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Forest Health Through Silviculture

Proceedings of the 1995 National Silviculture Workshop

Mescalero, New Mexico
May 8–11, 1995

Abstract—Includes 32 papers documenting presentations at the 1995 Forest Service National Silviculture Workshop. The workshop's purpose was to review, discuss, and share silvicultural research information and management experience critical to forest health on National Forest System lands and other Federal and private forest lands. Papers focus on the role of natural disturbances, assessment and monitoring, partnerships, and the role of silviculture in forest health.

Keywords: forest health, resource management, silviculture, prescribed fire, root diseases, forest pests, monitoring.

Compiler's note: In order to deliver symposium proceedings to users as quickly as possible, many manuscripts did not receive conventional editorial processing. Views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations or the USDA Forest Service. Trade names are used for the information and convenience of the reader and do not imply endorsement or preferential treatment by the sponsoring organizations or the USDA Forest Service.

Cover photo by Walt Byers

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Foreword

The 1995 National Silviculture Workshop was held at the Inn of the Mountain Gods in Mescalero, New Mexico, and hosted by the Lincoln National Forest, Region 3, and the Rocky Mountain Forest and Range Experiment Station. This was the latest in a series of biennial workshops started in 1973 in Marquette, Michigan, with a comprehensive review of uneven-aged management. The purpose of this workshop was to review, discuss, and share silvicultural research information and management experience critical to achieving healthy forest ecosystems on National Forest System and other Federal and private forest lands. Authors represent a cross section of the forest vegetation management and protection communities and address the importance of the role of silviculture in maintaining and restoring healthy forest ecosystems from the viewpoints of research, education, and land management. Unfortunately, not all speakers were able to prepare papers for this proceedings.

A stimulating field trip to the Mescalero Apache Reservation and the Lincoln National Forest was hosted by the Mescalero Apache Tribe, Bureau of Indian Affairs, Lincoln National Forest, and Rocky Mountain Station personnel. The field trip gave the participants an opportunity to observe and discuss forest research and management activities in the Southwest and to compare contrasting management approaches to forest health problems on different land ownerships.

The Washington Office Timber Management (WO-TM) and Forest Management Research (WO-FMR) staffs appreciate the efforts of our hosts in New Mexico. Special acknowledgment is made to Wayne Shepperd, Rocky Mountain Station; Larry Mastic and Earlene Ellett, Lincoln National Forest; John Shafer, Southwest Region; and Dave Koch, Bureau of Indian Affairs, for their leadership and support in planning, arranging, and hosting the workshop. Also commended are the speakers for their excellent presentations; the moderators who led the sessions; the 170 people representing all NFS Regions and Research Stations; several WO NFS and Research Staffs; Mescalero Apache Tribe; Bureau of Indian Affairs; State of New Mexico; Republic of Mexico; and the special guests who participated in the workshop.

Papers published in this proceedings received limited editing to ensure rapid publication of the proceedings and a consistent format. Therefore, authors are responsible for the content and accuracy of their individual papers.

The diligence and thoroughness of Lane Eskew (Station Editor) and Carol Losapio (Editor) of the Rocky Mountain Station, and Louise Brown (Writer/Editor) of the Southern Station, in producing this proceedings are to be commended.

Dennis Murphy	Nelson Loftus
Timber Management	Forest Management Research
Washington, DC	Washington, DC

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Opening Remarks

Chip Cartwright[1]

Good morning and welcome to the Sacramento Mountains of New Mexico. For those of you who drove up, the trip from Alamogordo to Cloudcroft gives a good example of the nature of our Southwestern forests. They tend to be isolated on the tops of mountains rising out of arid regions. We like to believe that the forests here in the Southwest are such treasures that we keep them well-hidden!

That being the case, I really want to thank the people of the Mescalero Apache Tribe, Lincoln National Forest, and Sacramento Ranger District for sharing their forest with us for a few days. I also want to thank all the people from the Forest Service, the Bureau of Indian Affairs, the Mescalero Tribe, and the Secretaria de Agricultura y Recursos Hydraulicos of Mexico for all the work they have put into bringing this meeting about.

If any of you have ever been involved in putting together a meeting like this one, you know very well that it doesn't just happen. It takes months of planning and more than a few anxious moments to get this far. The fact that we are all here in this beautiful setting shows that all of these folks did a fine job and deserve a round of applause for their work.

The theme of this meeting is "forest health through silviculture." What do we mean when we talk about forest health? That is one of the things that will be discussed at length at this session. It's also an interest of mine because of my background in ecosystem management, so I'm sure you will allow me to give you some of my perspective on this issue.

Jay O'Laughlin at the University of Idaho defined forest health as "a condition of forests reflecting the complexity of their ecosystems while providing for human needs." Note that one of the major parts of this definition deals with maintaining the complexity of the forests.

Traditionally, many silvicultural practices have led to a reduction in complexity because it was felt that this would result in producing more of what were considered to be the desirable outputs available from forests. We have come to a point where we value all potential outputs of the forest, including the spiritual and noncommercial outputs much more than we did in the past.

We have also come to realize that simplifying the forest will result in less of all outputs in the long run. When the forest is simplified too much, we have an unhealthy forest. It is unhealthy because it is less able to absorb and recover from disturbances and because it is less able to meet the needs of us humans who depend on it in so many ways.

Silviculturists have also come a long way in moving from "timber growers" to people who manage for multiple values, including forest health. However, there are still challenges to be met. One of these is to be sure that you complete the transition from timber management to ecosystem management and to insure that you are recognized as ecosystem managers. You need to bring to interdisciplinary teams, line officers, and our many publics an in-depth knowledge of how forest ecosystems function, what is outside the historic range of variability, what is not sustainable, and how these systems can provide for human needs without damage to the ecosystem itself.

To accomplish this will require close cooperation between managers and scientists to insure application of the latest research findings and adequate monitoring of management results to allow adaptive management. "Adaptive management" means changing management practices where necessary to achieve desired results.

Considering these challenges, I would like to express some of my views on how I think we will need to change our silvicultural practices. First, I think that we must find ways to provide for human needs while maintaining the complexity of the forests. That complexity must include all the

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conditions that would be found within the historic range of variability of the forests. This will not be easy, but it is essential to maintaining forest health and to meeting the expectations of the owners of the forests.

Fortunately, we do have some help in meeting this challenge. In looking at the agenda for this session, I see that there are several presentations on natural disturbance factors in forested ecosystems. Understanding the functions of the ecosystem, including disturbance events, will be key to maintaining forest health. Understanding the forces that shape the forest will lead to understanding the forest's structure. Our job will be to devise treatments that will result in the same structures while removing products from the forest for human use.

This brings me to my second point. I believe that we must move beyond the old silviculture, which was mostly based on individual stands. We must consider forest structure on a landscape basis and a small-group basis as well as a stand basis. This will be necessary if we are to mimic the overall structure of the forest within the historic range of variability.

The more a forest moves outside its historic range of variability, the more powerful are the forces that are trying to bring it back. Another way of looking at forest health is to say that we have an unhealthy forest when these forces become so great that we can no longer manage them, or we can't accept the consequences that result when these forces are released. My third point is that we must go beyond just developing treatments that will maintain forest health and must convince skeptical members of the public that these treatments are appropriate.

As an example of why this is necessary, let me quote a recent survey conducted by "American Forests" magazine. It asked if people believe that timber should be harvested on public lands, excluding national parks. The response was 47 percent "yes" and 44 percent "no."

This is so close that you might as well say that half of the people of this country think that trees should not be cut on national forests or other public lands. However, the multiple-use mandate of the Forest Service has not changed. The production of wood products is a part of that mandate. We must make it compatible with maintaining forest health.

The same survey found that 72 percent of the people think that forests in their area of the country are either somewhat healthy or very healthy. This being the case, it is easy to see why they do not think we need to manage these forests.

Our job will be to continue to point out forest health problems where they exist without overstating the case. From a global perspective, this will include managing forests of the United States in ways that reduce environmental pressures on other parts of the world. Then, we must prove that any treatments we propose will make the situation better, not worse. If people do not believe there is a problem, they do not believe there is a need for a solution.

Adjusting our management to meet these needs should be enough to keep everyone busy for a long time. For this week, though, let's make the most of an opportunity for some calm reflection and debate on the issue of forest health. We have a number of very knowledgeable speakers scheduled, so let's learn all we can from them. We also have many years of experience represented by the people in this room. Let's take the opportunity provided by this session to talk to each other and share these experiences. We can learn a lot from each other.

Above all, let's relax, learn all we can, and have a pleasant week in a beautiful setting.

Forest Health From Different Perspectives

T. E. Kolb, M. R. Wagner, and W. W. Covington[1]

Abstract.—Forest health is an increasingly important concept in natural resource management. However, definition of forest health is difficult and dependent on human perspective. From a utilitarian perspective, forest health has been defined by the production of forest conditions which directly satisfy human needs. From an ecosystem-centered perspective, forest health has been defined by resilience, recurrence, persistence and biophysical processes which lead to sustainable ecological conditions. Definitions and understanding of forest health are also dependent on spatial scale, with increasing ambiguity associated with increasing land area and numbers of trees.

INTRODUCTION

The term "forest health" is being increasingly used in the context of forestry and natural resource management. For example, the term has been the subject of several recent articles (e. g., Smith 1990, Burkman and Hertel 1992, Kessler 1992, Haack and Byler 1993, Sampson and Adams 1994) and a recent Society of American Foresters task force report, "Sustaining Long-Term Forest Health and Productivity" (SAF 1993). Forest health is also increasingly used in government mandates concerning forest management. For instance, the "Forest Ecosystems and Atmospheric Research Act of 1988" mandated the USDA Forest Service to develop surveys to monitor long-term trends in the health of forest ecosystems (see Burkman and Hertel 1992). Moreover, under new federal forest management operating philosophies, such as ecosystem management, forest health has emerged as a central objective for the desired future condition of forests that replaces, to some extent, management for sustained commodity output (USDA 1993a, SAF 1993).

Despite its widespread use, the term "forest health" is frequently used without a clear definition, making its application to forest management difficult. In cases where the term has been defined

(e. g., McIntire 1988, Monnig and Byler 1992, USDA 1992, 1993a), alternative definitions and viewpoints of forest health have not been thoroughly discussed (however, see O'Laughlin et al. 1994). We feel that the overall concept of forest health needs to be more thoroughly examined given its growing use and importance as a management objective. Like it or not, foresters and other natural resource professionals are currently, and will continue to be, participants in public debates over land management where health analogies and metaphors are used. The potential for miscommunication in such debates is great. In fact, we believe that miscommunication about forest health is common in discussions between parties which have very different expectations from the forest. Therefore, it is essential that common definition and conceptual understanding of forest health be agreed upon each time it is introduced into the discussion. Moreover, the need for clarity is of considerable importance given that a healthy forest is viewed as a desired future condition and maintenance of forest health is viewed as a constraint that may limit forest uses on public lands in the future.

In this paper, we discuss different definitions of forest health, problems in scaling the concept of health from individuals to ecosystems, and the relationship between forest health and pest management, often using southwestern ponderosa pine, *Pinus ponderosa* var. *scopulorum*, forests as an example. A central point of this paper is that

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ambiguity should be minimized by defining the term when it is used, or at least by discussing the concepts included in the term.

FOREST HEALTH DEFINITION

Aldo Leopold

Although forest health is a relatively new term in forestry, notions of land health have existed for millennia (Norton 1991, Callicott 1992). Most contemporary views of forest health stem from the writings of Aldo Leopold (Leopold 1949, Callicott and Flader 1992). In several of his essays, Leopold decried widespread symptoms of land "sickness," such as reductions in vegetation cover and ensuing soil erosion, resulting from land abuse. He argued for the practice of land health in which practitioners would seek to maintain the sustainability of ecological conditions and processes by conserving the ecological integrity or coevolved diversity of the land. Leopold supported the restoration of sample native ecosystems present before industrialization of the American landscape. These restored areas were to serve both as laboratories and as standards for comparison in his practice of land health (Flader 1974).

Utilitarian Perspective

More recent definitions of forest health range between utilitarian (anthropocentric) and ecosystem (ecocentric) perspectives. The utilitarian perspective emphasizes forest conditions which directly satisfy human needs, while the ecosystem perspective emphasizes the maintenance sustainable ecosystems over the landscape. From a utilitarian perspective, a desired state of forest health can be considered "a condition where biotic and abiotic influences on forests (pests, pollution, silvicultural treatments, harvesting) do not threaten management objectives now or in the future" (McIntire 1988, USDA 1993a). That is, a forest is considered to be healthy if management objectives are satisfied, and unhealthy if they are not.

"Consistency with objectives" is a theme common to both utilitarian and ecosystem definitions

of forest health. Failure to meet objectives, stated by either human uses or ecological conditions, indicates an unhealthy forest. The utilitarian perspective is perhaps more deeply rooted in the "consistency with objectives" theme in that pests are traditionally defined as organisms that interfere with intended uses of forests (Barbosa and Wagner 1989). The "consistency with objectives theme" in forest health definitions has been criticized in the context of ecosystem management philosophy (Wagner 1994). On one hand, a healthy forest depends on meeting management objectives, while on the other hand, a healthy forest is a management objective according to recent ecosystem management philosophy. This results in circular logic and creates a paradox where a desired state of forest health depends on the occurrence of a healthy forest! Solutions to this paradox include removal of the "consistency with objectives" theme from forest health definitions or removal of forest health as an objective of ecosystem management.

The utilitarian definition implies that a healthy forest can be described by many standards. A single forest condition could be viewed as healthy from one perspective or use but unhealthy from another. For example, a common component in southwestern ponderosa pine forests is dwarf mistletoe, *Arceuthobium vaginatum* sbsp. *cryptopodum*. Dwarf mistletoe is well-known to reduce the growth of ponderosa pine (Beatty 1982) and increase mortality (Hawksworth and Geils 1990) and would be viewed as being unhealthy from the perspective of wood fiber production. However, abundance and species richness of birds is higher when dwarf mistletoe is present (Bennetts 1991) and the northern spotted owl nests in witches' brooms caused by mistletoe in Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, (Martin et al. 1992). Consequently from a perspective of bird species habitat and diversity, the presence of dwarf mistletoe may constitute a healthy condition. Thus, dependency on objectives can create obvious problems in generating a definition of forest health, particularly when land management objectives are not static.

The utilitarian perspective of forest health is especially appropriate for those situations where management objectives are unambiguous and consist of a small number of complementary

human uses. This situation is largely restricted to private industrial forest lands which emphasize the production of wood fiber, and wilderness areas which emphasize the preservation of natural processes (i.e., processes with minimal human influence). Application of the utilitarian definition of forest health to forest lands managed for multiple objectives, such as most of the National Forest System, is a problem because management for multiple objectives complicates the prioritization of objectives. Some authors have proposed a return to a land management philosophy that allocates land to categories of similar uses as a way to simplify the formulation of objectives and consequently the evaluation of forest health (Seymour and Hunter 1992, Wagner 1994).

Ecosystem Perspective

Difficulties in application of the utilitarian perspective of forest health to forest lands managed for multiple uses suggests the need for an ecosystem perspective of forest health that emphasizes basic ecological processes which characterize forest ecosystems whose presence on the landscape can be sustained over time scales of at least many decades. Some examples of forest health definitions from the ecosystem perspective are: "a forest in good health is a fully functioning community of plants and animals and their physical environment," and "a healthy forest is an ecosystem in balance" (Monnig and Byler 1992). These examples provide a starting point for thinking about forest health from an ecosystem perspective. Terms such as "balance" and "fully functioning" are effective in steering our thoughts towards ecosystem characteristics which appeal to many segments of the public, especially those who believe that nature has an inherent equilibrium, or balance. Unfortunately, most ecologists agree that ecosystems tend to be chaotic in behavior, and not "in balance," especially when viewed over long time periods.

Other ecosystem definitions of forest health include the idea of resilience. For example "a healthy forest is one that is resilient to changes.." (Joseph et al. 1991), "the term forest health denotes the productivity of forest ecosystems and their ability to bounce back after stress" (Radloff et al. 1991), or "forest health can be defined as the ability

of a forest to recover from natural and human-caused stressors" (USDA 1992). A related idea is that a healthy forest is persistent on the landscape and recurs following disturbance (Botkin 1994).

