystems, then scenarios NPVenvSC1, NPVenvSC1VQ2, and NPVenvSC1VQ2Rec2 are the most suitable ones, producing the same averaged amounts

of harvested volume. However, these three scenarios represent a good example of how different ways of management can provide with the same desired output (harvested volume) at the same time as other values that would not compete with the main goal. The three of them also provided an irregular forest structure, a presettlement species composition, protected high and medium visually sensitive zones, and the same financial revenues (Table 11). In addition to this, the last scenario, NPVenvSC1VQ2Rec2, ensured semi-primitive recreational opportunities (motorized and non-motorized) in the area. The analysis of results would have allowed a decision maker to choose scenario NPVenvSC1VQ2Rec2 as the desirable one given the fact that, at no harvested volume costs, it provided other desirable benefits.

On the other hand, if the main goal were to manage the area for biophysical ecosystem values, some scientists could argue that the best option would be the no-management scenario. However there is room for other options. If we know those forest outcomes that will ensure the health, resilience and stability of the ecosystem and those parameters can be quantified, them we can include them as part of the system and identify those benefits that do not compete with these goals. Suppose that our principal ecological goal was to achieve the presettlement species composition of the vegetation, develop an irregular forest structure, and have a large percentage of the land classified as sawtimber stands. The no-management scenario scored the highest values for the representation of sawtimber stands in the forest, but 11 other scenarios accomplished the three goals though with a lower percent of sawtimber stands. An evaluation of what other benefits each of these 11 scenarios provided should be done before a decision is made. In the development of the Bigelow Preserve model, the impact of recreational users on

fragile ecosystems was not included due to the lack of information. Therefore, the protection of fragile ecosystems was only from a timber management point of view, but it did not consider the potential impact due to recreational uses.

Finally, if the main objective is to find a balanced array of forest benefits, including financial revenues, while keeping the forest healthy and preserving its integrity in the long and short terms, those scenarios that scored the shortest Euclidean distance and the highest variability index would be the potential candidates among which the decision maker could find the best management alternative. In the Bigelow Preserve, the best alternative would be one of the following management scenarios: SustenvSC1VQ1Rec1, SustenvSC1VQ2Rec2, NPVSC1VQ1Rec1, SustenvSC1VQ1, SustenvSC2VQ1Rec1, SustenvSC1Rec1, and NPVenvSC1VQ2Rec2.

Euclidian distance represents a powerful tool in the decision-making processes. The main advantage of its use lies in its simplicity and flexibility for adjustment to other cases and decision criteria. Scenarios could be compared with just one indicator, and no matter how many goals we needed to achieve they all could be represented in an n-dimension space. However, this indicator is sensitive to the output measurements that we use, and results could easily be manipulated. Outcomes with different units of measurement can be normalized by calculating the percent decrease from the maximum level of the outcome that the forest capacity can provide. Hence, there is no need to translate outputs into a common measurement unit, as we commonly found in the literature where values are estimated in monetary units.

Within a sustainability context and at the landscape level, the original hypothesis was tested (not in the statistical sense) finding that the variety of forest products, services

and conditions is a direct function of the value that forests represent for society. In other words, forest management directions that favor the greatest variety of conditions and activities lead to a greater aggregate value than those directions that favor narrower goals. An additional advantage of providing a wide range of forest benefits, which is not captured with the Euclidean distance, is that at the landscape level a diverse set of forest uses has a greater flexibility for adapting to new social needs and policies than forests that provide very limited set of values, especially timber production, as the only management goal in a forest. Forest processes and forest responses are time consuming and, although it is true that it does not take a long time to remove the vegetation, it certainly takes a long time to return a forest to a mature state. The "social resilience" of the forest becomes higher when the forest can provide more than one use at the large landscape level. However, this is only true when none of the uses jeopardize the others, especially ecological values and the ecological integrity of forest ecosystems.

In the described modeling environment, the limitation of using the Euclidean distances and tradeoff analysis as decision support tools relays on how well the model construction reflects reality, the accuracy of the data that these models are based on, and the definition of management goals, which depends on how well ecosystems, social needs and economic markets are known.

6.8. FUTURE RESEARCH

An analysis of how indicators can modify results within the developed methodology could contribute to an estimation of the sensitivity of this method to data manipulation. Indicators that reflect the state of the forest and other management goals

that we desire to accomplish are one of the basic elements for an accurate analysis. I believe that the outputs considered in the proposed model were accurate and quantified the proposed goals. However, comparing our results with another study that could include other indicators (economic, social and or ecological) could certainly improve this technique. This method represents a flexible tool that allows considering as many indicators as needed and creating models for any case. The challenge involves questions of available data and the accuracy of quantifiable techniques to estimate responses of natural process.

Financial opportunity costs reached levels up to 55 percent among the scenarios considered in this study. Further research should be conducted on the social willingness to pay for this opportunity cost in order to provide other benefits. Although it is true that the ecological integrity of the forest should be a priority in strategic planning to ensure the stability and health of the forest today and for generations to come, as well as preserving its biodiversity, there is a point at which forest capacity can provide different competitive uses without jeopardizing the ecosystem. Which uses should be prioritized is a matter for decision makers; answers depend on who should pay for these benefits.

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APPENDIX A: MAPPING CRITERIA FOR THE FOUR RECREATIONAL OPPORTUNITY SPECTRUM CLASSES[1]

1. PRIMITIVE.

Remoteness: an area at least 2 miles from all roads, railroads, or trails with motorized use.

Size: 5,000 acres or larger but can be smaller if contiguous with semi-primitive nonmotorized class

Evidence of humans: evidence of humans unnoticeable; essentially unmodified natural environment; trails needed to carry expected use are acceptable; structures are extremely rare.

Social setting: usually less than 6 parties encountered per day and 3 or fewer parties visible at campsites.

Managerial setting: on-site regimentation is low, with controls primarily off-site.

Very high probability of experiencing solitude, freedom, closeness to nature, tranquility, self-reliance, challenge and risk. Unmodified natural or natural appearing environment. Very low interaction between users. Restriction and controls not evident after entry. Access travel is nonmotorized on trails or cross country. No visual vegetative alterations, Management of the vegetation is allowed during those times of the year with less recreational use (winter). Access for people with disabilities can be "most difficult" and very challenging. No site modifications for facilities. Interpretation through self-discovery. No on-site facilities. No facilities for user comfort. Use native materials.

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[1] Adapted from the USDA Forest Service Classification

2. SEMI-PRIMITIVE NONMOTORIZED.

Remoteness: an area at least 1/2 mile from all roads, railroads, or trails with motorized use; can include primitive roads and trails if usually closed to motorized use.

Size: larger than 2,500 acres but can be smaller if contiguous with a primitive class.

Evidence of humans: some setting modifications are acceptable; little or no evidence of primitive roads or motorized use of trail and roads; structures are rare and isolated.

Social setting: usually 6 to 8 parties encountered on the trail per day and 6 or less visible at campsites.

Managerial setting: on-site regimentation and controls present but subtle.

High probability of experiencing solitude, closeness to nature, tranquility, self-reliance, challenge and risk. Natural appearing environment. Low interaction between users. Some evidence of other users. Minimum of subtle on-site controls. Access and travel is nonmotorized on trails, some primitive roads or cross country. Vegetation alterations: sanitation salvage to very small units in size and number, widely dispersed and not evident. Access for people with disabilities is "difficult" and challenging. Rustic and rudimentary facilities primarily for site protection. No evidence of synthetic materials. Use undimensioned native materials. Interpretation through self-discovery. Some use of maps, brochures, and guidebooks. No on-site facilities.

3. SEMI-PRIMITIVE MOTORIZED.

Remoteness: an area within 1/2 mile of primitive roads, railroads or trails used by motor vehicles.

Size: larger than 2,500 acres

Evidence of humans: may have moderate alterations of the natural setting that are not noticeable to motorized observers traveling on trails or primitive roads in the area; strong evidence of primitive roads and motorized use of them and trails; structures are rare and isolated

Social setting: low to moderate frequency of contact with other parties

Managerial setting: on-site regimentation and controls present but subtle; actual numbers are to be developed to meet regional needs; peak days may exceed.