While we agree that resilience to dramatic change at the landscape level may be a desired component of a healthy forest, measuring the degree of resilience of a forest is difficult. Although lack of resilience is evident a posteriori when a forest has been significantly altered by stress or disturbance, the a priori presence of resilience is difficult to quantify, especially in the absence of detailed monitoring of physiological and ecological characteristics which promote recovery following stress or disturbance. In other words, we really don't know the degree of resilience of a forest until it has been exposed to and changed by stress or disturbance. Resilience is a useful ecological concept in the context of ecosystem health. However, difficulty in quantifying resilience suggests problems in its use in defining and measuring forest health.

A more useful definition of forest health from an ecosystem perspective should include specific types and rates of ecological processes and numbers and arrangement of structural elements that lead to and maintain diverse, productive, forest ecosystems. This perspective is based on a mechanistic view of forest ecosystems where important ecological processes would be identified and objectively measured to assess the health of the system. An example is given by Haskell et al. (1992) who offer that a healthy ecosystem should be "free from distress syndrome." In this context, "distress syndrome" of an ecosystem is characterized by the following group of symptoms (Rapport 1992): reduced primary productivity, loss of nutrient capital, loss of biodiversity, increased fluctuations in key populations, retrogression in biotic structure (a reversal of the normal successional processes whereby opportunistic species replace species more specialized in habitat and resource use in the absence of severe disturbance), and widespread incidence and severity of disease. Unfortunately, quantitative information on rates of essential ecosystem processes, such as net primary productivity, nutrient cycling, or decomposition, and structural characteristics, such as snags and landscape corridors, that create and maintain diverse, productive, sustainable forest ecosystems

is presently not available for many regions. This type of information may be available for some forest types in the future if efforts like the Environmental Monitoring and Assessment Program, administered by the US. Environmental Protection Agency, are adequately supported for at least the next several decades.

Of course, there are potential problems with this highly quantitative approach to defining and measuring forest health. One problem is the identification of threshold rates of important ecological processes which lead to degraded resource conditions. In most cases, knowledge of the "normal" range of temporal and spatial variation for rates of important ecological processes is lacking. Specification of "normal" rates and trajectories of succession is a problem in some regions. Techniques for understanding ranges of variability in ecosystem structure and processes in past times are being developed (Morgan et al. 1994). However, the degree to which these techniques can be used to determine past levels of all important ecological processes is uncertain. Some have suggested a pre-European settlement baseline of range of variability for pine-dominated forests which evolved under the influence of frequent, low-intensity fires (e.g. Monnig and Byler 1992). Whether a baseline patterned after pre-European settlement or other past forest conditions is appropriate for other forest types is unclear.

Another potential problem with the quantitative approach to defining and measuring forest health is the cost. Despite the public's willingness to support environmental protection in surveys, some of this apparent support may diminish when it is time to actually pay for this level of research and monitoring. Given our current knowledge of ecosystem ecology, long-term support for forest health research and monitoring will be required in order to implement a highly quantitative approach to defining and measuring forest health. Such an approach could yield scientifically defendable data on the health of forest ecosystems if previously identified problems could be surmounted.

In the absence of detailed quantitative information on desired rates of ecosystem processes, present definition of forest health from an ecosystem perspective should at least include qualitative statements of the types of processes, structures,

and resources needed to support productive forests in the sense of satisfying at least some of society's objectives. For example, we consider a healthy forest ecosystem to have the following characteristics:

1) the physical environment, biotic resources, and trophic networks to support productive forests during at least some seral stages;
2) resistance to dramatic change in populations of important organisms within the ecosystem not accounted for by predicted successional trends;
3) a functional equilibrium between supply and demand of essential resources (water, nutrients, light, growing space) for major portions of the vegetation; and
4) a diversity of seral stages, cover types, and stand structures that provide habitat for many native species and all essential ecosystem processes.

Specification within these four criteria allow for definitions of forest health which span the gap between landscapes which are natural, e. g. near pristine (i.e., pre-industrial or presettlement characteristics) and landscapes which are artificial, e. g. intensively managed for industrial uses.

We believe that a useful ecosystem concept of forest health must consider patterns and rates of change in forest composition and structure, or succession. This recognition of the temporal variability of forest vegetation was noted by Leopold (1949) who offered that "health is the capacity of the land for self-renewal." Thus, a definition of forest health must consider the capacity for forest replacement within the timespan of succession. Acceptable rates and patterns of forest replacement following disturbance will vary widely among different ecosystems and climatic regions, but should reflect historical rates and patterns to the extent that these rates and patterns sustain desirable ecosystems. For example, a long succession to forest cover following disturbance is not necessarily an indication of poor forest health if slow succession is a historical characteristic of the ecosystem because of naturally harsh environmental conditions.

Our definition also recognizes that dramatic change in vegetation composition and structure

following stress or disturbance is inevitable over portions of a landscape. For example, small openings in the canopy are common due to root disease, windthrow, and other factors. Such openings are not necessarily unhealthy because they can increase availability of resources to understory vegetation and tree regeneration and may enhance values such as wildlife habitat and aesthetics. However, dramatic change may be undesirable when it occurs at scales other than those experienced over the recent evolutionary development of an ecosystem. For example, many ecologists believe that fire suppression activities in the western United States have led to the development of dense, homogeneous conifer stands over widespread areas (e.g. Covington and Moore 1994). This is very different than the mosaic of stand ages, structures, and species mixtures which were likely maintained by fires prior to Euro-american settlement. Widespread, dense stands are particularly prone to attack by bark beetles and other biological agents which colonize heavily stressed trees.

The emphasis in our definition of forest ecosystem health on the balanced availability of resources for portions of the vegetation, instead of all the vegetation, recognizes succession as a process which can occur, at least in part, because of changes in resource supply to components of the vegetation. For example, the emergence of late-successional species is partially a consequence of the decline of early successional species resulting from their failure to acquire resources at levels sufficient to meet their high nutritional and metabolic demands. In other words, there are winners and losers when plants are competing for resources in a healthy forest. Thus, we should not automatically assume that all instances of decline by a single species, or groups of species with similar ecological characteristics (i.e., early successional or pioneer types), reflect poor forest health. Evaluation of forest health must be made within the context of successional processes and ecosystem dynamics.

THE PROBLEM OF SCALE

Much of the current ambiguity about forest health has arisen because of attempts to take a concept developed at the individual organism level and elevate it to describe a landscape process. Most dictionary definitions of "health" emphasize the condition or functioning of a single organism. Extension of this concept to a complex system, such as a forest, is based on the analogy between the functioning of an organism and an ecosystem. Kessler (1992), for example, makes an analogy between the health of a human and the health of a forest. This type of analogy is based on the Clementsian concept of community ecology (Clements 1916) where the ecosystem is viewed as a superorganism. Despite the apparent usefulness of the superorganism analogy for describing the status of ecosystems, Clementsian concepts have been discarded by most contemporary ecologists and thus are not recommended for discussions of forest health.

There are other problems with the use of the term "health" to describe the status of ecosystems (Ehrenfeld 1992). From a scientific perspective, it is difficult to determine a normal state for communities whose characteristics are often in flux because of disturbance. From a practical perspective, attempts to define health in rigorous scientific terms may diminish its present value as an intuitive, general concept. In fact, Ehrenfeld (1992) concluded that health is not a valid ecological concept, but does have value in communication between scientists and non-scientists regarding the production of values by ecosystems. Although the limitations of the term suggest that it should not be used in a rigorous ecological context, it is likely that "health" will continue to be used to describe and mandate management objectives for forests.

Health has been applied to forest ecosystems at several scales ranging from an individual tree to landscapes. The concept becomes more ambiguous with increasing complexity of the system to which it is applied. One definition of health, "absence of disease" (Haskell et al. 1992), actually leads to a precise definition for an individual tree because disease can be defined as a "deviation in the normal functioning of a plant caused by some type of persistent agent" (Manion 1991). Forest pathology is a long-standing discipline in forestry that some refer to as "the study of tree health" (Tattar 1978). In this context the health of a tree can be evaluated by such indicators as crown condition, growth rate, and external signs of disease-causing agents. A dead or dying tree is not healthy.

The health of a stand is complex and must consider many more dimensions than the health of a tree. The health of a stand relates to the management objectives for that stand (utilitarian perspective) and to the long-term functioning of the organisms and trophic networks which constitute the stand (ecosystem perspective). Tree mortality in a stand would not indicate an unhealthy condition as long as the rate of mortality was not greater than the capacity for replacement. Stand objectives such as wildlife habitat, soil and water protection, and preservation of biodiversity do not require a healthy condition for all trees in the stand. A dead tree is not healthy, but it may be part of a healthy stand! The health of a forest ecosystem (i.e. large watershed or landscape) is more complex than the health of a stand. The health of a forest ecosystem depends both on society's objectives for the forest (utilitarian perspective), and upon the interaction of biotic (including humans) and abiotic processes that produce the range of habitats required for continued existence of native species (ecosystem perspective).

A NEED FOR SIDEBOARDS

There is a clear need to place bounds on the concept of forest health. Many forest pest management specialists think of themselves today as forest health specialists. For example, the USDA recently formed a "National Center of Forest Health Management." The current emphasis of the center is on the development of pest management strategies and technologies (USDA 1993b). However, based on our definition of forest health, forest health specialists would require broad training in physiology, ecology and ecosystem science. Traditional pest management has primarily focused on the influences of insects and diseases on commodity outputs. The role of insects and diseases in ecological processes is frequently less emphasized in the traditional education of pest specialists, although entomologists and pathologists are not without appreciation for the ecological role of these organisms (Haack and Byler 1993, Clancy 1994, Schowalter 1994). We suggest restricting the term "forest health" to the examination of the role of biotic and abiotic agents in ecosystem level processes. Pest management would then be a sub-

discipline of forest health with an emphasis on the influence of biotic and abiotic agents in the production of commodity outputs. Entomologists and pathologists would continue and hopefully increase their examination of the role of insects and diseases in ecosystem-level processes.

EVALUATING FOREST HEALTH— SOUTHWESTERN PONDEROSA PINE FORESTS

Given our definition of a healthy forest ecosystem, when is a forest considered to be unhealthy? The type of thinking needed to answer this question can be illustrated by using ponderosa pine forests in the southwestern United States as a case study. To address this question, we refer to the four essential elements in our definition of forest ecosystem health: 1) physical and biotic resources to support forest cover; 2) resistance to dramatic change; 3) functional equilibrium between supply and demand of essential resources; and 4) diversity of seral stages and stand structures. The physical and biotic resources are presently in place to support ponderosa pine forests in most areas of the Southwest that have historically supported them, except perhaps some riparian sites. Using this criterion, our ponderosa pine forests are probably healthy. However, for the other three criteria, it would be difficult to argue that we have a healthy forest.

A significant threat of dramatic change in forest composition and structure at the landscape level exists in much of the southwestern ponderosa pine forest due to pine bark beetles, *Dendroctonus* spp., *Ips* spp. These insects are well-known to reach outbreaks when forest stand density exceeds the carrying capacity of the site (Sartwell and Stevens 1971, Barbosa and Wagner 1989). Conditions are very favorable for pine bark beetle in northern Arizona and "it is probably only a matter of time before another large outbreak occurs" (Wilson and Tkacz 1994). Tree mortality associated with widespread bark beetle outbreaks often increases the risk of severe, stand-replacing wildfire over large areas.

Present high stand density and forest floor accumulations in many southwestern ponderosa pine forests compared with presettlement condi-

tions (Covington and Moore 1992, 1994) has increased the destructive potential of wildfires to the degree where there is a significant risk of eliminating forest cover at the landscape level. These factors have also created an imbalance between demand and supply of water, nutrients, and growing space for major portions of the vegetation (Covington and Sackett 1986, unpublished data on file with T. E. Kolb in the School of Forestry, Northern Arizona University), especially herbaceous vegetation (Covington and Moore 1994). Nutrient cycling rates are likely low because of fire exclusion and the lack of compensating factors such as microbial decomposition. This creates a situation in which large nutrient reserves are found in forest floor material in a form unavailable to plants (Covington and Sackett 1990).

The relatively homogeneous nature of the southwestern ponderosa pine forest does not provide a balanced diversity of seral stages, cover types, and stand structures. Underrepresented types include native prairie vegetation, tree regeneration, and old growth (USDA 1993c). Forests tend to be evenaged with a dense, uniform canopy and little recent regeneration. These dense stand conditions were created by past grazing practices, fire exclusion, and other environmental conditions favorable for pine establishment in the early part of this century. Thus, many southwestern ponderosa pine forests fail to meet three out of the four criteria needed to satisfy our ecosystem definition of a healthy forest.

FOREST HEALTH SUMMARY

Although there are problems with the use of health concepts to describe the complex array of factors that influence ecosystems, the growing use of the term demands that natural resource managers understand health issues. It is also important to recognize that one's view of a healthy forest may vary considerably between utilitarian and ecosystem perspectives, as well as over spatial scales. One solution to the present dichotomy which exists between utilitarian and ecosystem-centered definitions of forest health is to combine elements of both viewpoints into a single definition. For example, O'Laughlin et al. (1994) offer that "forest health is a condition of forest ecosystems that sustains their complexity while providing for human needs."

Moreover, the ecosystem perspective of forest health is not necessarily in conflict with the utilitarian perspective if both are applied to large landscapes composed of a mosaic of different stand ages, structures, and levels of management intensity appropriate for satisfying the range of demands placed on the landscape by society. Satisfaction of these demands will require maintenance over the landscape of many native species and all of the ecosystem processes that ultimately provide resources and habitat for their survival.

Current forest health problems were caused by past lack of understanding of the importance of disturbance in forest ecosystems and poor understanding of public values by forest managers. Forest health problems certainly exist in areas in the western United States where conditions have been altered over the past several decades by concentrated harvesting of early successional species or fire exclusion in fire-adapted ecosystems (McIntire 1988, Covington and Moore 1992, Wickman 1992, O'Laughlin et al. 1993, Covington and Moore 1994, Covington et al. 1994). However, we believe that present concerns over forest health also reflect failures in defining management objectives that are acceptable to society. In the absence of well-defined and widely publicized objectives for forest management which reflect the diversity of values held by society, forest health will continue to be a concern even with dramatic breakthroughs in our scientific understanding of forest ecosystem processes. On the other hand, public expectations must be tempered with the understanding that, in many cases, the range of values potentially delivered by forests is limited by biological constraints to insure sustainable forest ecosystems. Forest scientists and managers are obligated to clearly communicate these biological constraints to the public. In the current political system of the United States, identification of priority objectives for forest management within these biological constraints is a public decision which is often difficult and tedious and thus rarely achieved.

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Fire in the Forest

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Abstract.—From ancient philosophies to present day science, the ubiquity of change and the process of transformation are core concepts. The primary focus of a recent white paper on disturbance ecology is summed up by the Greek philosopher Heraclitus who stated, "Nothing is permanent but change." Disturbance processes, such as fire, provide a window into the emerging world of nonequilibrium theory. In contrast to a steady state view of the world, nonequilibrium theory asserts that biological communities are always recovering from the last disturbance. Disturbance is somewhat of a misnomer, connoting disruption of an equilibrium. Disturbance is about death and rebirth, the continuous process of renewal. Incorporating the process of renewal and transformation is the key to creating healthy forests and effective organizations. The process of continuous renewal in organizations is embodied in the concept of learning organizations. Building shared vision is one of the cornerstones of a learning organization and is the first step to incorporating disturbance ecology in land management practices.

INTRODUCTION

This setting for the 1995 National Silviculture Workshop, the Inn of the Mountain Gods, has a special meaning in the history of fire. Hominids first used fire some 1.4 million years ago. The primordial use of fire was not for heat or light, but for religious ceremony. According to Joseph Campbell (1972), fire may well have been the first enshrined divinity. Neolithic people acquired reliable fire-making techniques around 7000 BC. Since then, native peoples have touched virtually every corner of the world with their firesticks. Around the world, native people tell remarkably similar stories of how humans came to possess and use fire. The stories usually involve the theft of fire from mountain gods with the aid of a trickster/hero and a relay to pass fire from one to another (Campbell 1959). The trickster/hero has taken a variety of forms: for the Thompson river Indians of British Columbia, the trickster was Coyote; for the Creek Indians of Georgia and Alabama, Rabbit; for the Chilcotin, Raven; and for the Andamanese of

the remote islands in the Bay of Bengal, Kingfisher. In Polynesia the trickster/hero was Maui, in many parts of Africa, Anansi, while for the Germanic tribes, it was Loki; and for the Greeks, Prometheus.