Moderate probability of experiencing solitude, closeness to nature, tranquility. High degree of self-reliance, challenge and risk in using motorized equipment. Predominantly natural appearing environment. Low concentration of users but often evidence of others on trails. Minimum on-site controls and restrictions present but subtle. Vegetation alterations very small in size and number widely dispersed and visually subordinate. Access for people with disabilities "difficult" and challenging. Rustic and rudimentary facilities primarily for site protection. No evidence of synthetic materials. Use undimensioned native materials. Interpretation through very limited on site facilities. Use of maps, brochures and guidebooks.

4. ROADED NATURAL.

Remoteness: an area within 1/2 mile of roads and railroads.

Size: no size requirement

Evidence of humans: modification of the natural setting is acceptable; modifications must remain unnoticed from sensitive travel routes and use areas; strong evidence of designed roads and highways; structures are scattered and unnoticeable on the sensitive travel routes

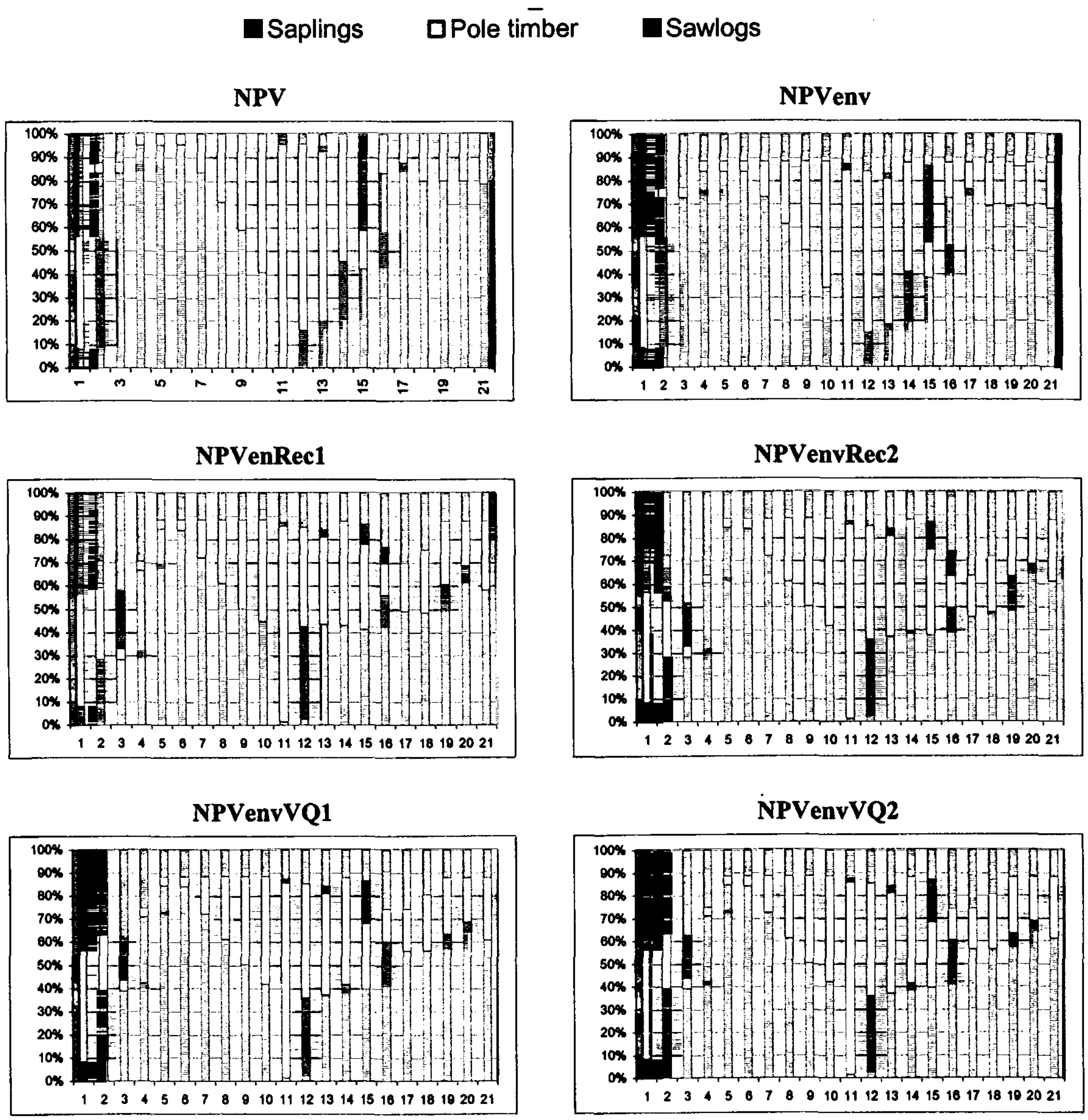
Social setting: frequency of contact is moderate to high on roads and low to moderate on trails and away from roads; actual numbers are developed by each region and may be exceeded during peak use days.

Managerial setting: on-site regimentation and controls are noticeable but harmonize with the natural environment.

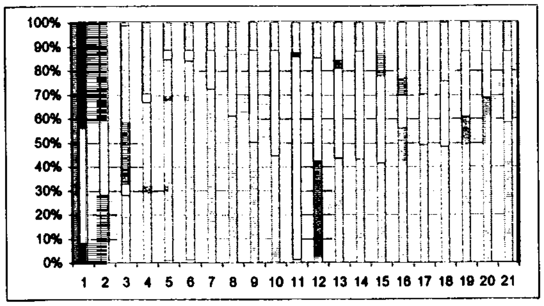
Opportunity to affiliate with other users in developed sites but with some chance for privacy. Self-reliance on outdoor skills of only moderate importance. Little challenge and risk. Mostly natural appearing in environments as viewed from sensitive roads and trails. Interaction between users at camp sites is of moderate importance. Some obvious on-site controls of users. Access and travel is conventional motorized including sedan, trailers, RVs and some motor homes. Vegetation alterations done to maintain desired visual and recreational characteristics. Access to people with disabilities is "difficult" and challenging. No on site facilities except signing at major road junctions. Occasional sanitary facilities for user health protection. Site modification by users only. Interpretation by simple wayside signs made of native-like rustic materials.

APPENDIX B: FIGURES RELATED TO THE LAND PERCENTAGE DISTRIBUTION AMONG STAND DIAMETER CLASSES OVER TIME IN THE BIGELOW PRESERVE FOREST

Figure B.1: Land percentage distribution among stand diameter classes over 21 simulated periods (of 5 years each) in the Bigelow Preserve forest and under each considered management scenario.



NPVenvVQ1Rec1



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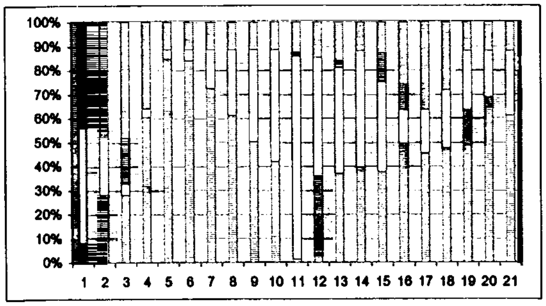

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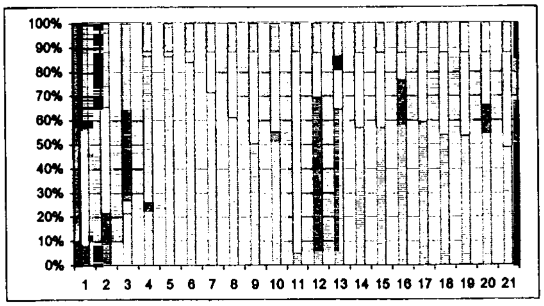

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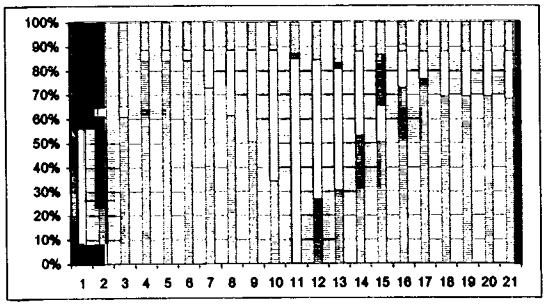

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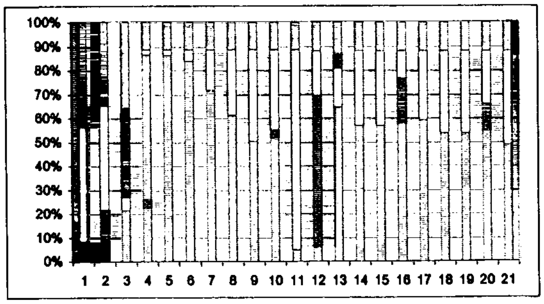

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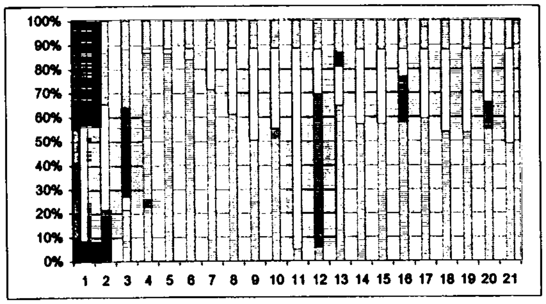

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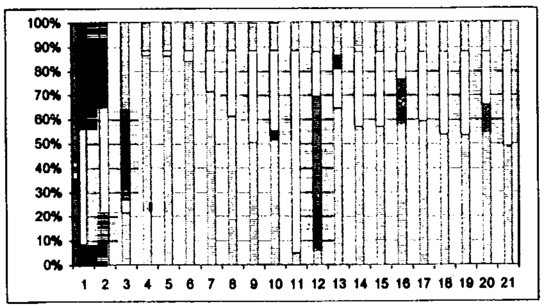

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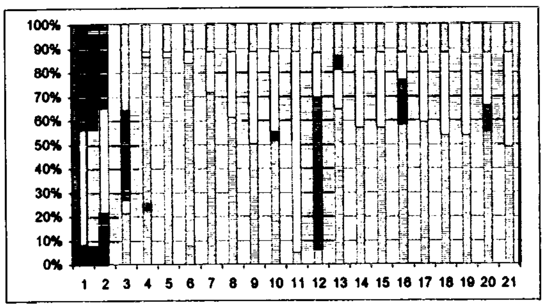

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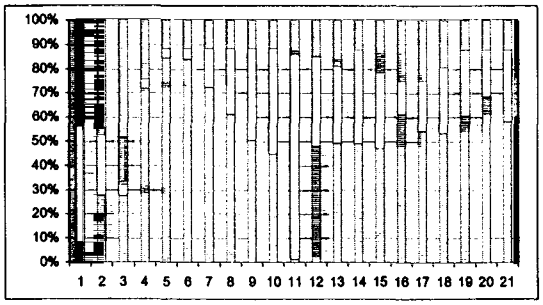

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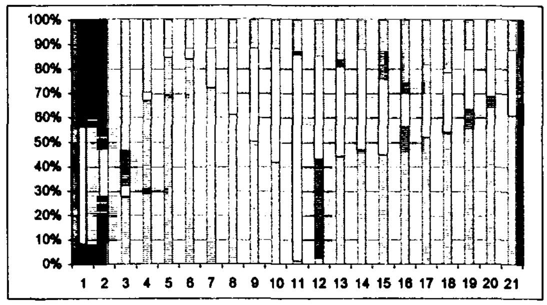

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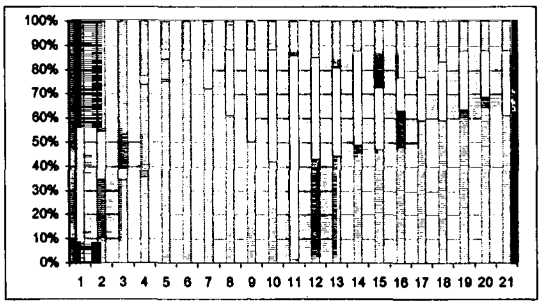

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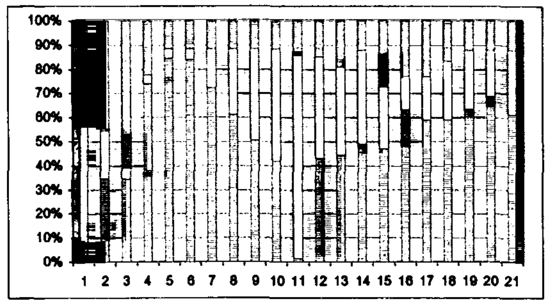

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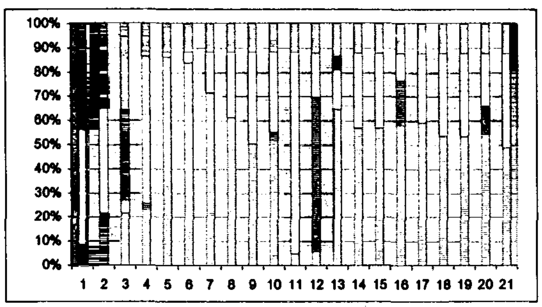

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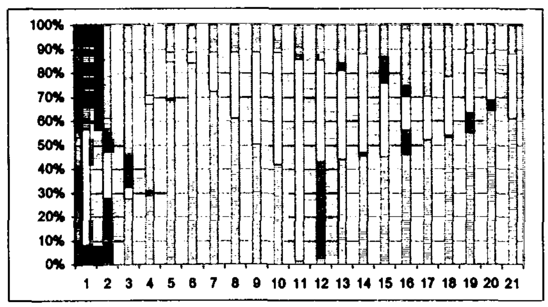

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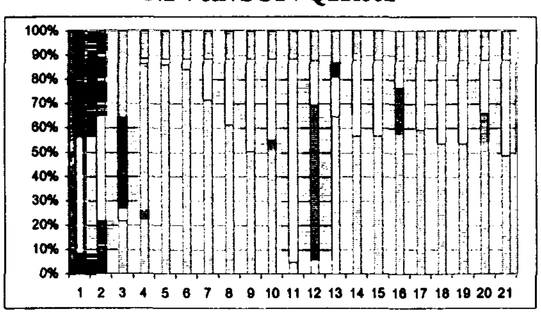

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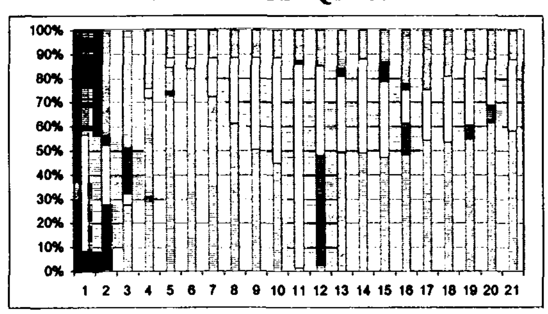

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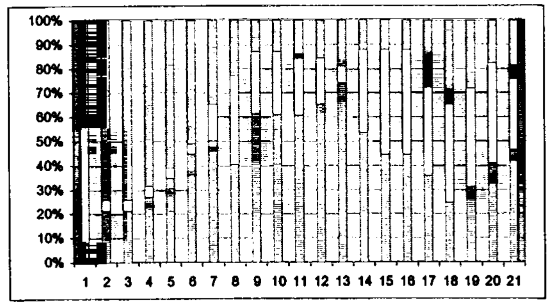

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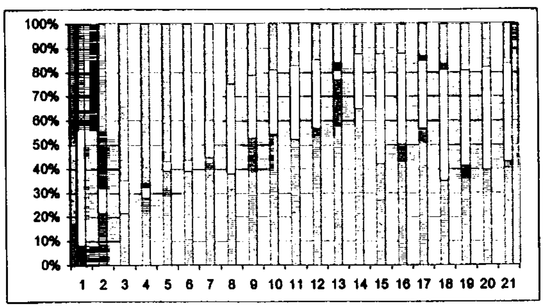

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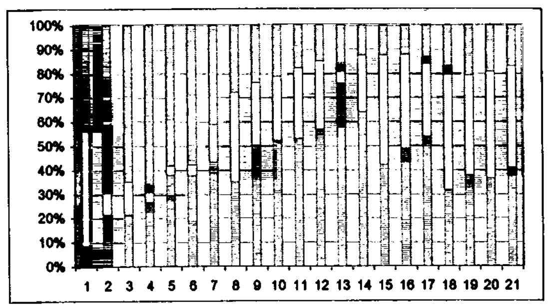

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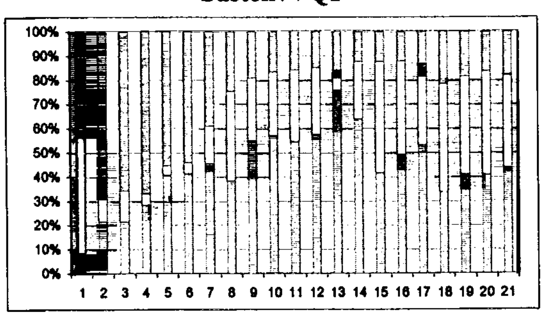