In mythology, fire has often been linked with birds. My sole visual aid today depicts the phoenix (feng-huang in China), a universal symbol of death and rebirth, which is what disturbance ecology and hence this paper is all about.

Does anyone recall what the first national conference held by the Forest Service was about? The first national conference, the Mather Field Conference of 1921, arranged by Chief Greeley, was about fire. The decade preceding this conference was marked by the controversy between advocates of light burning and advocates of fire protection/suppression. Fire control and light burning were viewed as an either/or proposition. As a result of the Mather Field Conference, the protectionist policies formulated by Coert duBois, Stuart Show, and E.I. Kotok became dominant. Fire historian Stephen Pyne (1982) notes, "The intellectual and practical success of the conference marked the beginning of a national extension of systematic fire protection methods and the beginning of the end for light

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burning." Yet, light burning was never completely extinguished (Schiff 1962). As I look over the agenda for this workshop, I am hopeful that this national meeting will contribute to the resurrection of light burning and, thus, the integration of aesthetic and utilitarian doctrines. In the April 1920 issue of Sunset magazine then Chief of the Forest Service, Henry S. Graves, wrote "Torch in the Timber," an article denouncing light burning and advocating protectionist policies. Today, I present this paper, "Fire in the Forest," a testimonial to the fundamental importance of incorporating disturbance processes, such as fire, in our thinking and our management practices.

DISTURBANCE AND FIRE

The Directors of Forest Fire and Atmospheric Sciences Research, Fire and Aviation Management, Forest Pest Management, and Forest Insect and Disease Research recently chartered a team to develop a white paper on disturbance processes and ecosystem management. (The paper is available on Internet at the Forest Service home page site - http://www.fs.fed.us). The intent of the white paper is to broaden awareness of the role and significance of disturbance in ecosystem dynamics and resource management. The primary focus of the paper is summed up by the words of the ancient Greek philosopher Heraclitus, "Nothing is permanent but change."

Heraclitus emphasized the connection between all things, including opposites. For him, fire was the primal element, the essential material uniting all things. Ancient China developed similar concepts embodied in the symbol of Yin and Yang. Yin and Yang express a cyclical theory of change, of becoming and dissolution and an interdependence between the world of nature and the events of man. Yin and Yang literally mean dark side and sunny side of a hill, which has definite implications to the way fires burn. Perhaps the ancient Chinese created the first symbol of disturbance ecology.

The white paper is not a state-of-the-art summary on disturbance ecology. Yet, the paper acknowledges the increasing importance of nonequilibrium theory in the science of ecology. Equilibrium theory has long dominated ecological

thought and public policy. This theory asserts that systems are at equilibrium—in a steady state, with overall species composition and relative abundance stable through time—as a result of biotic interactions among its members. These systems return to their original structure after disturbance. The very word disturbance is somewhat of a misnomer, connoting disruption of an equilibrium. Disturbance is about death and rebirth, the continuous process of renewal. Nonequilibrium theory asserts that biological communities are always recovering from the last disturbance (Reice 1994). Not only are all ecosystems (aquatic as well as terrestrial) disturbed, but most are disturbed frequently relative to the life history of the dominant species. Even apparently pristine, remote rainforests are often recovering from the last disturbance. Paleoecological data (pollen and phytoliths of Zea mays, and charcoal from grass fires found in lake/swamp sediment cores) from remote regions of seemingly untouched neotropical wildernesses demonstrate a 4,000 year history of human disturbance. (Bush and Colinvaux 1994).

Yes, disturbance is ubiquitous. For example, around the world, the dominance of pine and oak forests of virtually all species and in virtually all regions is due primarily to fire (Spurr and Barnes 1980). We often recognize the important role of fire in ponderosa and jeffrey pine forests in the West, longleaf and slash pine forests in the South, aspen and lodgepole pine forests in the Rocky Mountains, giant sequoia in the Sierra, redwood forests on the Pacific Coast, jack pine forests in the Lake States, dry sclerophyll forests in Australia, and savannas around the world. Yet, fire has also played a critical role in the development of areas we do not typically associate with fire: heathlands and moors of Western Europe and the British Isles, the mixed hardwood forest complex of the Eastern United States (particularly oak on dry sites), boreal forests of North America and Eurasia, taiga and tundra of the frozen North, and swamps, bogs, marshes, and prairies of the world. The consequences of failing to recognize the importance of disturbance processes can be dramatic. The highest mammal extinction rate in the world occurs in the spinifex grasslands of Australia where the fire regime has changed from frequent aboriginal

burning to infrequent burning (Gill and Bradstock in press).

Nonequilibrium theory is also interwoven into the science of complexity and the study of complex adaptive systems, a collective designation for nonlinear systems defined by the interaction of large numbers of adaptive agents (Waldrop 1992). An ecosystem is a prime example of a complex adaptive system. Each ecosystem is a network of many agents (biological, chemical, physical) acting in parallel in an environment produced by its interactions with the other agents in the system. Agents are constantly acting and reacting to other agents; thus, change is constant. Complex adaptive systems are continually unfolding and in transition. To cope with constant change, developing optimum strategies becomes problematic. The most we can do is continuously improve. Prediction, feedback, and learning; i.e. adaptive management (Holling 1978, Lee 1993, Walters 1986, Walters and Holling 1990), are not optional, they are essential to developing strategies that work in an environment of constant change.

So the question becomes, how do we incorporate the ideas of disturbance and nonequilibrium theory into management practices. To find the answer, we must look at organizational development and its current focus on learning and transformation.

TRANSFORMATION AND MANAGEMENT

Just as disturbance processes are central to functional ecosystems, the process of renewal/transformation is central to functional organizations and may be the single most important challenge facing organizations today. Transformation is the result of learning. Consider the case of 3M. Two of 3M's core competencies are innovation and the ability to transform itself. Livio DeSimone, chairman and CEO, believes that 3M's philosophy is the fundamental reason the company can renew itself continuously: "Senior management's primary role is to create an internal environment in which people understand and value our way of operating. . . . Our job is one of creation and destruction—supporting individual initiative while breaking down bureaucracy and cynicism. It all depends

on developing a personal trust relationship between those at the top and those at lower levels" (Bartlett and Ghoshal 1995). Creation and destruction . . . sounds a lot like disturbance ecology.

Shared Vision

The process of continuous renewal in organizations is embodied in the concept of learning organizations (Argyris 1990, Argyris 1993, Argyris and Schon 1978, Senge 1990, Senge et. al. 1994). Building shared vision is one of the cornerstones of a learning organization and many authors have noted the importance of vision in all of today's organizations (Block 1986, 1993; Covey 1989, 1990; Covey, Merrill and Merrill 1994; Fritz 1984; Greenleaf 1970; Senge 1990; Senge et. al. 1994; Wheatley 1992).

I would like to take a minute to share my vision for the restoration of short-interval fire adapted ecosystems on National Forest lands. I see open stands of large pine trees (for example, longleaf pine in the Southern Coastal Plain, ponderosa pine in the West), lush native bunchgrasses and a carpet of wildflowers. There are clumps of regeneration. I smell the pine and wildflowers. I hear the birds—songbirds, hummingbirds, woodpeckers, and raptors. There is a great diversity of life especially in the understory. The midstory is sparse. If I look closely, I can see evidence of "no trace" logging. Fire is an integral part of this forest. So at times, I can feel the heat of the gentle fire and smell the smoke as it quietly disperses. Aldo Leopold (1949) defined land health as a vigorous state of self renewal. Here is a healthy forest, dynamic and changing. It has economic value (wood products, forage, recreation), biological diversity, and yes, aesthetic and spiritual value. It has utilitarian and aesthetic value, too often in conflict and seen as an either/or proposition in today's world. It is time to get off the utilitarian-aesthetic see-saw, for a lot of energy is spent on a see-saw going nowhere.

The purpose for sharing my vision with you is NOT to convince you to adopt my vision, although I suspect we have a lot in common. My purpose is twofold: first, to provide an example that illustrates the characteristics of a "well-formed" vision; and second, to emphasize the need to start building shared vision. It is not so much what the vision

is, as what it does (Kiefer and Senge 1984). Vision catalyzes alignment wherein people operate as an integrated whole.

A well-formed vision has at least seven characteristics. First, it is an end result, not a process. Second, it is a desire, not an obligation. Third, it is specific. To state the obvious, a vision should be capable of being seen. Thus, the vision must be specific enough so you know it when you see it. Fourth, it is not avoiding or ridding yourself of something unwanted. Fifth, it is not limited by what you think is possible. Sixth, it is in present tense. Seventh, it has nothing to do with being number one. Focus on good work, not on standings or recognition.

If you haven't gone through one of these exercises, you might take a couple of minutes now to begin the process. Relax, close your eyes if you wish, and get quiet. Ask yourself, "what do I really want?" Develop a picture that you can see. Does your vision contain the seven characteristics of a well-formed vision?

Building shared vision is not about top management going on a retreat to develop a vision statement and then selling it to the rest of the organization. Building shared vision is not a top-down process. It is a top-down and bottom-up process that is highly participatory. All individuals need to develop and share their own visions. The act of sharing brings about greater meaning, clarity, and alignment. So that is my vision, what's yours? And what are the public's visions of future forests? Developing the desired future condition in the forest planning process should include building shared vision with our partners and our adversaries. This is an extremely critical task, and we need to do a better job with it. For example, we could employ the techniques of dialogue (Isaacs 1993a, 1993b). As Margaret Wheatley states, "We need to be able to trust that something as simple as a clear core of values and vision, kept in motion through continuing dialogue, can lead to order" (Wheatley 1992).

Consider the experience of Shell Oil Company as described by Phillip Carroll, president and CEO:

"We began our transformation through a process designed to create a mission, vision, and values powerful enough to engage the minds and hearts of all 22,000 people in the corporation. The process—which is ongoing—encourages people to share their ideas about who we are, who we want to be, and where we fall short of those aspirations. The emerging dialogue from this process is producing a valuable dissonance that forces people to look deep within themselves and discover their personal visions for the company. This is important, since our transformation will not be complete until the personal visions of all our people converge into one collective vision." (Carroll 1995)

Current Reality

To create effective change, an accurate description of current reality is needed in addition to a shared vision. The creative process (Fritz 1984) requires a vision of a desired result and a clear and honest view of current reality. The discrepancy between the two provides a tension that seeks resolution. That tension is the energy that enables creation. When developing vision and examining current reality, we must consider disturbance processes. Our information systems for assessing and reporting current reality need work. We currently have anecdotal reports on the loss of longleaf pine communities, the loss of ponderosa pine communities, the loss of aspen communities, and increasing stand densities (where once there were 20–25 trees per acre, there are now 800–1200 trees per acre). We do not have an annual report on the state of the health of the National Forests but we are working toward that end.

CONCLUSION

Alvin Toffler calls these times of turbulent change, "the hinge of history" (Toffler 1990). Indeed, we have witnessed many paradigm shifts. In science we have gone from the age of Newton and an obsession with reductionism to the age of quantum mechanics, chaos, and complexity. In organizational development, we have seen a shift from Frederick Taylor's concept of "scientific management" to the ideas of "quality" (as expressed by Deming, Juran, Fiegenbaum, and others), and the "learning organization" (as expressed by Argyris, Senge, and others). In ecology, we have moved from the ideas of Clementsian

succession and equilibrium theory to a recognition of the ecology of patch dynamics and the importance of disturbance-recovery regimes in nonequilibrium theory. Several consistent themes are inherent with each of these new ideas ushering in the Tofflers' (1994) third wave. Chief among them are: constant change, nonequilibrium, and continuous transformation through learning. At a fundamental level, disturbance in ecosystems and learning in organizations are closely linked by the concepts of death, rebirth, and transformation.

Finally, I'd like to spend a minute on the importance of core competencies to organizations, especially during times of change (Nevis et. al. 1995, Prahalad and Hamel 1990). After the Mather Field Conference, fire suppression became a core competency of the Forest Service. Chief Forester Henry Graves declared in 1913 that "the necessity of preventing losses from forest fires requires no discussion. It is the fundamental obligation of the Forest Service and takes precedence over all other duties and activities." Chief William Greeley's autobiography begins with recollections of the 1910 fires and the statement, "fire prevention is the No. 1 job of American foresters." He openly professed that he considered "smoke in the woods" as the yardstick of progress in American forestry (Pyne 1982). During these times of organizational change, it is important to re-examine, re-establish and foster our core competencies. I suggest that disturbance ecology in general and the use of prescribed fire in particular be considered core competencies of the agency. Prescribed fire is one of the most powerful tools available for the silviculturist, the range manager, the wildlife biologist, and the wilderness manager. Prescribed fire is desperately needed to restore the health of the long-needle forests and other fire-adapted communities.

Perhaps it is time once again to consider "smoke in the woods" as a primary yardstick of progress in American forestry. However, our challenge today is to increase the amount of prescribed fire (conservative estimates are by a factor of 10) while minimizing the negative impacts of smoke. Healthy, productive ecosystems and clean air are important to our society. We can do both.

And perhaps it is time to once again steal fire from the mountain gods and through a great relay, bring fire and the message of disturbance ecology back to the modern-day people of the world. And perhaps one day, the Phoenix will replace smokey bear as the defacto symbol of the Forest Service.

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Disturbance in Forest Ecosystems Caused by Pathogens and Insects

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Abstract.—Pathogens and insects are major driving forces of processes in forested ecosystems. Disturbances caused by them are as intimately involved in ecosystem dynamics as the more sudden and obvious abiotic disturbances, for example, those caused by wind or fire. However, because pathogens and insects are selective and may affect only one or several related species of trees, or the less vigorous or genetically unfit members within a species, the resulting patterns of disturbance may differ from those caused by abiotic factors. Pathogens and insects may cause disturbance through direct effects on the host species, interactions with abiotic disturbance agents, or interactions with each other. Pathogens and insects can act as ecosystem roguers of weakened trees and sometimes as scavengers, decomposing the killed trees and effecting the release of nutrients essential for ecosystem response. Responses of forests to disturbance by pathogens and insects can range from those that maintain the current domain of species composition, structure, and processes and interactions, and those that favor the development of more successionally advanced species, to those that result in significant changes in species composition, structure, and relationships. The first two responses often are associated with disturbances caused by native pathogens and insects, while the third response is more typical of that to exotic organisms. Pathogens and insects play major roles in ecosystem dynamics; understanding these roles is key to facilitating ecosystem management.

INTRODUCTION

Pathogens and insects are major driving forces of the disturbance process in forested ecosystems (Castello et al. 1995, Harvey et al. 1993). And disturbances caused by pathogens and insects are as intimately involved in ecosystem dynamics as the more sudden and obvious abiotic disturbance factors of wind and fire. White and Pickett (1985) define disturbance as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." Disturbance, then, releases resources that are bound in (nutrients) or restricted by size or structure (light, moisture, space) of aging biomass,

and makes them available for new growth by existing or replacement species.

Both abiotic and biotic disturbance agents effectuate the availability of these resources. However, because pathogens and insects are selective and may affect only one or a few related tree species, or the less vigorous or genetically unfit members within a species, the resulting patterns of disturbance may differ from those caused by abiotic factors (Castello et al. 1995).

DISTURBANCE-RESPONSE RELATIONSHIPS

Pathogens and insects may cause disturbance and subsequent response through direct effects on a host species, interactions with abiotic disturbance agents such as moisture and temperature extremes and air pollutants, or interactions with each other,

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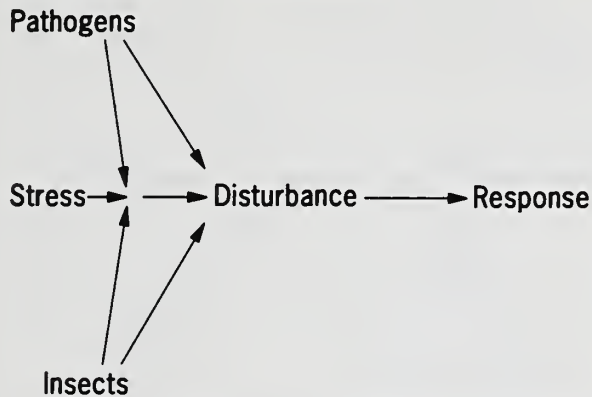
Figure 1.—Pathogens and insects cause disturbance to forest vegetation directly or through interactions with other abiotic stress agents.