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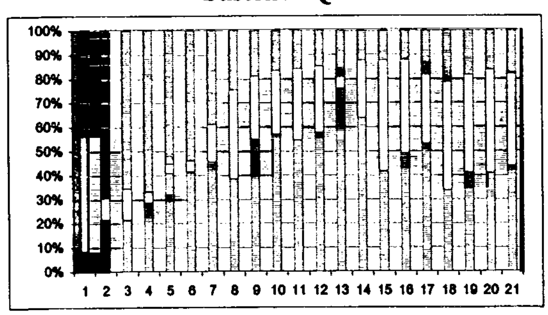

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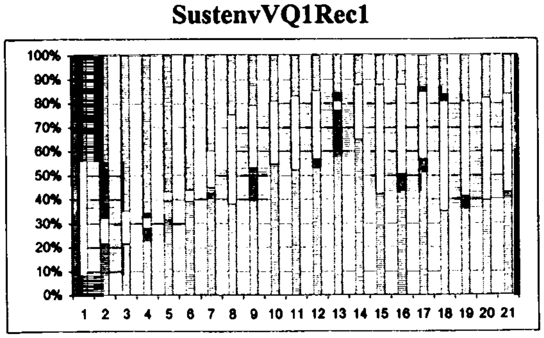

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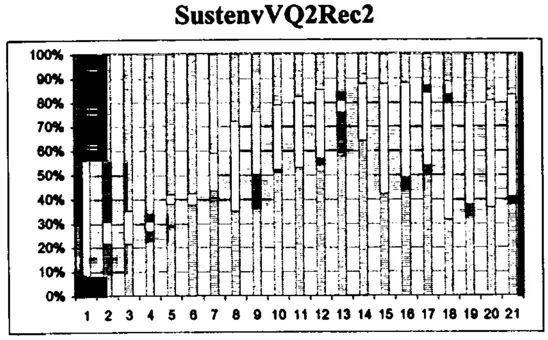

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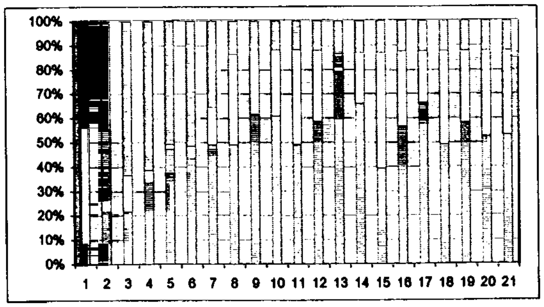

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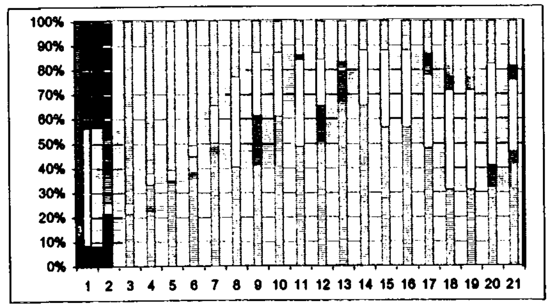

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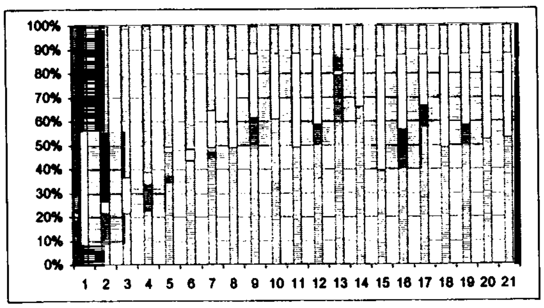

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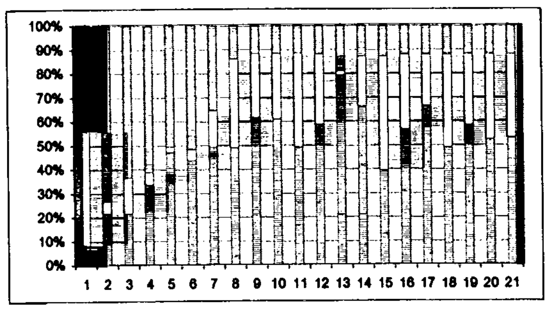

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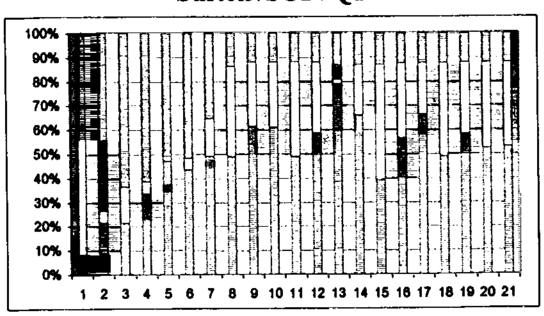

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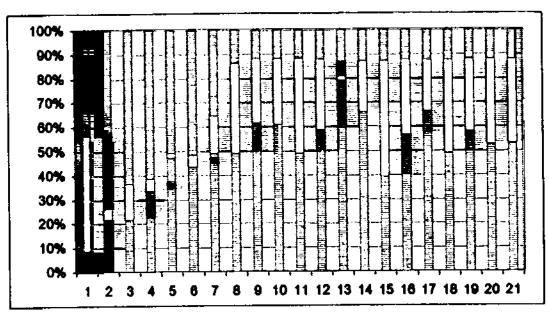

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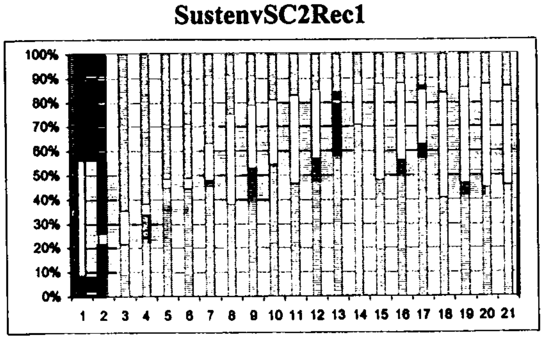

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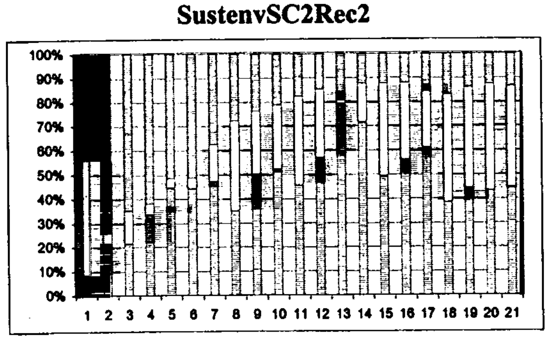

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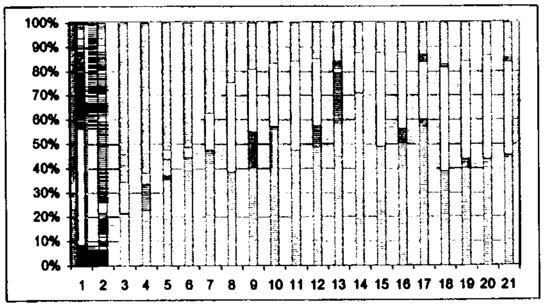

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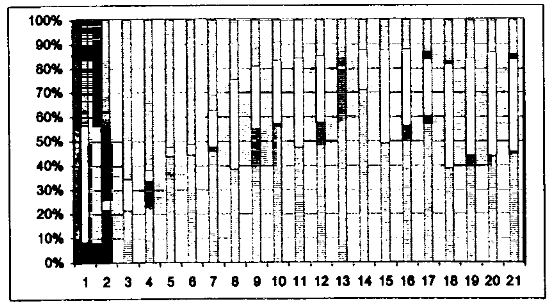

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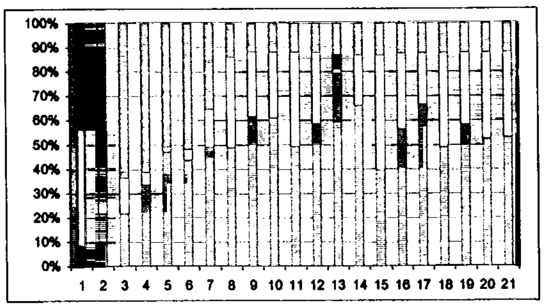