Figure 2.—Response to disturbance by pathogens and insects can result in vegetation changes (response) that are highly susceptible to new pathogens and insects (new disturbance), resulting in different vegetation relationships (new response).

e.g., gypsy moth defoliation and Armillaria root disease (Wargo 1977, 1981) (fig. 1).

In some disturbance relationships, the pathogen or insect may illicit a response to the disturbance that results in an increase in susceptibility of the replacement species to other disturbance agents (fig. 2). An example of this relationship is the effect of white pine blister rust, caused by *Cronartium ribicola*, on western white pine, *Pinus monticola*, forests (Monnig and Byler 1992). In forests of the West, blister rust (the disturbance agent) has killed more than 90 percent of this species in infected stands and has led to major changes in species composition (the response to disturbance) in these forests. Douglas-fir, *Pseudotsuga menziesii*, is now the dominant species along with grand-fir, *Abies grandis*. Both are highly susceptible to Douglas-fir beetle and root disease (the new disturbance agents). Mortality in these stands from root disease occurs long before forest maturation, and the resulting "forests" are understocked root-diseased patches of brush and susceptible trees (the new response) (Monnig and Byler 1992).

DISTURBANCE REGIMES

Disturbance regimes are used to characterize the spatial and temporal patterns of disturbance and subsequent response of forest communities, i.e., death of dominant individuals in a forest canopy

and their replacement (Runkle 1985). Disturbance regimes and response, as indicated by mortality and regeneration, reflect the temporal and spatial distribution of disturbance and its relationship to geographic, topographic, environmental, and plant community gradients or patterns (White and Pickett 1985). Occurrences of disturbance are measured over time: frequency, the mean number of events per time period, is used to express the probability of an event occurring in any given year; return interval (cycle or turnover time) is the mean time between disturbances. Disturbances also vary in intensity. For physical disturbance, this is equivalent to the physical force per area per time; for biological disturbances such as those caused by pathogens and insects, it is closely related if not equivalent to population or inoculum levels. Severity of the disturbance is described as its effects on the organism community or ecosystem, and usually is measured in numbers of trees killed, basal area lost, or biomass destroyed. Host susceptibility has a major influence on severity of disturbance caused by pathogens and insects. Intensity and severity determine the magnitude of the disturbance and consequently the response to it.

The attributes of disturbance regimes, spatial and temporal distribution, frequency of occurrence, and magnitude of disturbance and subsequent response, are influenced by a number of factors (fig. 3). For pathogens and insects, these attributes depend on the whether the host-organ-

Attributes	Modifiers
Spatial Distribution	Native or Exotic
Temporal Distribution	Inoculum Potential
Frequency	Population Dynamics
Magnitude	Susceptible Populations
	Forest Maturation

Figure 3.—Attributes of disturbances regimes and factors that modify the magnitude of disturbance by pathogens and insects.

Figure 4.—Disturbance by pathogens and insects can result in responses that maintain current vegetation, promote successional change, or cause major vegetational changes in forest ecosystems.

ism relationship is native or exotic, inoculum or population potential and rate of change, and age and distribution of the susceptible host.

RESPONSE TO DISTURBANCE

Several responses to disturbance are shown in figures 4 and 5. Actual response to disturbance by pathogens and insects depends on the stage of forest development (Oliver 1981) when disturbance occurs, and, of course, the particular organism. Certain pathogens and insects can operate only at specific stages of forest development and maturation, others function at several stages, and still others function only in mature forests that have been predisposed to attack by other disturbance agents. The relationship of forest development and pathogen-induced mortality is illustrated and discussed effectively in Castello and others (1995).

Resilient responses (sensu Holling 1973) are those that usually return to vegetation relationships extant at the time of disturbance (current domain). These resilient responses are typical of native organism/tree associations that have occurred over long periods (Amman 1977).

The interaction of lodgepole pine, *Pinus contorta*, fire, and mountain pine beetle, *Dendroctonus ponderosae*, (MPB) is an example of this relationship (Monnig and Byler 1992). Young lodgepole pine stands are resistant to MPB but they increase in susceptibility as stands mature. Eventually, beetle populations explode and, by mass attack, kill large

Figure 5.—Responses to pathogens and insects sometimes depend on whether the organism is native or exotic. Exotic organisms usually cause the greatest disturbance, which can result in the greatest change.

numbers of lodgepole pine. This mortality provides fuel for fires which recycle the dead trees and open cones for the deposit of seed on the exposed soil. These sites are regenerated as the interaction of fire and beetles create mosaics of lodgepole pine stands of different sizes, ages, and hence susceptiblities. However, fire suppression has affected this relationship and has created vast areas of uniformly susceptible stands that are devastated by massive beetle outbreaks on many of these sites. Later successional species that are typically removed by fire events are replacing lodgepole pine. These stands are not as resilient and probably will be replaced in response to future disturbances.

Another response to native organisms is one that promotes succession in forest stands. Shade-tolerant species in the understory grow into gaps created in the overstory by the selective killing of individual or small groups of trees. Such trees are killed by fungal root pathogens, stem cankers, and borers. In these relationships, gaps tend to be small and successful colonization of the gap is primarily by later successional shade-tolerant species. In forests already dominated by shade-tolerant, later successional species, small gap disturbance maintains these forest types, e.g., beech, *Fagus grandifolia*, and hemlock, *Tsuga canadenis* (Runkel 1984, 1985, Twery and Patterson 1984). Disturbances that cause large gap formation (> 400 m^2) allow less shade-tolerant, earlier successional species such as tulip-poplar, *Liriodendron tulipifera*, to colonize the gaps and become part of the canopy (Runkel 1985).

A third response to disturbance can be a major shift in species composition structure and relationships. This type of response can occur when aggressive native pathogens and insects are triggered to outbreak conditions and cause severe disturbance over fairly large areas.

In gaps created by aggressive root pathogens, such as *Armillaria ostoyae* in some interior western conifer forests, shifts in species composition from the susceptible pioneer species of Douglas-fir and lodgepole pine to the more disease-resistant and shade-tolerant western hemlock, *Tsuga heterophylla*, western redcedar, *Thuja plicata*, and subalpine fir, *Abies lasiocarpa* (Shaw and Kile 1991). Van der Camp (1991) referred to these relationships as "root-disease climaxes."

Disturbance from outbreaks of the southern pine beetle, *Dendroctonus frontalis*, also results in a shift from pine forests to hardwood forests as the pine dies (Schowalter 1985). However, the hardwood forests are fire intolerant. Fueled by the abundant dead wood, fire kills them and the forest composition reverts to pine. In the absence of fire, the forests shift to hardwood species (Schowalter 1981, 1985).

EXOTIC ORGANISMS

This third response is more typical of disturbance by exotic pathogens and insects that historically have caused intensive and severe distur-

bances over large areas (Haack 1993; Haack and Byler 1993) and which will continue to pose serious threats to forested ecosystems (Liebhold et al. 1995).

The effect of white pine blister rust on western white pine and the subsequent shift in species to Douglas-fir and true firs, as described earlier, (Monnig and Byler 1992) is another example of the severe effects of an exotic pathogen.

The chestnut blight fungus, *Cryphonectria parasitica*, has virtually eliminated American chestnut, *Castanea dentata*, from forests of the East, resulting in forests dominated by oak, *Quercus*, species (Stephenson 1986) that are highly susceptible to defoliation by the gypsy moth, *Lymantria dispar*, also an introduced insect. Indeed, the rate of spread and subsequent effects of gypsy moth probably are related significantly to the effects of the chestnut blight on the oak population.

The gypsy moth has caused considerable disturbance to the oak forests of the Northeast. Introduced to the eastern United States in the 1860's, it has spread southward through the predominantly oak forests of the Appalachian Mountain range. All American oak species are highly preferred food sources and, therefore, highly susceptible to defoliation. Mortality in many areas has been severe, though the ecological consequences of this disturbance are not clear. In some sites, red maple is emerging as a replacement species, but many sites also are regenerating to oak or will regenerate to oak so long as browsing by unusually high numbers of whitetail deer is prevented. Increases in deer numbers are partially the result of increased browse made available by canopy mortality induced by gypsy moth. Ecosystems have complex interactions!

The hemlock woolly adelgid, *Adelges tsugae*, is another introduced insect that is causing significant mortality and that has great potential to change ecosystems. This insect was introduced to the West Coast during the 1920's and again to the East Coast during the 1950's (Annand 1924, McClure 1989). The potential for *A. tsugae* to cause disturbance was not recognized until after there were significant infestations and subsequent mortality of hemlocks in southern New England during the late 1980's. Current hemlock popula-

tions have low genetic diversity, possibly related to their decline (pathologically induced) as a species in the Northeast about 4,700 years ago, as indicated by pollen records (Foster and Zebryk 1993). Hemlock is a late successional, highly shade-tolerant species whose demise will result in significant changes in species composition in sites where it is dominant. The potential socioeconomic impact also is great because hemlock is associated with riparian areas that receive heavy recreational use.

ECOSYSTEM ROGUERS AND SCAVENGERS

Not all pathogens and insects function as major disturbance agents. Many act as ecosystem roguers, alone or synergistically with other disturbance factors. They kill individual trees or small groups of trees that have been stressed by disturbances such as drought, wind, defoliation, and fire. Many trees that become marginal producers as they age or are stressed by disturbance continue to "tie up" or use large pools of resources of light, water, carbon, and nutrients. Pathogens and insects kill these trees, resulting in the release of nutrients and other favorable growth factors for use by the replacement vegetation. Some organisms, such as the *Armillaria* fungus also act as an ecosystem scavenger, decaying the woody substrate that falls to the forest floor. Thus, pathogens and insects can play beneficial roles in stabilizing a site by providing the resources (nutrients, light, moisture) for rapid recolonization of disturbed sites.

DISTURBANCE AND ECOSYSTEM MANAGEMENT

A concerted effort must be made to identify the physiological, spatial, and temporal conditions that affect risk and hazard from pathogens and insects. Cycles of biotic agents of disturbance are more difficult to determine and predict than physical agents because of the many interrelated biotic and abiotic factors that control their population dynamics. However, many insect outbreaks are keyed to the onset of specific climate and weather changes or to vegetation maturity, all of which can be monitored (Mattson and Haack 1987). Information on distribution, abundance, and potential impacts of pathogens and insects must be linked with information on landscape structure, species composition, potential successional pathways, and other disturbance regimes. This information along with data on the effects of soil, climate, and topography on the ecosystem are needed to accurately predict severity and duration of epidemics, their effects and impacts, and recurrences. Models of biology and impacts for insects such as the spruce budworm, tussock moth, southern pine beetle, gypsy moth, and diseases such as dwarf mistletoe and *Armillaria* and *Phellinus* root diseases are examples of useful information that already is available.

Disturbance by pathogens and insects is pervasive throughout forest ecosystems: it is not a question of whether disturbance will happen but what kind, where, and when. Forest management planners must incorporate information on disturbance by pathogens and insects into the USDA Forest Service's forest plans. Specifically, they must determine the types of pathogens and insects that can be expected within particular ecosystems, develop criteria for determining where disturbances will occur, and calculate the probability of occurrence. This information along with data on the vulnerability of certain areas to particular pathogens and insects and the management objectives for those areas can be used to more accurately assess the impact of disturbance and determine appropriate management alternatives. Incorporating data on disturbance potential by pathogens and insects into land management plans will increase our ability to respond appropriately. An understanding of these disturbance effects is critical to ecosystem management!

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Forest Development Leading to Disturbances

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Abstract.—Natural disturbance in western U.S.A. forest ecosystems is related to forest succession, growth, and structural development. Natural disturbance may be biotic (insects and diseases) or abiotic (fire, wind, avalanche, etc.). Natural disturbances are more appropriately thought of as natural processes; disturbance is a social connotation implicating economic loss. Forest development influences the amplitude of natural processes, which in turn influences forest development. Understanding balances among ecological processes, and how these processes influence wildlife, timber, and other valued resources is becoming increasingly important for land managers. We can use currently available vegetation management tools and concepts to keep some of the natural disturbances within socially acceptable limits. This is the role and responsibility of silviculture in ecosystem-based forest management.

INTRODUCTION

Forest development occurs through the complex interactions of ecosystem processes. Rock and soil weathering, along with inputs of solar energy, rain, and dust, interact with forest plants producing a myriad of forest structures. Forests are integral in carbon cycles, nutrient cycles, energy fixation, and other ecosystem functions (Mueller-Dombois and Ellenberg 1974). Outputs from forest ecosystems include water, fiber, fauna, and other resources important to humans. During forest development, ecosystem processes may perturb the system; if the process adversely affects a resource important to humans, then the process is often called a "disturbance." Some processes operate insignificantly in very young forests but become very important in older forests; thus, forest development may lead to disturbance. Generally, agents that operate to release carbon are referred to as disturbance agents. In this paper we discuss the relation of forest development to three general agents: fire, disease, and insects, we give examples of influ-

ences of human activities on disturbance processes, and we discuss strategies on how to deal with disturbance by regulating forest development.

FOREST DEVELOPMENT AND FIRE

For thousands of years fire shaped the composition and structure of North American forest, woodland, and shrubland and grassland ecosystems (Pyne 1982). For example, cores taken from pond sediments in a subalpine lodgepole pine site on the Lolo National Forest in western Montana show clear evidence of several severe fires and a few dozen less severe fires during the past 11,000 years (Johnson et al. 1994). Analysis of fire scars on trees in ponderosa pine/interior Douglas-fir forests documents frequent low-intensity fires dating back as far as the late 1400s (Arno 1976). Analysis of fire scars on giant sequoia stumps provides a continuous record of frequent fires extending back 2,000 years (Swetnam 1993).

Historically, most western forest types were characterized by one or more of the following fire regimes based on fire severity: (1) nonlethal understory fires; (2) mixed and variable fires; and (3) stand-replacement fires (Brown 1995). If most of the forest cover (80 percent or more) dies as a result of fire it is considered stand replacement. If most of

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the forest survives, it is considered nonlethal understory fire. If severity is in between it is classified as a mixed regime.

The pond sediment record from the lodgepole pine site on the Lolo National Forest is suggestive of a mixed severity fire regime. In contrast, fire history evidence from lodgepole pine ecosystems in the greater Yellowstone Park vicinity indicate a stand-replacement fire regime (Romme 1982; Barrett 1994). In Glacier National Park, Montana, lodgepole pine ecosystems represent both these fire regimes (Barrett et al. 1991). The mixed fire regime (having more frequent and less severe fires) is associated with relatively dry environments and gentle topography while the stand-replacement fire regime is associated with a wetter climatic region and steep topography. Fire history from most ponderosa pine/Douglas-fir sites indicates a nonlethal fire regime, although some sites experienced mixed or variable fire regimes (Arno et al. 1995b).

The effect of fires was to favor dominance by fire-dependent tree species. These are early seral species that are fire resistant, regenerate abundantly in response to fire, or exhibit both these attributes. Attempts to exclude fire during this century have lengthened intervals between fires in the nonlethal and in some of the mixed fire regime types (Agee 1993). This allows advanced successional development and accumulations of dead and living fuels in many forests. Most logging treatments fail to counteract the buildup of understory conifers because thinning small noncommercial trees is costly.

Attempts to exclude the fire process from fire-dependent forests have often resulted in a shift in forest composition, structure, fire regime, and susceptibility to insects and diseases. It is common for underburn and mixed fire regime types to be transformed into stand-replacement fire regimes as a result of fire exclusion (fig. 1) (Agee 1993; Arno 1988; Arno et al. 1993; Barrett et al. 1991). By contrast, in historical stand-replacement fire regimes, attempts to exclude fire have had relatively little effect (Hawkes 1980; Kilgore 1987; Johnson et al. 1990; Barrett et al. 1991). Numerous lightning fires have been suppressed while quite small, but this is presumably offset by additional ignitions from

MAJOR TYPES	SERAL	CLIMAX
Dry Seral PP	Ponderosa pine	Douglas fir
Moist Seral PP	Ponderosa pine, Larch	Douglas fir, Grand fir
Riparian Seral PP	Ponderosa pine, Larch	Grand fir
Seral LPP	Lodgepole pine, Larch, Douglas fir	Subalpine fir
Seral WBP	Whitebark pine, Lodgepole pine	Subalpine fir, Spruce
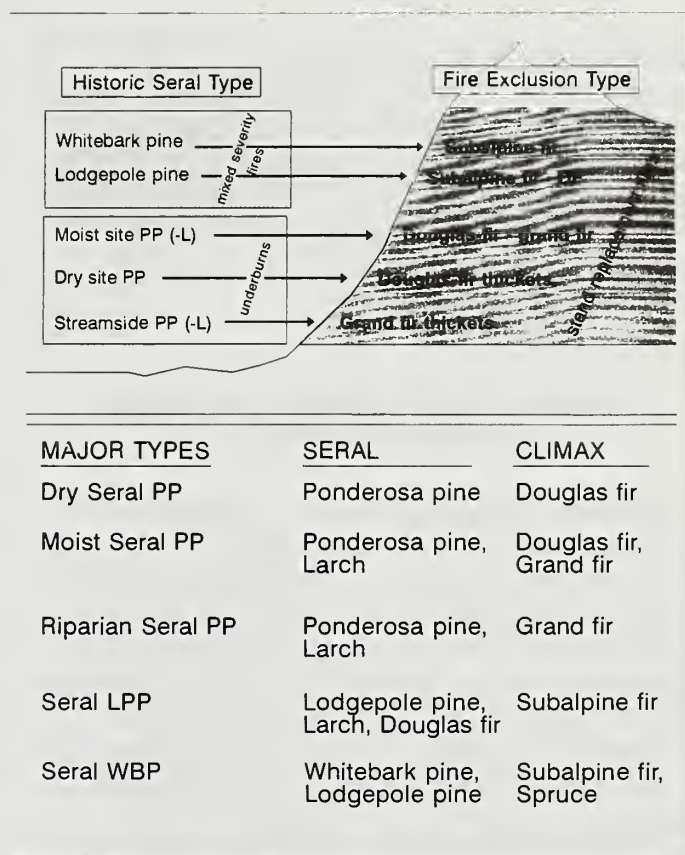
Figure 1.—A schematic representation of pre–1900 and modern forest structure and fire regime types on the east slope of the Bitterroot Range south of Missoula, Montana.

large numbers of human-caused fires. The possibility exists that suppression could have appreciable effects in some geographic areas, especially where units of this type are small, isolated, and surrounded by other kinds of forest or vegetation where fires have been largely excluded.

Ecological ramifications of excluding fire or shifting fire regimes in fire-dependent forest types are only superficially known (Kauffman 1990). There is broad agreement among forest ecologists that effects of fire exclusion practises have been profound in many of the forests formerly characterized by a nonlethal fire regime (Agee 1993). Subtle, long-term effects of fire exclusion might include changes in soil chemistry that upset balances controlling tree growth and pathogen relationships (Hungerford et al. 1991). In wildland forests where management goals emphasize main-

taining biodiversity and ecological processes, various applications of prescribed fire can often be used as a surrogate for the natural fires of the past (Arno and Brown 1991; Hungerford et al. 1991). We are incorporating prescribed fire as a silvicultural component in studies designed to return ponderosa pine/Douglas-fir forests to more natural structures (Arno et al. 1995a).

FOREST DEVELOPMENT, INSECTS, AND DISEASES

Numerous insects and diseases interact with forests in varying stages of successional development and may contribute to altered fire regimes noted above. Forest biomass is the primary substrate for economically important insects and diseases as well as those that are not. Ecologically these agents function to recycle carbon in the ecosystem—they are process agents. For the purposes of this paper, two forest types are considered—interior Douglas-fir, representing low-elevation dry-site conditions, and lodgepole pine, representing mid-elevation moist site conditions. Four important pests—western spruce budworm, Douglas-fir dwarf mistletoe, and Armillaria root disease in Douglas-fir forests, and mountain pine beetle in lodgepole pine forests—are considered relative to forest development.

Interior Douglas-fir Forests

Interior Douglas-fir forests for the most part occupy Douglas-fir habitat types (Pfister et al. 1977). As discussed above, these habitat types were formerly dominated by ponderosa pine and western larch, the seral, shade-intolerant fire-adapted species. However, selective harvest of the seral species, along with a dramatic reduction in the frequency of wildfire, have caused a conversion to Douglas-fir and widespread forests of this species now exist in place of western larch and ponderosa pine. The current Douglas-fir forests are highly susceptible to western spruce budworm, dwarf mistletoe, and root disease.

Western spruce budworm is native to western North American coniferous forests. Primary hosts are grand fir, Douglas-fir, white fir, subalpine fir,

and Engelmann spruce. When weather conditions, forest structure, and parasite and predator populations are favorable to budworm, populations expand rapidly to high levels (Carlson and Wulf 1989). At epidemic levels, nearly every host tree may be defoliated by this insect during any given year of the outbreak. Outbreaks usually last from 7–10 years; during this time significant numbers of host trees may die. Understory trees seem to be most vulnerable; larger overstory host usually survive except under the most severe outbreaks (Johnson and Denton 1975). Outbreaks subside due to interactions of limited food base, adverse weather, increasing effects of parasites and predators, and other factors (Campbell 1985).

Serious budworm outbreaks—those that last several years—kill trees, causing significant accumulations of dead material that can fuel wildfires. If a forest is spared from fire, Douglas-fir will regenerate and start the cycle again. If wildfire does occur, it tends to be far more intense and severe than those that occurred pre–1900 and may cause significant changes in soil structure, soil nutrient profiles, and may induce serious sedimentation in streams. Providing that some old seral veterans are left, the site may seed back to larch or ponderosa pine. In most cases, however, Douglas-fir is the sole remaining conifer and the site eventually will regenerate to this species.

Dense Douglas-fir stands are highly susceptible to *Armillaria* root disease as well as budworm (Hagle and Shaw 1991; Kile et al. 1991). The two agents may even function together. *Armillaria* is often found on trees defoliated for several years— overstory and understory. *Armillaria* centers live for extremely long periods of time (Shaw and Roth 1976), and the fungus is opportunistic. When suitable substrate is available i.e., moisture/nutrient-stressed Douglas-fir, *Armillaria* centers can expand rapidly and kill trees over large areas. As with budworm, this dead material serves to fuel the severe wildfires that are most certain to come. And, as with budworm, in the absence of fire the root disease centers will regenerate to Douglas-fir; the cycle continues.

Douglas-fir forests are also highly susceptible to dwarf mistletoe (Hawksworth and Wiens 1972; Baranyay and Smith 1972). The complex structure

of these forests—several crown layers—increases the chances of successful infection by dwarf mistletoe seeds in comparison to open grown stands dominated by seral species. Mistletoe is even more insidious in its effects than root disease. It takes a long time, 100 years or longer, for significant mortality of the host to occur. Nevertheless, this disease, like budworm and root disease, recycles carbon and helps set the forest up for serious wildfire events.

Lodgepole Pine Forests

Lodgepole pine forests are an interesting contrast to Douglas-fir forests. Lodgepole pine is highly shade-intolerant and is nearly always seral whereas Douglas-fir is shade-tolerant and mostly climax (Pfister et al. 1977). The largest, most continuous lodgepole forests occur on subalpine fir habitat types (Volland 1985). Lodgepole pine typically regenerates following stand-replacing or mixed-severity fires (Lotan et al. 1985). It grows rapidly and dominates the site, but subalpine fir, the shade-tolerant cohort, regenerates well under the canopy of lodgepole; lodgepole forests older than 60 years typically have an understory of alpine fir.

Mountain pine beetle is a serious pest of lodgepole pine. Forests become susceptible to the beetle when average tree diameter is 8 inches or more and stand age is over 80 years (Safranyik et al. 1974). This insect is the most serious insect/disease process agent known to lodgepole pine forests (Amman et al. 1977). Mortality of lodgepole under siege by the beetle is spectacular. Infestations and associated mortality may cover hundreds of thousands of acres at a given time.

In an ecological context, the insect functions in recycling carbon. Large areas of dead pines are a huge concentration of fuel, whether standing or fallen, setting the stage for a continuing cycle of stand-replacing or mixed-severity fires (Lotan et al. 1985). If fire is removed from lodgepole pine forests, succession will lead to a forest dominated by subalpine fir. Subalpine fir forests are highly susceptible to western spruce budworm at elevations below 7000 ft m.s.l. (mean sea level). So, in either case—lodgepole or subalpine fir—forest development sets the stage for other ecological

processes, in these examples the carbon-cycling agents. *Armillaria* root disease may predispose lodgepole pine to infestation by the beetle during periods when the beetle is endemic (Tkacz and Schmitz 1986). The interactions among process agents—insects and disease—is complicated and poorly understood, and deserves further study in light of current interest in ecosystem-based management.

MODELING INTERACTIONS AMONG ECOSYSTEM PROCESSES

The conceptual context of relating forest development to other processes, or "disturbances", is reasonably straightforward. In today's environment of high-speed computers, data bases, Geographical Information Systems, and other software, we are in a position to model forest development so we can use results in forest management planning. Modeling interactions influencing forest development interactions is problematic.

SIMPPLLE is an object-oriented modeling system recently developed for simulating ecosystem processes (Chew 1995). Simulations with SIMPPLLE on the 55,000 acre Stevensville West Central Integrated Resource Analysis unit in the Bitterroot Valley provide examples of these interactions. Levels of stand-replacing fire for five stochastic simulations without fire suppression activities, starting from current conditions are shown in figure 2. Figure 3 shows the occurrence of stand-replacing fire for five other simulations that include the continuation of our current fire suppression activities. The level of the severe western spruce budworm process that corresponds with each set of fire simulations is shown in figure 4. Continuing to manage the current landscape with fire suppression produces a significantly higher level of budworm activity. Increased budworm activity causes an increase in fuel accumulation, eventually resulting in a higher probability of stand-replacing fires. The continuing increase in the buildup of fuels unquestionably sets the stage for severe stand-replacing fire. This projected increase in stand-replacing fire is shown in figure 5 which is a summary of 30 stochastic simulations. The long term cycling between fires and budworm activity is shown for a 20 decade simulation in
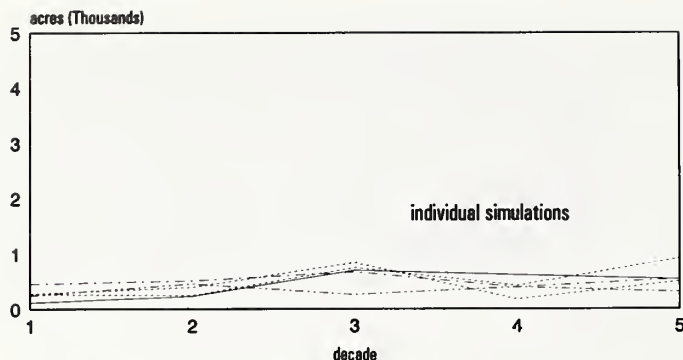
Figure 2.—Acres of stand replacing fire for five stochastic simulations without fire suppression starting from current conditions for Stevensville West Central.
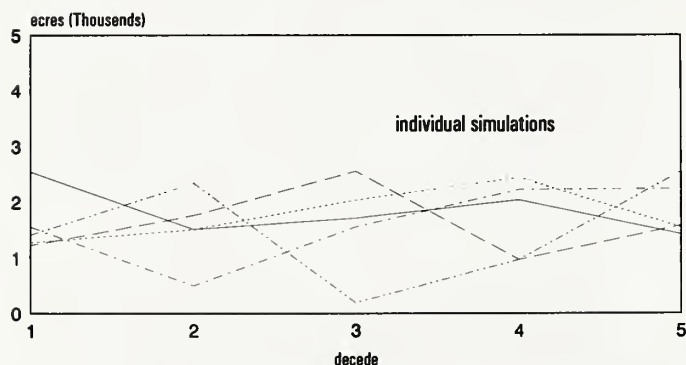
Figure 3.—Acres of stand replacing fire for five stochastic simulations with fire suppression starting from current conditions for Stevensville West Central.

figure 6 on Coram Experimental Forest, a 3030 hectare area in NW Montana. With fire at a low level the shade-tolerant budworm host species increase creating stand structures that favor budworm survival and peak feeding activity. The increase in budworm activity creates a fuels buildup that eventually results in fires reducing the suitable host conditions. A similar relationship for fire and root disease on the 9094 hectare Alden Creek area in North Idaho is shown in figure 7. The amplitude and frequency of the processes in these long term cycles are linked to stand development.

The level of budworm activity that is simulated to occur even without fire suppression is still higher than what has been simulated from historic landscape conditions. Relaxing our fire suppression efforts as a management alternative can have an impact on other processes (fig. 8), but in and by

itself, not enough to create desired future conditions that feature insect/disease resistant dry-site forests with low frequency of stand replacing wildfire. Budworm and root disease will continue at high levels and species composition will not shift quickly enough from shade-tolerant to intolerant. Species groups relative to historic conditions are shown in figure 9. Management alternatives that advocate natural stand development with no intervention by managers, or that maintain the current fire suppression policy, or even not suppressing wildfire, will cause a major gain in the shade-tolerant species (grand fir and Douglas-fir) at the expense of ponderosa pine and western larch. Clearly, some combination of intermediate harvest combined with underburning will be necessary to restore the seral species in a meaningful way.
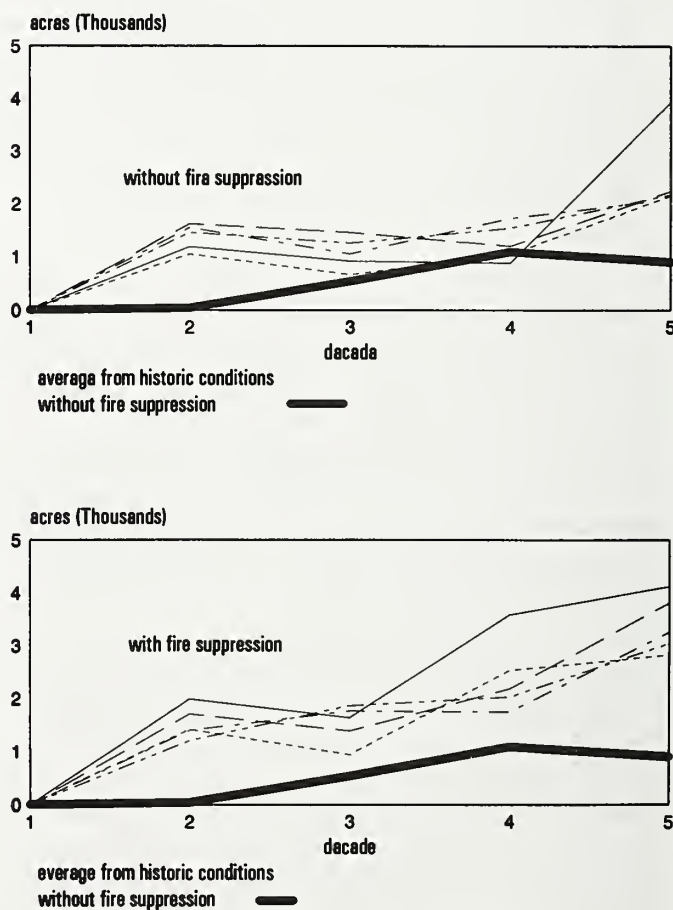
Figure 4.—Acres of severe western spruce budworm for stochastic simulations with and without fire suppression, starting from current conditions for Stevensville West Central.
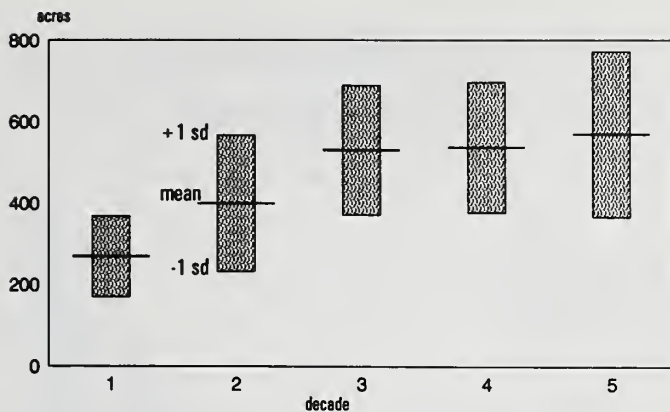
Figure 5. —Means and standard deviations for stand replacing fire based on 30 stochastic simulations with fire suppression from current conditions for Stevensville West Central.