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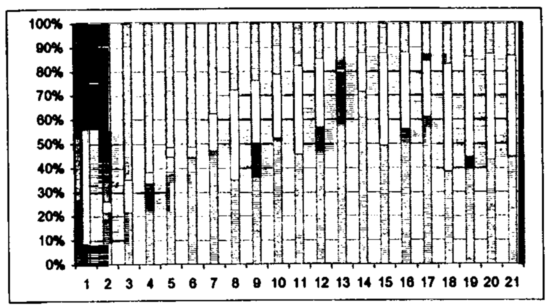

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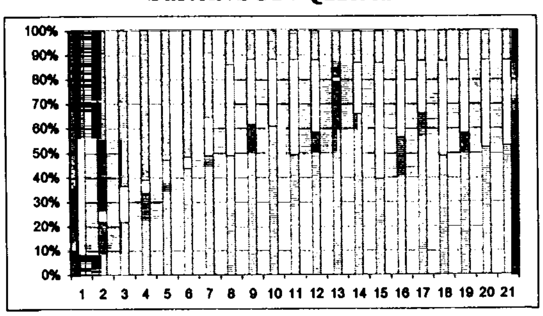

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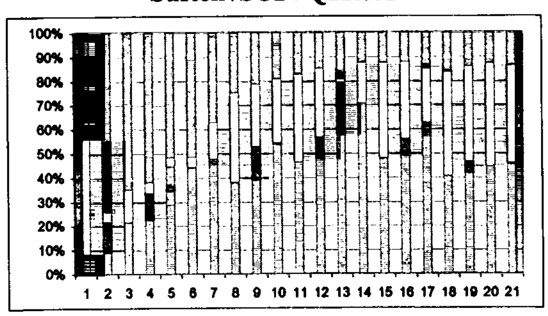
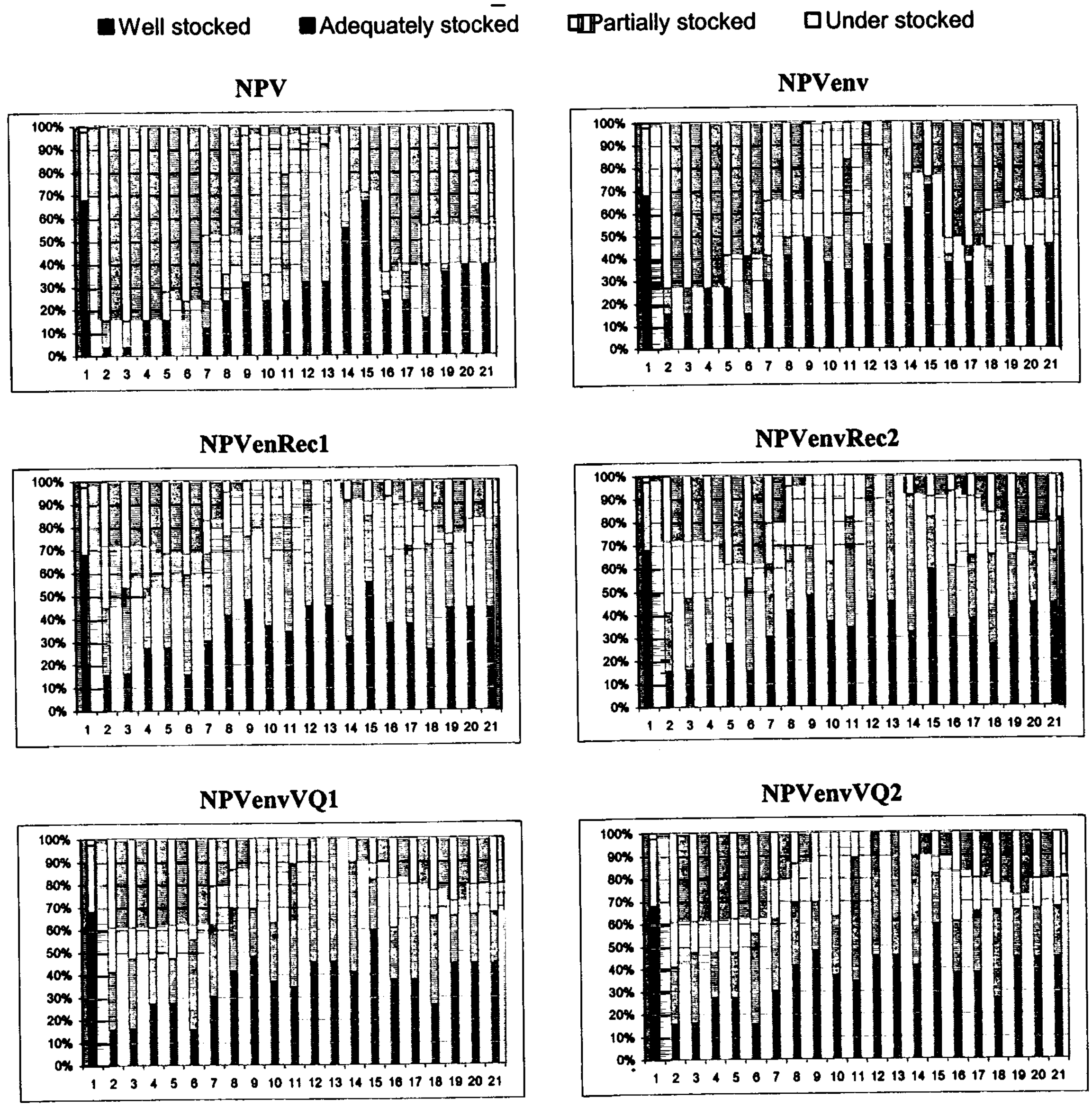


APPENDIX C: FIGURES RELATED TO THE LAND PERCENTAGE DISTRIBUTION AMONG STOCKING CLASSES OVER TIME IN THE BIGELOW PRESERVE FOREST

Figure C.1: Land percent distribution among stocking classes over the 21 simulated periods (of 5 years each) in the Bigelow Preserve forest and under each considered management scenario.



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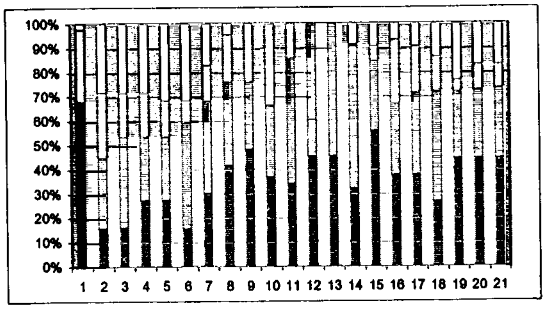

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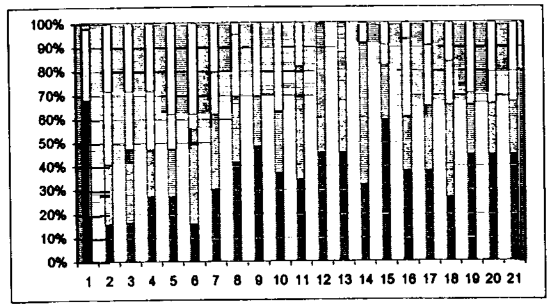

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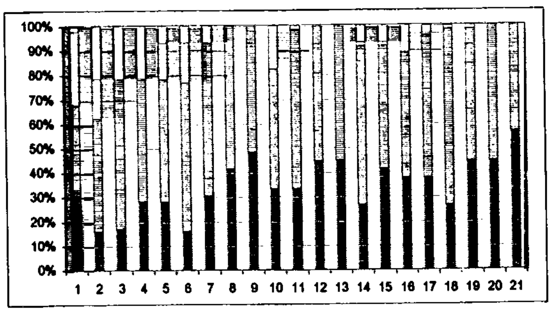

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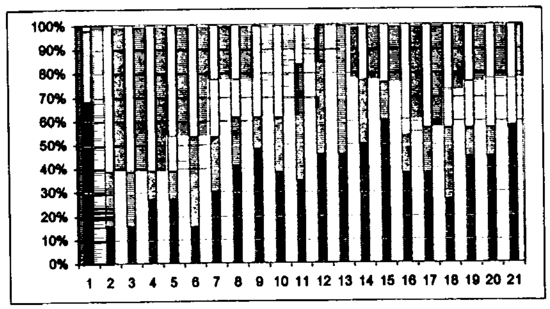