MANAGING ECOSYSTEMS FOR MULTIPLE BENEFITS: THE ULTIMATE PROCESS

We are beginning to better understand the complex interactions that occur among ecosystem processes and forest development. This understanding should lead to better management of our forests. In light of our new knowledge and understanding, there appear to be two major schools of thought concerning ecosystem management: ecocentric and utilitarian. One school advocates that ecosystem structure, process, and function need to be maintained in order to assure long-term ecosystem viability, without defining output levels needed by human beings. This approach, that we label the "ecocentric" approach, rapidly becomes fuzzy in that it is difficult to decide which, and at what levels or ranges of variations, the various structures, processes, and functions need to operate. In fact, this is impossible to do without invoking social parameters to define suitable indicators of ecosystem health because ecosystems undergo continuous change. For example, consider the mountainside adjacent to the smelter at Kellogg, Idaho. For many years this smelter emitted large quantities of heavy metals and sulfur oxides. Soils near the smelter are now highly acid (Ph = ca 3.0 – 3.5) and are laden with lead, cadmium, and zinc. The original conifer forest is gone. Nevertheless, there is still an ecosystem, and it has structure, function, and process. If one attempts to disregard human values (which is quite impossible) and consider this ecosystem as an entity unto itself

(anthropomorphic?), then the two states of the ecosystem—before smelter and after—simply exist. A similar case can be made for natural interventions such as glaciation, or, in a longer time frame, landform modification due to tectonic activity.

The alternative approach, the "utilitarian" approach, is to consider ecosystems as important reservoirs of resources valuable to human beings. In this approach we can *define what we want and need* from ecosystems, and then structure management to produce these resources within the capability of the system. We can define sustainable levels of wildlife, esthetics, wood, water, or whatever. This approach has high merit in view of an expanding and demanding world-wide human population. We can define acceptable structures and desirable process levels that will meet management objectives. Forest management will hopefully adopt this approach. However, there is plenty of doubt that it will. Forest managers are under pressure both from groups advocating extreme environmental viewpoints to protagonists for extreme utilization, and decisions are difficult to make.

In line with the utilitarian approach, if we are to alter processes that adversely influence social amenities related to forest development, then we must consider traditional and non-traditional silviculture along with prescribed fire. Fire is an essential process of western North American ecosystems, and can be and is used in an applied sense to alter structural development, recycle nutrients, maintain seral species, and minimize impacts of forest pests. Where chainsaws are prohibited (wilderness, for example), prescribed natural fire may be the tool of choice. For those areas with approved Prescribed Natural Fire (PNF) programs in the Northern Region, 193,460 acres have burned within the parameters of the programs since 1972. However, there are many more wilderness acres where fire is not used due to risk to adjoining private lands. Prescribed manager-ignited fire is another potential tool for use in wilderness areas. However, use is limited due to interpretations of management restrictions in the Wilderness Act of 1964. Consequently, fire will function in an unnatural role in Wilderness landscapes lacking a PNF program.

Prescribed ignited fire, not associated with intermediate cutting, also has strong potential as a
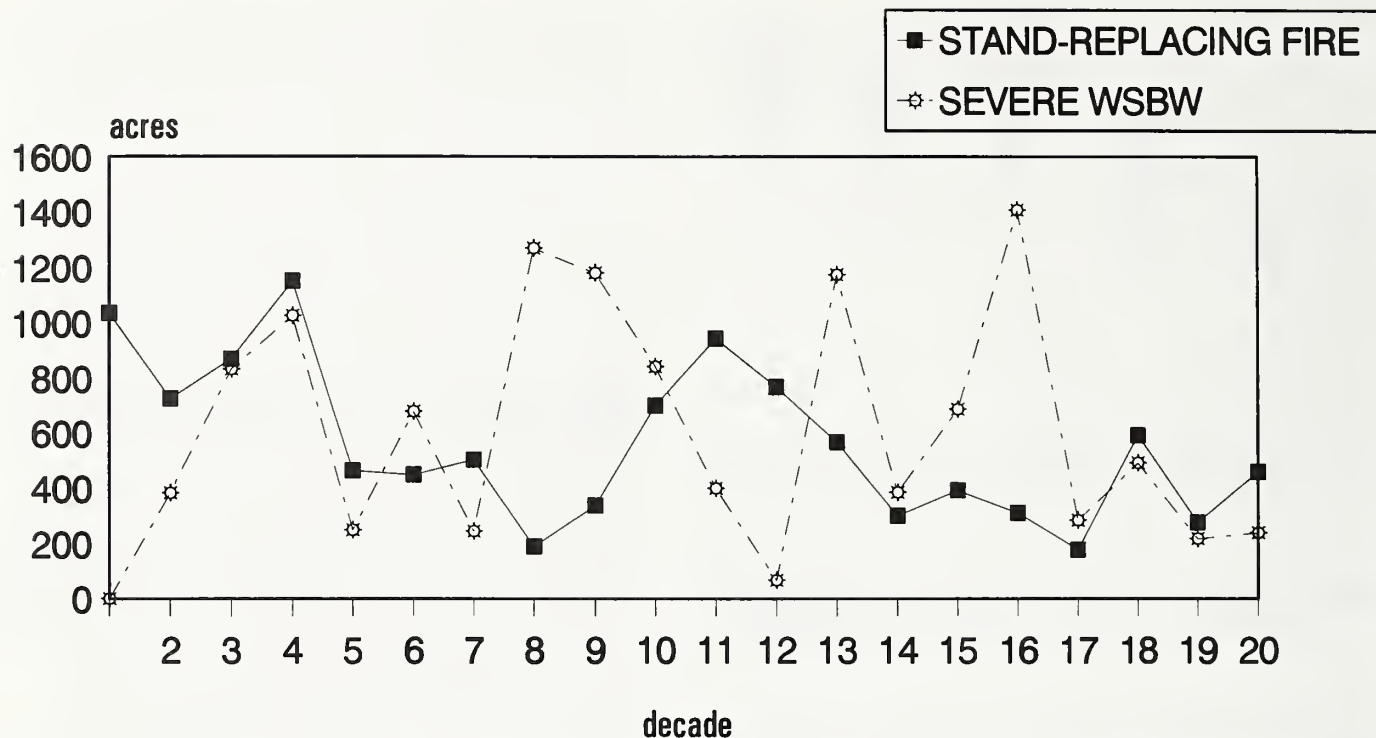
Figure 6.—Acres of stand replacing fire and severe western spruce budworm processes for a 20 decade simulation for Coram Experimental Forest in NW Montana.
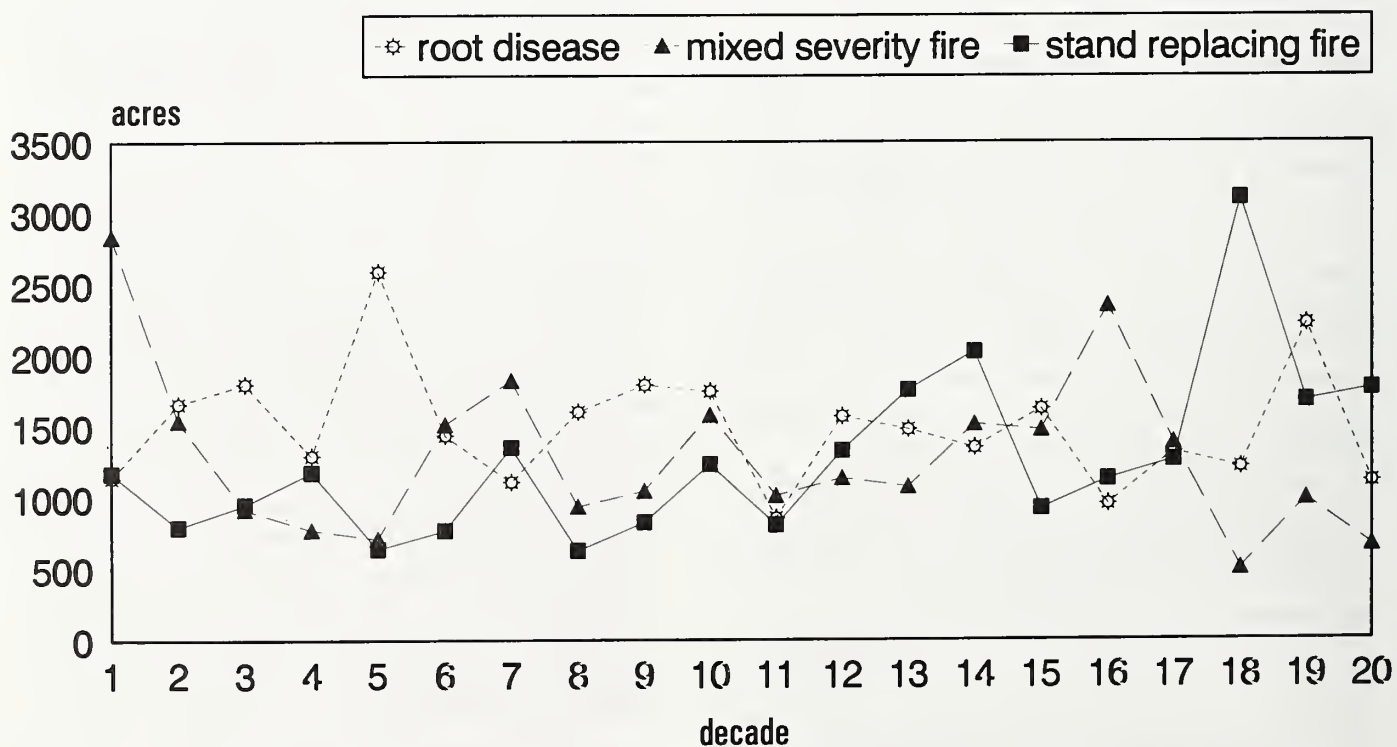
Figure 7.—Acres of the fire and root disease processes for a 20 decade simulation for Alden Creek in North Idaho.

INSECT & DISEASE PROCESSES
accumulated acres for a 5-decade projection

acres (thousands)

■ with fire suppression
▨ without fire suppression

light wsbw
severe wsbw
pp-mpb
light lp-mpb
severe lp-mpb
root disease
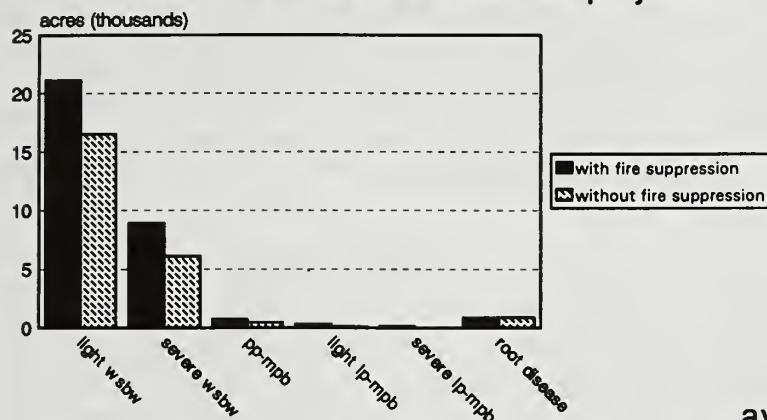
FIRE PROCESSES
average acres per decade

acres (thousands)

■ with fire suppression
▨ without fire suppression

stand replacing fire
mixed severity fire
light severity fire
total fire
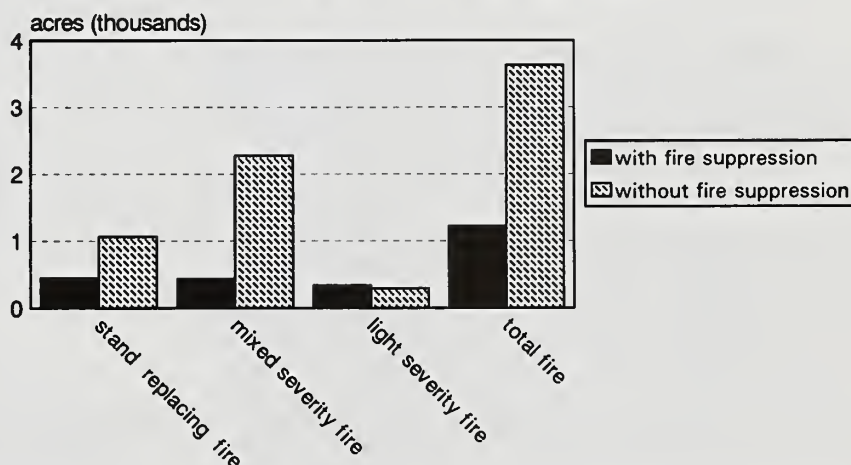
Figure 8.—Comparison of acres of insect and disease and fire processes from simulations with and without fire suppression for Stevensville West Central.

management tool outside Wilderness but on lands unsuitable for timber as a primary output. Over 11 million acres fall into this category in Forest Service Region 1 alone. Fire very much needs to be re-introduced into these landscapes, but may be limited due to air quality standards and declining funding. Nevertheless, Ranger Districts are building programs and increasing requests for alternative funding and are building partnerships with non-federal organizations, such as the Rocky Mountain Elk Foundation, to accomplish goals.

There is ample opportunity to invoke combinations of harvest and prescribed burning to restore fire as a process and decrease the amplitude and frequency of insect/disease outbreaks on tens of millions of acres defined as suitable for multi-

resource management on national forest lands of the inland west. Funds from timber sales can help with costs associated with burning, the burning will reduce fire hazard, especially important at the urban/wildland interface, and other resource amenities will be enhanced. For these actions to be truly effective, harvest and burning) need to be conducted on landscapes, not individual small stands. There exists an incredibly large volume of intermediate-size, commercially saleable, Douglas-fir and grand fir in the northern Rocky Mountains that needs to be harvested as an integral part of ecosystem-based management that has a utilitarian focus.

Research is currently underway to support landscape-level management that deals with forest
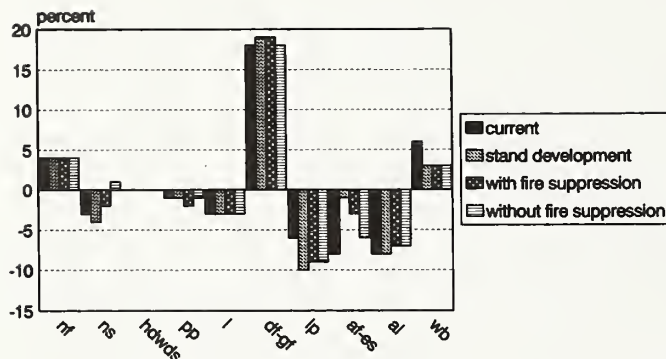
Figure 9.—Comparison of percent change in species groups from historic conditions for current conditions and simulations of stand development only, and with and without fire suppression for Stevensville West Central.

development and disturbance agents. One example is the Bitterroot Ecosystem Management/Research Project (BEMRP), a research/development project to restore social values to an ecosystem adversely affected by unnatural forest development associated with exclusion of low-intensity fire. Although the Project is focused on the Bitterroot National Forest in the northern Rocky Mountains in Montana, it addresses a problem affecting much of the 40-million acre ponderosa pine type in the western U.S.A. and Canada. The problem, stated before in this paper, is that reduced frequency of fire and logging selective for high-value seral species for the last 100 years or so has caused a major shift in species composition and stand structure. Formerly dominated by ponderosa pine and larch, with scattered Douglas-fir and grand fir, the forests are now dominated by the two latter species. The major goal of BEMRP is to develop landscape alternatives to convert the dense stagnated Douglas-fir/grand fir forests to a more natural ponderosa pine/western larch condition, utilizing intermediate harvest and prescribed burning.

BEMRP, currently funded for five years, is an interdisciplinary project. New studies include the relationships of fauna to forest development and detailed analyses of historic fire regimes in relation to forest development. Modeling will simulate forest development affected by various ecological processes such as fire, insects, and disease and to optimize vegetation management given varying resource objectives. Importantly, studies are underway to determine better ways of assessing social wants and needs and to more efficiently involve diverse publics in forest management planning. More than 25 individual studies have been started under BEMRP. BEMRP involves five units of the Forest Service Intermountain Research Station, the University of Montana, the State of Montana, the Bitterroot NF, and the Northern Region, Forest Service. Detailed information on BEMRP is available on request (Carlson 1994).

CONCLUSION

Disturbances will happen in forests whether we plan for them or not, but there are many potential benefits to society in guiding forest development over large landscapes. Desired future conditions must take into account the needs and wants that society will demand from forested lands. It seems prudent for mankind to regulate forest development and disturbance so that social benefits can be realized in an organized and predictable fashion. If we don't, then nature will do it for us, with a high probability that the outcome will not be positive for human beings.

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The Way to a Healthy Future for National Forest Ecosystems in the West: What Role Can Silviculture and Prescribed Fire Play?

Douglas W. MacCleery[1]

Abstract.—The 1994 wildfires in the U.S. West have highlighted a problem of forest health and fuel buildups that has been increasing for decades. In many Western forest ecosystems, forest biomass per acre has risen substantially since the 1940s and many forests have dense, fire-prone understories. If current trends continue, there will be: 1) increasing risks to National Forest ecosystems from insects, disease, and conflagration events, 2) a rising toll of loss and degradation of watershed values and wildlife habitats from abnormally intense wildfires, as well as continued losses in the biological diversity of vegetation types that were historically characterized by frequent, low intensity, fires, 3) increased risks to the human communities located in forested areas and to the fire fighters sent in to protect them, and 4) significant and increasing losses to taxpayers in fire suppression costs and resource values

Major barriers to taking the management actions needed to effectively address forest ecosystem health include: 1) erroneous public perceptions about the nature of American forests prior to European settlement, 2) piecemeal and uncoordinated implementation of federal environmental laws, 3) focusing on the short-term environmental impacts of projects, while ignoring the long-term risks of failure to take the actions necessary to restore forest health, and 4) lack of consistent, reliable information on the specific extent of forest health problems, and on the treatment measures needed to address them.

INTRODUCTION

The catastrophic Western fires of 1994 have spotlighted a problem that has been building for decades—the growing susceptibility of many Western forest areas to insects, disease, and catastrophic wildfire. Ironically, the cause of this problem is a century of reduced presence of fire in these ecosystems.

Decades of fire exclusion has been a major contributor to poor forest health and forest management problems. On August 29, 1994, Forest Service Chief Jack Ward Thomas discussed these problems in testimony before the Senate Subcommittee on Agricultural Research, Conservation, Forestry, and General Legislation Committee on Agriculture:

This year's wildfires have brought to the public's attention a forest health problem that had its beginnings over 100 years ago. In Idaho, and in much of the West, the health of National Forests,

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other federal lands and private and State lands is closely related to changes in the historic role of fire on those lands. . . . The same problems will be with us next summer and each summer in the future unless we recognize that some actions are necessary to return fire to the environment in a way that achieves desired outcomes, to improve forest health and reduce the risk that fire will damage site productivity or destroy human life and property (Thomas 1994).

The twin problems of fuel build-ups and declining forest health, and their effect on ecosystem diversity and sustainability, are likely to be the single most significant environmental challenge facing National Forest managers over the next two decades. The challenge will be great physically and biologically because such problems are extensive on federal forest lands (Sampson et al. 1993, Thomas 1994, USDA/FS 1993b).

The challenge will also be significant intellectually and emotionally because effective solutions will require the public and National Forest managers to rethink some strongly held assumptions about the nature of forests prior to European contact and on the role that natural and human induced processes played in those forests.

It will require the Forest Service and the forest conservation community to come to grips with the often divisive issue of whether and how humans should intervene in natural forest ecosystems. While other forms of intervention, such as timber harvesting, have been a primary focus of public attention, the reduction in ecosystem fire in the West has been one of the most profound and significant human interventions of any that has occurred over the last century.

ORIGIN AND HISTORY OF FOREST HEALTH PROBLEMS IN THE WEST

The assertion is often made that today's Western forest health problems are the result of the aggressive fire suppression activities initiated by the Forest Service and other federal agencies in the 1930s, coupled with the extensive harvest of Western pine forests after World War II. While there is some truth to these assertions, they tell only a partial story.

A substantial reduction in ecosystem fire had already occurred over much of the West by the late 1880s or even before. It coincided with the disintegration of the cultures of native peoples in the area, virtually all of whom actively used fire as a major land management tool (Anderson 1990, Arno 1985, Boyd 1986, Bowden 1992, Cronon 1985, Gruell 1985, Pyne 1982, Williams 1989, Williams 1994). Reduced ecosystem fire was associated with the elimination of Indian burning, with the settlement of western valley areas, and, especially, with increased livestock grazing, which broke up fuel continuity (Sampson et al. 1993).

Even in the absence of timber harvesting, exclusion of fire will eventually result in the elimination of ponderosa pine, aspen, and other forest types characteristic of frequent fire regimes. This transition can clearly be seen occurring in National Parks and Wilderness areas and in other areas that have never been logged. Many forests in these "protected" areas are now being replaced by dense stands of fire and insect susceptible fir and mixed conifer species (Sampson et al. 1993).

FOREST ECOSYSTEMS HAVE CHANGED PROFOUNDLY

A number of studies have been made which use repeat photography comparing late 19th century landscape photographs to those recently taken from the same photo points (Gruell 1980, Gruell 1983, MacCleery 1994, Progulske 1974, USDA/FS 1993c, Wyoming State Historical Society 1976). These studies universally demonstrate the profound ecological changes that have occurred over the last century in Western forest landscapes. These photos record dramatic increases in the understory density and overstory biomass volume of forest vegetation over the last century, and a decrease or complete elimination of both the aspen component and in the herbaceous understory in conifer stands. In addition, grasslands have become woodlands and open woodlands have become dense forests. Other non-photographic studies strongly corroborate the existence of such changes (Covington and Moore 1994, Sampson et al. 1993).

The reduction in fire is not just causing forests to become more dense. The overstory trees of many

forests are also older on the average than they would have been without this change. An example is the Flathead National Forest in Montana (where the Bob Marshall Wilderness is located). A reconnaissance survey done in 1899 estimated that about 18 percent of the forest area of the Flathead was in a mature forest condition, and 6 percent was old-growth; but by 1990 the area of mature forest had increased to 33 percent, and the area of old-growth to 20 percent (USDA/FS 1992).

ECOLOGICAL EFFECTS—LOSS OF BIODIVERSITY, DETERIORATING FOREST HEALTH, MORE INTENSE WILDFIRES

Biological diversity has already been profoundly affected by these changes, even before the potential ecological effect of an increase in intense wildfire is considered. A recent Forest Service study shows a substantial loss in the aspen component in the forests of the Southwest. Based on forest inventory data, it found that between 1962 and 1986, the area of aspen forests had dropped by 46 percent. The study predicts that if these trends continue, in less than three decades aspen will cease to exist as a distinct forest type in the Southwestern region (USDA/FS 1993a). This same study found that the area of the forest type that is the beneficiary of reduced fire occurrence, the mixed conifer type, increased by 81 percent.

The ecological effects of reduced ecosystem fire depend on the nature of the forest. In warm, dry forest ecosystems which historically were characterized by frequent, low-intensity fires, elimination of fire leads rapidly to the development of a dense, multi-storied forest structure—subject to increasing mortality from drought, other forest health problems, and stand-replacing conflagrations, which seldom occurred in the past (USDA/FS 1993b). These low intensity fire adapted forest types, which are estimated to comprise more than half of the forest area in the Interior West, typically occupy lower elevations (USDA/FS 1993b). Because of their accessibility, such lands often have been rather extensively roaded.

In higher elevation forests, which tend to be cooler and moister, the ecological effects of fire exclusion are typically less profound than in lower elevation forests, at least over the short term. Many cool, moist forest ecosystems were historically subject to infrequent, stand-replacing fires. But even in these forests, reduction in historic fire has had substantial ecological effects in some areas. The aspen component has been substantially reduced, many meadows and openings have diminished in size or disappeared altogether, and existing forest stands have overstory trees which are older on-the-average than historically. The ecological diversity and "patchy-ness" of the forest landscape has been reduced. Such forests will be subject to increased insect epidemics and to larger and more intense stand-replacing conflagrations than typically would have occurred in the past.

Of course, there are many gradations between warm/dry and cool/moist forest ecosystems. Many forests were subject both to relatively frequent low intensity fires, as well as occasional stand-replacing conflagrations when weather and forest conditions were right. When viewed from a spatial and temporal scale, the picture can be quite complex. Within the same general vegetation community, there are significant variations in fire frequency and effects over time, depending on periodic drought cycles, topography, and human influences. And within the same general landscape, there can be major variations in vegetation communities and fire behavior depending on soil characteristics, aspect, slope and related factors, eg. north vs. south slopes. Brown (1994) has proposed a classification scheme for fire regimes that should assist in improving understanding and awareness of the complex processes involved.

These complexities make it difficult to simply characterize the vegetation changes that are occurring as the result of fire exclusion. Much of the debate on the forest health issue is focused on these differences and opposing interpretations as to their relevance. While more research into the ecological effects of these changes is certainly needed, a general pattern does emerge. Due to changes in forest density, understory composition, and the kinds of tree species that are emerging to replace the existing forest canopy, the forests that are now developing will be decidedly more susceptible to insects, disease, drought, and catastrophic fire than those of the past. When fires do occur in such forests (as they inevitably will), they will tend to be

intense, stand replacing, soil damaging fires, beyond that which would have been typical in the past.

Even high elevation forests, where stand replacing fires were the norm in the past, will likely be subject to larger and more intense fires than in the past due to increased structural homogeneity and reduced patchy-ness (Barrett et al. 1991). This will likely lead to reduced biological diversity over time.

There are also immediate watershed effects of the denser forests as well. It has long been known that the density of forest vegetation affects hydrologic functioning, particularly streamflows during the dry season. It is a common observation in the forests of the Interior West that streamflow rates often increase after stand replacing fires destroy most vegetation. Today, many streams in Western forest areas which were perennial streams a century ago now do not flow year around, and low flows in many others are lower than they used to be. Low flow rates affect water temperature and are a critical factor for fish and other aquatic life.

BIOMASS CHANGES ON NFS LANDS— HOW EXTENSIVE?

Today the volume of net forest growth on the National Forest System as a whole is more than twice the volume of removals. Net forest growth is total forest growth reduced by losses due to mortality, rot, etc.

It is estimated that total (gross) forest growth on National Forest System (NFS) lands is about 22.5 billion board feet (BBF) per year, or 4.5 billion cubic feet (BCF). Forest mortality is estimated at about 6 BBF or 1.2 BCF, and timber harvest in FY 1994 was 5.0 BBF or about 1.0 BCF, about half of which was salvage of mortality. This means that the- net addition- of live forest biomass on NFS lands was—almost 14 billion board feet—or about 2.8 BCF, just in FY 1994 alone (USDA/FS 1993d).

Because net forest growth has substantially exceeded removals since at least the 1950s (and likely decades before that), average forest biomass per acre on NFS lands has risen substantially over the last century. There are major regional differences, however, in where this biomass is being added. Since 1952, average net NFS forest biomass per acre in the East and South has doubled; in the Interior West (Regions 1, 2, 3, and 4), it has in-

creased by 44 percent; and on the Pacific Coast it has dropped by 14 percent (USDA/FS 1993d).

The significant increase in NFS forest biomass in the East and South is understandable and positive because these forests were heavily cutover and burned in the late 1800s and early 1900s prior to acquisition by the Forest Service. The reduction in forest biomass on NFS lands in the Pacific Coast is also understandable since the post World War II period marked the beginning of major timber harvesting activities on NFS lands in the West. While average NFS forest biomass on the Pacific Coast has dropped by 14 percent since 1952, it still is more than twice that of NFS lands in the eastern U.S. (3812 cubic feet/acre vs. 1528 cubic feet/acre in Eastern NFs) (USDA/FS 1993d).

The increase in NFS forest biomass in the Interior West is another story, however. This increase comes on forests which were not heavily cutover during the settlement period, and occurred even in the face of timber harvesting that averaged more than 2 billion board feet per year between 1960 and 1990. This biomass increase largely represents the legacy of fire exclusion in the Interior West. Biomass buildups have occurred largely in the smaller diameter classes. The volume of trees in diameter classes less than 17 inches increased by 52 percent between 1952–92; and today such trees comprise two-thirds of total stand volume on all lands in the Interior West. The volume of trees greater than 17 inches has been stable since 1952 (USDA/FS 1993d).

The above figures include live biomass only. There has also been a significant, but undetermined, increase in dead biomass in the Interior West. In many western forest ecosystem, biomass recycles primarily through fire, rather than decay.

The large forest biomass increases in the Interior West cannot continue indefinitely. If humans do not make purposeful adjustments, nature most certainly will, as last year's wildfires graphically demonstrated.

CHALLENGES AND BARRIERS TO ECOSYSTEM MANAGEMENT: THE "NATURAL" FOREST PARADOX

One of the most significant barriers to addressing the forest health issue is not physical or biologi-

cal—neither is it related to a lack of scientific or technical knowledge. Rather it lies in public perceptions as to the nature of pre-European forests.

Today, we have some strongly held popular images of what American forests were like prior to European contact. One of these is the image of the "forest primeval," the idea that pre-European contact forests were dominated by a "blanket of ancient forest." This image is one of continuous, closed-canopy, structurally complex, all-aged "climax" forests which nature maintained for long periods in a steady-state, equilibrium balance with the environment. We have a corollary image of a pre-contact native peoples who lived in the forests and on the plains, but really didn't do much to change either (Bowden 1992). There is overwhelming physical, biological, as well as anthropological evidence that both of these images are incorrect (Arno 1985, Butzer 1990, Covington and Moore 1994, Denevan 1992, Kay 1995, Pyne 1982, Teensma 1991).

Both natural and human caused fires were major factors maintaining the open nature of vast areas of western forests (Pyne 1982). But Indian burning did much more than just add a supplemental ignition source to that of lightning. Because of its frequency and timing, in many areas aboriginal burning created entirely different vegetation mosaics and plant communities than would have existed without it (Blackburn & Anderson 1993, Boyd 1986, Kay 1995, White 1975). Most Indian fires were set in the spring and fall (when lightning is uncommon) and tended to create vegetation communities adapted to frequent, low intensity fires. In the absence of Indian burning, natural lightning fires in many forested landscapes would have been both less frequent, and more intense than Indian fires. Indeed, vegetation modification by native American burning likely tended to reduce the numbers of high intensity fires caused by lightning that otherwise would have occurred (Pyne 1982).

Erroneous images of the nature of forests prior to European contact exist not only in the public's mind. They are also strongly held by many of the managers and employees of the Forest Service and other federal and state agencies. These images continue to profoundly effect public policy today.

Today we are faced with a paradox: The dense stands that now exist in many National Parks, Wilderness areas and other "undisturbed" areas, which many in the public perceive as the "natural" forest condition, are the result of decades of human intervention in the form of fire control. But many of the open, park-like stands encountered by Euro-American settlers were themselves, to a significant extent, a product of thousands of years of intervention by native peoples. Reintroduction of natural sources of fire alone, such as lightning, will not likely restore these systems to what they were.

Under ecosystem management, the concept of "range of natural variation" has emerged—now often called the "range of historic variation" to recognize the influence of native peoples. While this is a useful concept, some people are opposed to any active human intervention in forested ecosystems, even if its purpose is to return them to their historic range. This ignores the fact that: 1) "passive" intervention in those systems in the form of fire exclusion has (and continues to) profoundly changed them; and that 2) active intervention by native peoples often helped create a number plant and animal communities that are relatively rare today.

One thing is clear: If a significant increase in forest mortality and catastrophic wildfire is considered socially and environmentally unacceptable, the current situation is unsustainable without some form of active human intervention. In the face of the profound ecological changes now occurring in many forests, human action will be necessary to achieve over the long term whatever "desired future condition" is likely to come out of National Forest planning. Active management will be required to maintain them, if such a decision is made, in an approximation of their pre-European condition. A paper addressing these problems was prepared last year by the Fire and Aviation Staff in the Washington Office (USDA/FS 1993b).

THE GROWING WILDLAND/URBAN INTERFACE PROBLEM

Since the 1970s, there has been a major increase in residential development in wildland vegetation types next to National Forest lands. This has vastly

complicated National forest management. Among other things, the increased flammability of forests increases the risks to those communities. In the last decade, conflagration events have destroyed hundreds of homes and killed dozens of people. In addition, protecting residential developments has increasingly tied up fire resources traditionally devoted to suppression of fires on National Forest lands. In September 1994, Undersecretary James Lyons estimated that during the 1994 fire season, as much as 75 percent of federal fire suppression resources were tied up protecting structures and residential communities (Lyons 1994). The presence of these communities also makes it more difficult to initiate a program of mechanical treatment and prescribed fire on adjacent federal lands.