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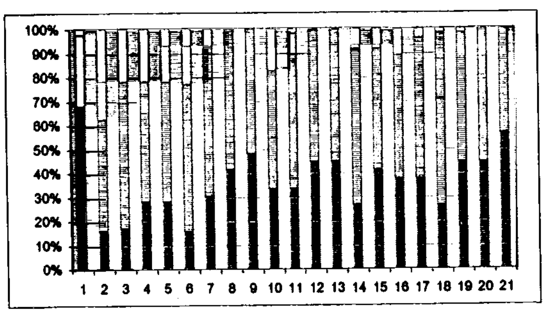

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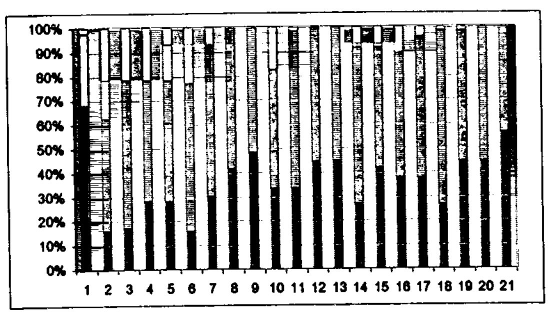

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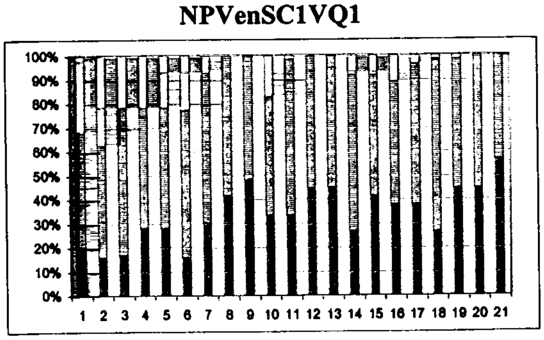

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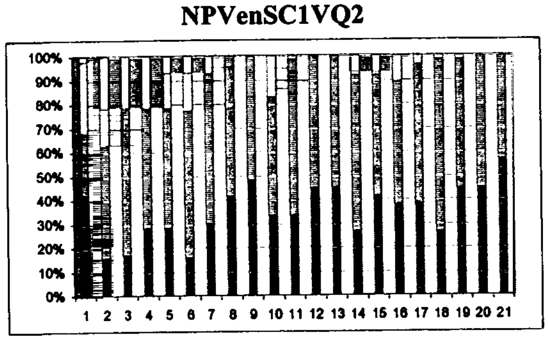

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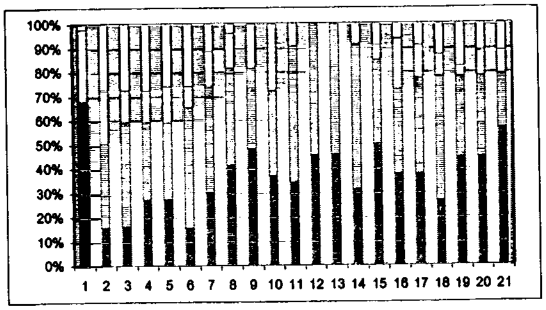

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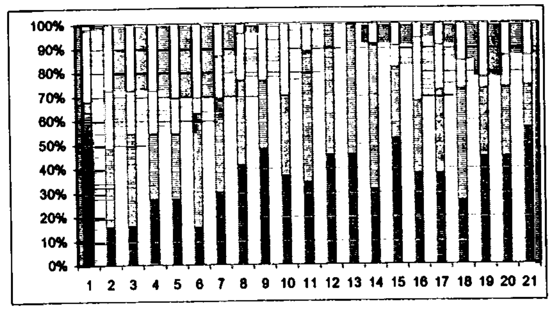

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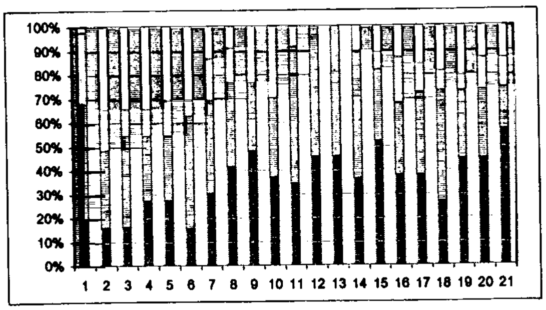

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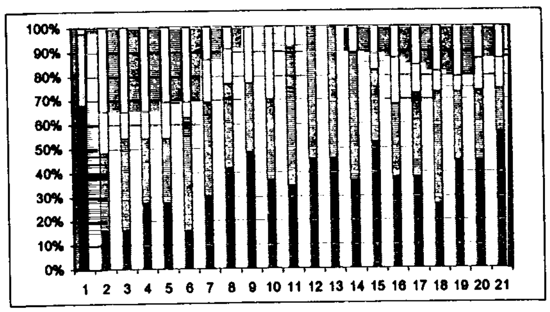

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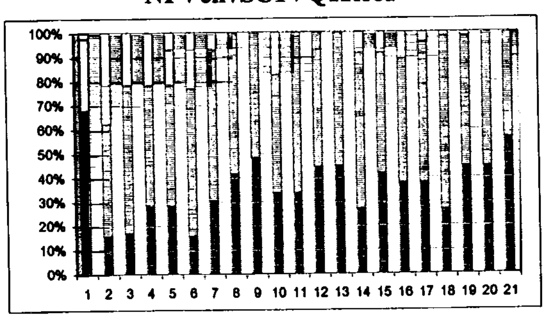

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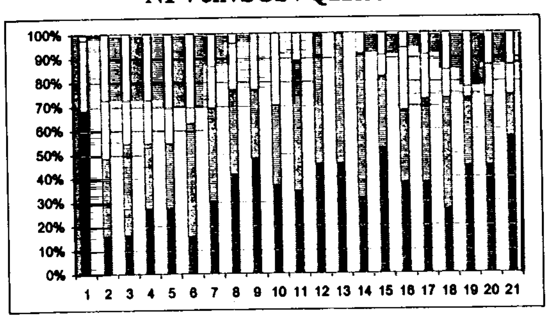

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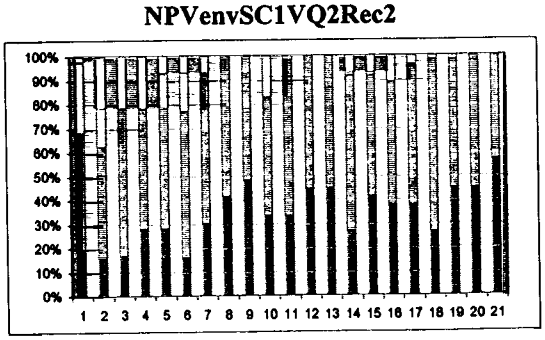

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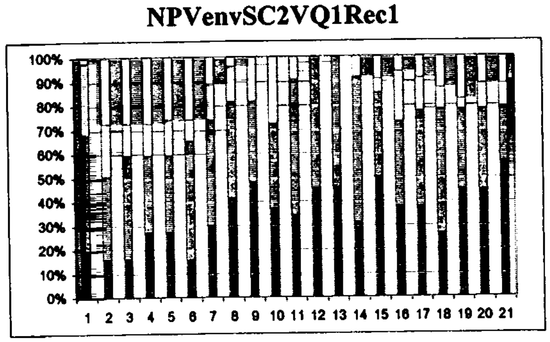

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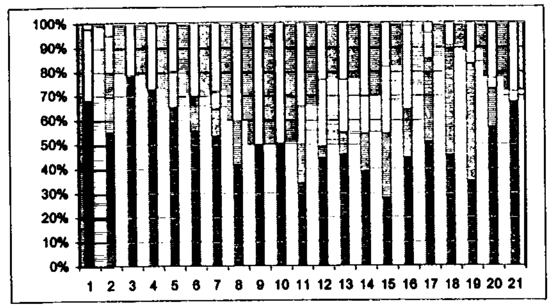

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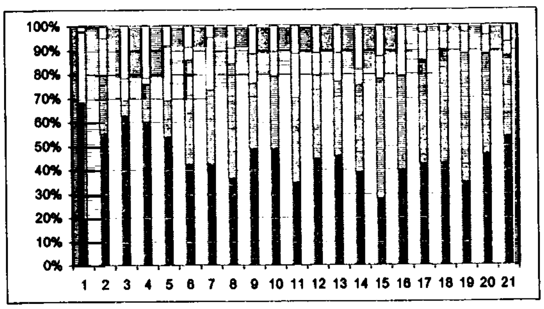

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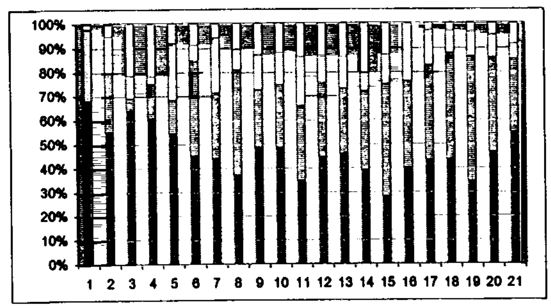

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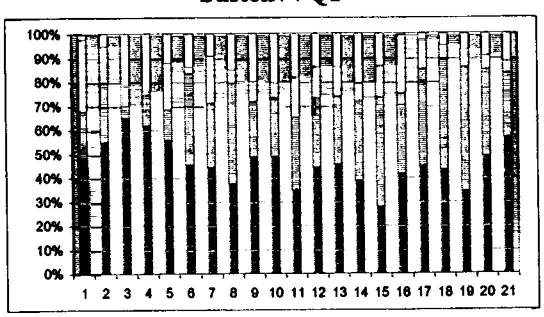

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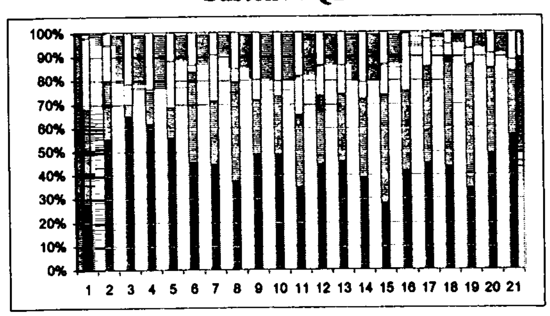

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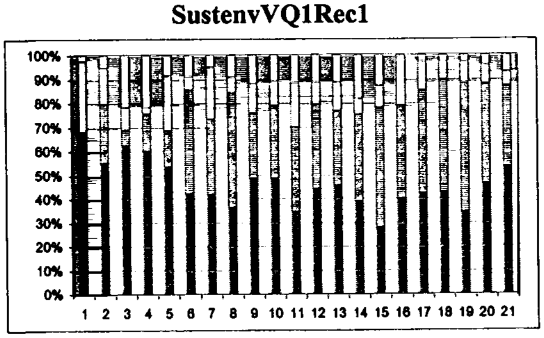

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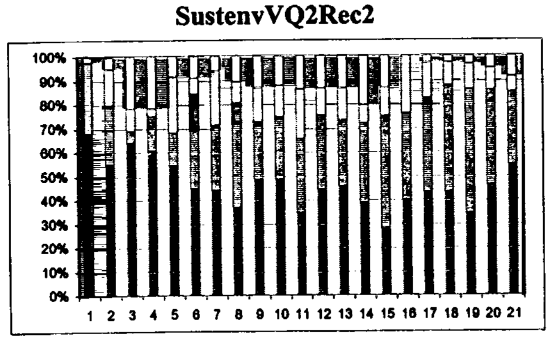

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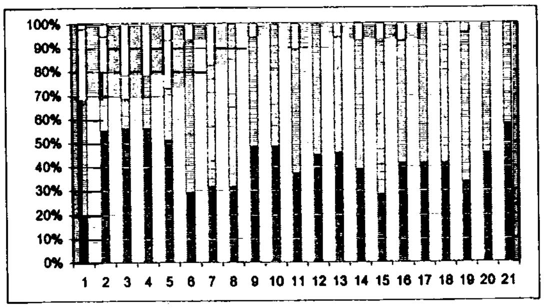

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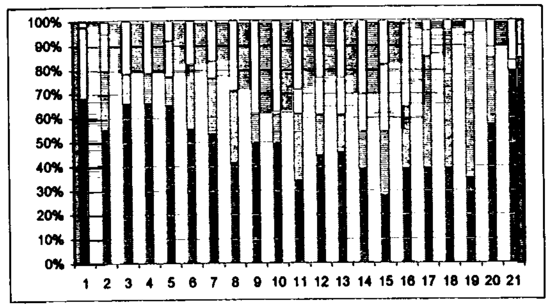

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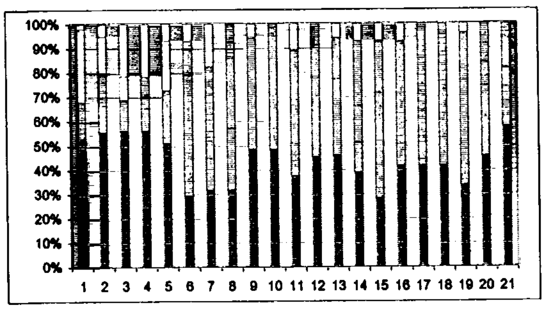

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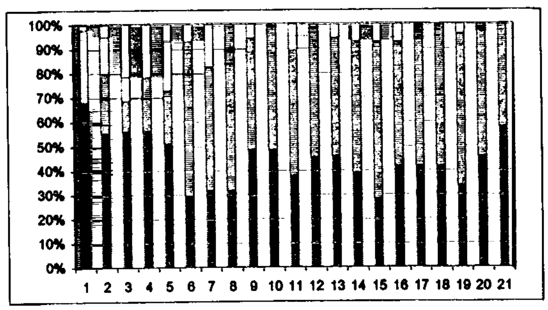

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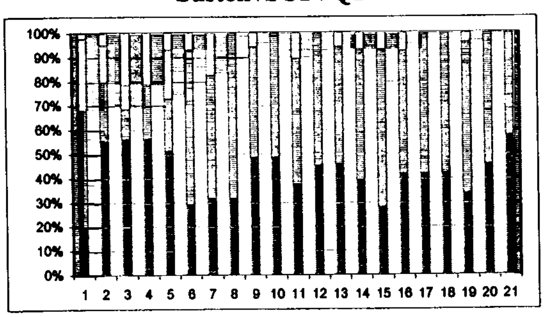

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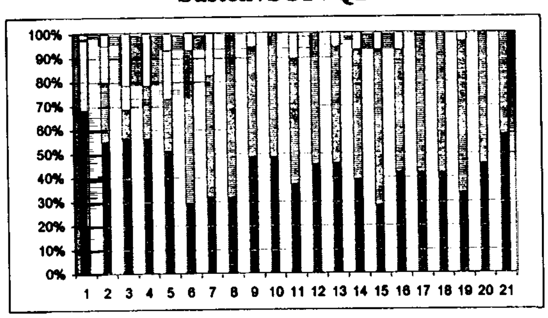

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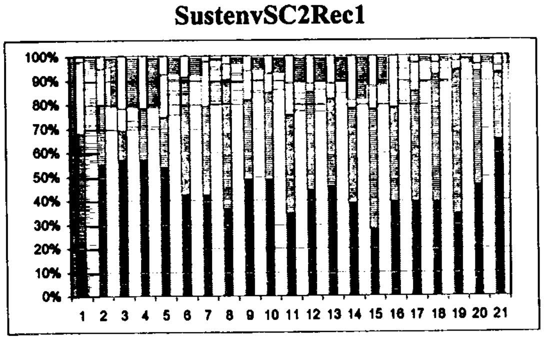

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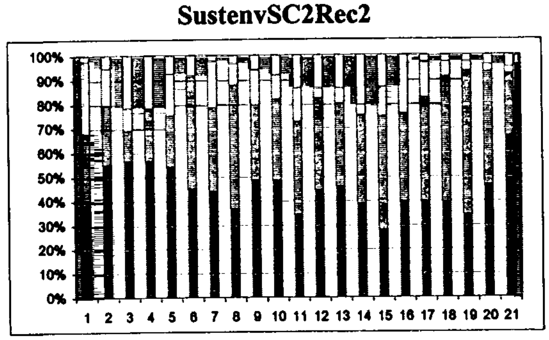

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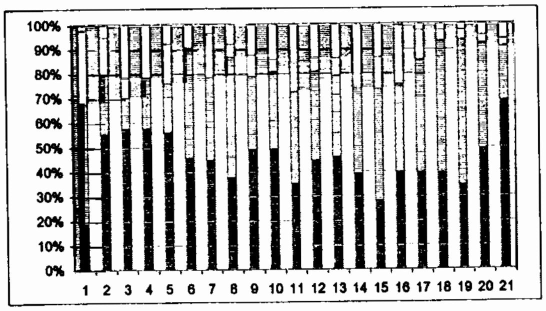

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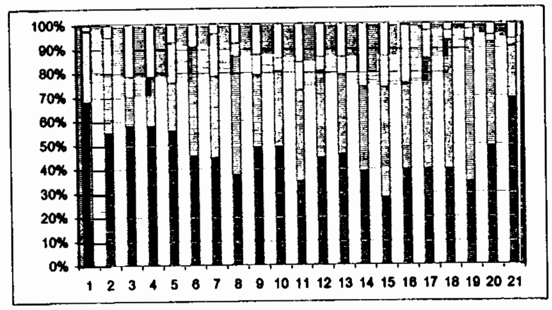

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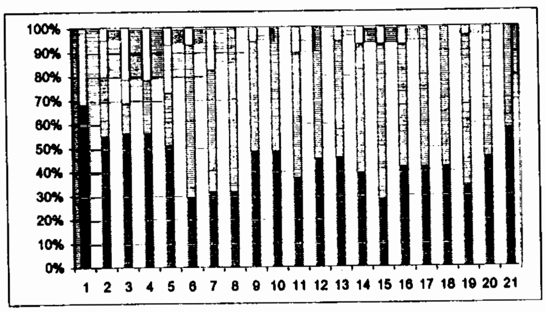

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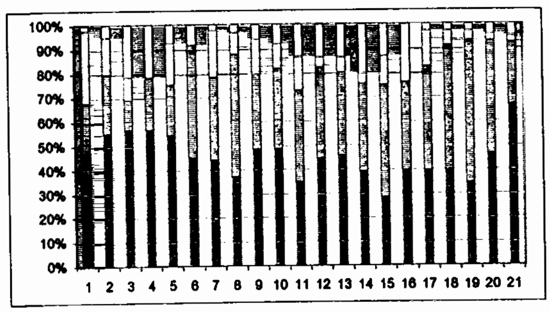

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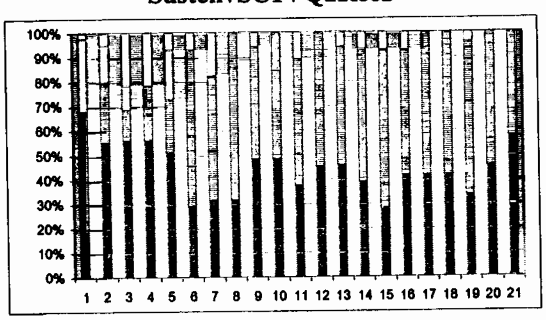

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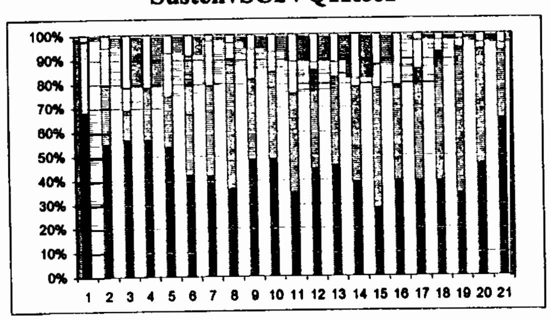

BIOGRAPHY OF THE AUTHOR

Milagros Álvarez Ibáñez was born on November 30, 1973 to Milagros Ibáñez Rabadán and Antonio Álvarez García in Madrid, Spain. She was raised in Madrid, where she graduated from La Guindalera School in 1991. She attended La Escuela Superior de Ingenieros de Montes (Universidad Politécnica de Madrid) and graduated in 1997 with a Bachelor/Master degree (degree that requires a minimum of 6 years of theoretical and practical courses, and a final thesis project) in Forest Engineering. As an undergraduate, she received four consecutive grants to carry out studies abroad during summer semesters from the Universidad Politécnica de Madrid (Spain), three of which she used to pursue studies at the University of Maine, and the four one she spent at the University of Lancaster (UK). She also obtained a one-year research grant in 1996 from the Spanish Department of Education. Mila received the Best Student Award in Forest Ecosystem Management, and the Best Student Award in Forest Policy and Administration in 1997. After her graduation in October 1997, Mila worked for La Universidad Politécnica de Madrid in the management strategies' field for three months.

In 1998, she returned to the University of Maine to pursue a Doctor of Philosophy degree in Forest Resources. While at the University of Maine, Mila published the following publications:

- Alvarez M. and M.T. Goergen. 2002. Consumption Issues for the Forestry Profession. *Journal of Forestry* (in press).
- Alvarez, M. 2001. Farm Bill Should Support Sustainable Forestry. *The Forestry Source* (July) 7(6).

- Alvarez, M., and D.B. Field. 2001. Forest Values. Literature Review. In Vancura, K., and E. Hradilova (eds.) *Seminar of Valuation on Forest Goods and Services.* Opocno, Czech Republic. November 2000. 87-100.
- Alvarez, M., and D.B. Field. 2001. Review of the Methodologies Applied in Forest Ecosystem Management to Estimate Natural Resources Values. In Vancura, K., and E. Hradilova (eds.) *Seminar of Valuation on Forest Goods and Services.* Opocno, Czech Republic. November 2000. 101-115.
- Alvarez, M., and I. Otero. 2000. Aspectos Socioeconómicos a Considerar en la Elaboración de Planes de Gestión de Espacios Naturaes. *Revista Forestal Española* 24: 4-10. (Social and Economic Variables to Be Considered in the Design of Natural Resources Management Plans. *Spanish Forestry Journal* 24: 4-10).
- Alvarez, M., and I. Otero. 1999. Diseño y Gestión de Corredores Ecológicos y Ecovías. *Libro Homenaje a Don Ángel Ramos.* Real Academia de Ciencias Físicas, Exactas y Naturales: 823-839. (Greenways Design and Management. In: *Memorial Book of Don Angel Ramos.* Royal Academy of Physics, Math and Natural Sciences: 823-839).
- Alvarez, M., and J. Solana. 1999. Análisis de Preferencias Paisajísticas en la Sierra de Ancares. Métodos. *Libro Homenaje a Don Ángel Ramos.* Real Academia de Ciencias Físicas, Exactas y Naturales: 905-929. (Landscape Preferences Análisis in La Sierra de Los Ancares. Methodologies. In: *Memorial Book of Don Angel Ramos.* Royal Academy of Physics, Math and Natural Sciences: 905-929).
- Alvarez, M., and A.P. Espulga. 1999. Introducción al Paisaje. In *Paisaje Teledetección y SIG.* I. Otero (ed.) Fundación del Conde del Valle Salazar: 3-33.

(Landscape, Introduction Chapter. In: *Landscape, Remote Sensing and GIS*. I Otero (ed.). Earl Valle Salazar Foundation: 3-33).

- Alvarez, M., I. Otero and J. Solana. 1999. Valoración y Análisis de Preferencias Sociales de los Distintos Conjuntos Paisajísticos de la Reserva Nacional de Caza de Los Ancares (León y Lugo). *Paisaje Teledetección y SIG*. I. Otero (ed.). Fundación del Conde del Valle Salazar: 37-158. (Social Preferences and Values of the Different Landscapes in the National Hunting Reserve of Los Ancares (León y Lugo). In *Landscape, Remote Sensing and GIS*. I Otero (ed.). Earl Valle Salazar Foundation: 37-158).

In 2001 she worked for the Society of American Foresters (SAF), of which she has been a member since 1998, in the Forest Policy Department. While there, she attended the SAF Leadership Academy Program. She is also a member of the Spanish Society of Forest Engineers, Colegio de Ingenieros de Montes, in Madrid (Spain) since 1996.

In 2000, Mila was the president of the Xi Sigma Pi Forestry Honor Society at the University of Maine. And in 1999, she was the Vice-President of the 15th Annual Conference of Graduate Students in Forestry and Environmental Sciences (CONFOR), hosted in Bar Harbor, Maine.

Mila is a candidate for the Doctor of Philosophy degree in Forest Resources from the University of Maine, August 2002.