In a major strategic evaluation of Forest Service fire management, a team recently recommended major changes in current approaches (USDA/FS 1995). Among other things, the team recommended that: 1) Fire ecology and fire effects considerations be integrated fully into National Forest ecosystem management planning and implementation at all levels, 2) the use of mechanical treatment and prescribed fire be increased dramatically to help restore ecosystem health, 3) the Forest Service reduce direct attack suppression responsibilities in residential wildland areas, 4) public education and local regulation be expanded to ensure fire safe building design and location in the wildland/ urban interface, and 5) fuel management areas or zones be established on NFS lands located next to residential areas.

The fuel management zones were considered necessary for two reasons: 1) to allow for more use of prescribed ecosystem fire on NFS lands without jeopardizing adjacent human communities, and 2) to reduce the level of fire suppression resources required to protect communities during fire emergencies.

THE ROLE OF SILVICULTURE AS A TOOL IN ADDRESSING FOREST HEALTH

While exclusion of fire from forested ecosystems is an underlying cause of the forest health problems we face today, returning fire alone, even on a carefully controlled basis, simply is not feasible in many situations. The use of silviculture, in conjunction with increased use of prescribed fire, will be essential in maintaining ecosystem health.

The silvicultural practices designed to maintain forest health will be different than those used to produce timber as a primary objective. Smaller material will be removed. There will be more use of thinnings, salvage, and other silvicultural treatments that involve removal of only a portion of the trees on a site. Wood product values will be lower and logging costs higher.

The potential exists for the use of silvicultural operations in support of forest health objectives to become win/win situations. The equipment and technology already exists to "tread lightly" and to carry out the silvicultural activities needed to maintain forest health. Many of these operations (but not all) will yield positive economic returns, particularly at recent timber price levels. And even when they do not, capturing of timber values can significantly reduce the total cost of the projects. These projects can reduce the substantial economic losses for wildfire suppression and site rehabilitation after severe wildfires. Last year the Forest Service spent almost one billion dollars on wildfire suppression.

Silvicultural treatments involving the sale of merchantable material can substantially reduce total treatment costs, reduce the risk of escaped prescribed fires, support local community economies, reduce the intensity of heat and fire (thus protecting soil and watershed values), increase dry season streamflow rates, and substantially reduce the amount of smoke that would otherwise be released. Going back to the levels of ecosystem fire and smoke that existed in pre-settlement times is simply not legally or politically feasible. Even with pretreatment, dealing with existing smoke management guidelines will be a major challenge.

It is not a question of whether these ecosystems will burn, but when and with what environmental and economic consequences. With respect to smoke, Chief Thomas has said that we must decide whether we want a little in the air a lot of the time, or a lot all at once. That is certainly true, but mechanical treatment and removal of biomass is one way to reduce the total amount of smoke that otherwise would go into the air.

FOREST SERVICE LEADERSHIP AND EFFECTIVE PUBLIC COMMUNICATIONS IS KEY

Introduction of silviculture and prescribed fire for forest health will not be without controversy. Strong Forest Service leadership will be a key factor in successfully forging such a social consensus. Substantial federal and state financial assets will also need to be devoted to forest health issues.

The tools and technologies currently exist to address the growing forest health problem in the West. Unfortunately, there is a lack of consistent, reliable information on the specific extent of forest health problems, and on the treatment measures needed to address them. In spite of these shortcomings, the biggest barrier is social—that is, forging the social consensus on the actions needed to manage NFS lands to maintain ecosystem health.

In a major strategic vision document, "The Forest Service Ethics and Course to the Future," Chief Jack Ward Thomas lays a solid foundation for addressing forest health issues (USDA/FS 1994a). Two major focus areas identified in this publication include ecosystem protection and ecosystem restoration. Actions called for under these focus areas include: "Understanding the roles of fires, insects and disease, and drought cycles in shaping ecosystems, and bringing that understanding to bear in management" (Ecosystem Protection); and "Promoting the use of prescribed fires in ecosystems that evolved with a fire regime . . . (Ecosystem Restoration).

The Forest Service's Western Forest Health Initiative, kicked off last fall, is a good start in putting this vision into action (USDA/FS 1994b). But continued strong Forest leadership and follow-through will be the key to ultimate success.

The Western Forest Health Initiative illustrates the barriers that will be encountered. It is clear that public trust is a significant problem. Some people will oppose any direct human intervention in forest ecosystems (although humans have been doing so for millennia). They will view use of commercial timber harvesting, even in support of ecosystem restoration objectives, as "business as usual." Controversy is likely to be particularly intense if NFS roadless areas are involved. People

will also be opposed to seeing smoke in the air on a regular basis.

On a positive note, many of the areas that have been the most profoundly affected by fire exclusion are lower elevation areas that are already roaded. Many have relatively moderate topography, which will greatly facilitate use of logging equipment and prescribed fire. The Forest Service should begin in these areas to demonstrate what the end result will look like and try to build a reservoir of public trust.

But long term staying power will be needed. Forest health problems were decades in the making will not be solved overnight. If the Forest Service does not enter the forest health arena recognizing the long term nature of the issue, but instead treats it as an "on again, off again" issue, it risks losing considerable agency credibility.

LEGAL AND ADMINISTRATIVE BARRIERS TO ACHIEVING FOREST HEALTH OBJECTIVES

It is not the purpose of this paper to explore in depth the legal and administrative barriers to implementing forest health goals. These have been documented elsewhere (Sampson et al. 1993; USDA/FS 1993b; USDA/FS 1995). Briefly, however, they include:

1) Agency aversion to risk and controversy. Public aversion to smoke and the aversion to the risk of escaped prescribed fire by Forest Service managers discourages National Forest managers in their use of prescribed fire, even when projects are approved and funded.

2) Piecemeal and uncoordinated implementation of federal environmental laws. The Endangered Species Act, Clean Air and Clean Water Acts, and other federal environmental laws by their nature tend to encourage a piecemeal and ad hoc approach to federal land management. Unfortunately, agency regulations and bureaucracies act to compound this tendency. The bureaucracies of the lead agencies for these laws tend to focus on the short-term impacts of projects, while ignoring the long-term risks of failure to take the actions necessary to restore forest health. An example are the guidelines for the protection of the Mexi-

can spotted owl, which mandate the maintenance of large areas of Southwestern forests as multi-storied types. Such conditions are highly conducive to conflagration events which seldom occurred under pre-European conditions. They are certain to be unsustainable over the long term.

In addition to their short-term bias, the analysis processes established pursuant to these laws are very costly, time consuming, and provide considerable opportunity for interest groups to intervene to block proposed actions.

3) An overly narrow focus and short term perspective taken by some Forest Service assessments and studies. Despite the profound effects that increasing forest density has on hydrological functioning (e.g., dry season low flow rates and their critical importance to fish and other aquatic life), this factor has been virtually ignored by many Forest Service regional, forest, and watershed level assessments of fish habitat. The historic role of aboriginal fire in shaping Western forest ecosystems similarly has been largely ignored. Such assessments often result in delaying management action while more information is gathered, even though some actions could be taken to address forest health, such as some salvage and thinning in already roaded areas, with very modest adverse short-term environmental consequences.

4) Lack of consistent, reliable information on the extent of forest health problems and on the treatment measures that will be needed to address them. The Forest Health Monitoring grid has not yet been established in the West, although work to do so is beginning. Forest Inventory and Analysis (FIA) provides reasonably good forest trend information on non-federal lands in the West. Unfortunately, NFS forest-level data is often not consistent with FIA data (and is very often inconsistent with data of adjacent National Forests). There currently exists little data on reserved forest-lands, such as Wilderness and National Parks, or on forestlands of low productivity. Reserved and low productivity forestlands comprise 45 percent of all NFS forestlands in the West. Information on treatment needs for forest health is also poor, and currently provides little basis for prioritizing federal expenditures at a national level.

The net collective effect of all of these barriers has been a strong bias in favor of delay, even in the face of strong Agency public statements on the need for prompt action. Such statements are well placed on this issue. The reality is that time is running out for taking effective action to address Western forest health problems. The time to act is now.

SUMMARY AND CONCLUSION

The forest health and fuel buildup problem is likely to be the most challenging resource issue to face the Forest Service over the next two decades. It will be challenging intellectually because it will cause the Agency and public to rethink some long standing images of forests and the role of humans in shaping them. It will require the Forest Service and the forest conservation community to come to grips with the often divisive issue of human intervention in natural forest ecosystems.

It will also be challenging physically, economically, and organizationally. Key to success will be Forest Service leadership—its persistence and effectiveness—in carrying through on a long-term public communications effort and on the necessary actions in the field to "walk the talk." A good groundwork has been laid in Chief Thomas' "Course to the Future" and the Western Forest Health Initiative. However, some actions of the Forest Service and other federal agencies run counter to the stated objective of aggressively addressing forest health problems. Failure to act in a positive and coordinated way to deal with this issue is likely to have serious long-term effects on both National Forest ecosystems and to the Forest Service's own credibility.

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Ecosystem Management, Forest Health, and Silviculture

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Abstract.—Forest health issues include the effects of fire suppression and grazing on forest stands, reduction in amount of old-growth forests, stand structural changes associated with even-aged management, changes in structure of the landscape mosaic, loss of habitat for threatened species, and the introduction of exotic species. The consequences of these impacts can be evaluated using an ecological approach based on conservation biology and several subdivisions of ecology. These disciplines provide a basis for assessing how the forested landscape has been altered from earlier conditions and for determining the potential consequences of these changes on forest health. Forest health issues are multiscaled, and landscape approaches may be especially helpful in identifying silviculture needs and approaches for improving the forest condition. The study of reference conditions and conducting a coarse-filter analysis are especially useful for identifying how existing conditions succeed or fail to maintain a healthy forest landscape.

INTRODUCTION

Forests in most areas have been altered from their natural state as a result of human activity. These effects resulted from forest management and timber harvest, grazing, introduction of weedy and exotic species and suppression of wildfires, as well as encroachment by rural and urban development. Even though certain features of forests were adversely impacted by these activities, past treatment of forests in many cases does not result in obvious loss of tree health at the individual level, making certain ecosystem or forest health problems hard to detect. Forests that were harvested in past decades, even by clearcutting large areas, often have regenerated and are growing vigorously. In many grazed stands, trees appear to be productive. Where fire suppression has seriously altered stand structure in forest types that normally experienced fire, stands usually contain large numbers of trees that appear healthy.

Even when forests appear to be healthy, their condition may be far from ideal for sustaining their productivity and for sustaining features in the landscape important for conserving biodiversity. For example, fire suppression in ponderosa pine, caused initially by heavy grazing and later by a policy of putting out small fires, has resulted in much higher stand densities than might have occurred historically (Covington and Moore 1994). In turn, this may have contributed to outbreaks of mountain pine beetle that have been severe in some heavily-stocked stands. When fires have occurred in dense stands, they often have burned much more intensely than they would have historically, killing many trees and either resetting the stand back to the regeneration stage or even putting the site on an entirely new successional trajectory. Similar conditions are found in mixed conifer and other forest types.

At larger scales, the condition of many landscapes also has been altered in ways that have left the landscape considerably different from the historical condition. The landscape mosaic may consist of healthy forest stands, but if a significant component has been removed or reduced in occurrence, or if the landscape has been fragmented or

unnaturally connected, the condition of the forest landscape may be far from ideal. As an example, old-growth forests have been depleted in many regions, resulting in a loss of habitat and forest function not readily substituted by other seral stages (Kaufmann et al. 1992).

The consequences of altering landscape mosaics are not completely known, but it is becoming increasingly clear that landscape pattern influences processes that operate at landscape scales. Impacts of fragmentation, including alteration in the mix, spatial extent, and spatial arrangement of seral stages, may have strongly negative effects on conserving historical biodiversity through habitat loss, isolation effects on reproduction, dispersal, and other migration processes, and population and community processes associated with edge and matrix effects (Fahrig and Merriam 1994; Saunders et al. 1991). In addition, alterations of the landscape scale pattern of distributions of stand structures may rescale keystone processes such as fire (Holling 1992; Turner and Romme 1994; Turner et al. 1993).

Some of these problems with forest or landscape conditions are apparent, but many have not been easy to recognize because many changes have been slow, and we tend to view existing conditions as normal and acceptable. The effects on forest structure and composition resulting from fire suppression went undetected for decades by most foresters and ecologists until early photographs or inventories were examined to determine how earlier stands were structured. Reductions of the old growth seral stage occurred incrementally, and it was not until old-growth forests in the Pacific Northwest became limited in extent that the amount of old growth in the landscape became an important issue. Similarly, landscape fragmentation has become a concern as a result of extensive modification of past forests and encroachment associated with road-building and population increases, particularly in mountain valleys and adjacent to urban centers (Kaufmann and Boyce 1995). In addition, forest insects and pathogens once treated as pests and stresses are now are recognized increasingly as forest regulating and control organisms (Haack and Byler 1993).

Forest management is undergoing a transition from a traditional silvicultural focus on timber production and multiple use ('utilitarian' silvicul-

ture, Kolb, this volume) to couching silviculture in an ecological approach to land stewardship (Swanson and Franklin 1992). Consequently, good silvicultural practice involves the use of silvicultural tools to address forest management in ways that place increased emphasis on sustaining or restoring conditions in the forest landscape. The challenge of forest management is to find ways to meet commodity needs while conserving ecosystem functions and long-term sustainability. Thus a critical need is for a systematic, defendable process for identifying how new management practices can help resolve ecological (e.g. forest health) problems found in present forest ecosystems and at the same time allow for commodity production without adding to or exacerbating existing problems.

EVALUATION PROCESSES

Forest management on National Forest lands focuses on ecosystems and long-term sustainability more clearly than it has in the past. Consequently, the context within which silviculture now occurs includes a perspective from additional disciplines that were not commonly addressed in earlier management. These include conservation biology and subdivisions of ecology dealing with landscapes, disturbances, and restoration. Conservation biology provides information regarding the conservation of biodiversity and factors that influence biodiversity and is often single species oriented. Landscape ecology addresses not only spatial and temporal hierarchies of scale, but also multiple levels of organization (species, communities, ecosystems). It addresses the roles of pattern, such as of seral stage and habitat type distribution, in ecosystem composition and function. Landscape ecology also focuses on processes that occur at larger scales than have been traditionally studied at tree or stand scales, such as migration of animals and plants, certain disturbances, hydrological processes, and land use. Disturbance ecology provides an understanding of the often non-deterministic way in which ecosystems change over time through disturbance phenomena such as fire, wind, drought, or insect and disease outbreak. Restoration ecology helps address the possibilities and limitations of recapturing ecosystem features lost or made rare by past human impacts on eco-

systems. Thus silviculture, in the context of an ecological approach to land stewardship, requires a systematic use of information from these additional disciplines to assure that forest management meets the goals of long-term sustainability and conservation.

Ecosystem assessments are now accepted as the basis for determining the ecological status of forest and rangeland systems (Bourgeron and Jensen 1993; FEMAT 1993). A number of questions, which should be applied at multiple scales, may be addressed by the assessment process. For example, what is a reasonable model of the structure of the reference or historical landscape (stand, etc.)? What is the structure of existing landscapes and stands, and what are the consequences of differences from historical conditions? What events or practices (e.g. fires, fire suppression, logging, grazing, urbanization) contributed to the development of the existing landscape or stand structure? What are the temporal changes in landscape and stand structure, both with and without significant human impacts? How do changes in landscape structure affect species, communities, or ecosystems? What are the impacts of introduced species, or of native species that have become weedy as a result of human alteration of ecosystems? What future scenarios are probable under different types of management

strategies, and what are the consequences of these alternatives on biodiversity and sustainability?

Kaufmann et al. (1994) outlined a process for an ecosystem needs assessment to identify specific ecosystem needs for conserving or restoring ecosystem structure, composition, and function. The assessment process (fig. 1) involves selecting an analysis area, evaluating the current status of the area relative to its historical condition using a coarse-filter analysis process, and then addressing rare or threatened components in the analysis area with a fine-filter analysis. While an ecosystem analysis may focus initially on a relatively small area, a complete ecosystem needs assessment ultimately must involve a wide range of spatial and temporal scales.

Reference conditions help characterize the variability associated with biotic communities and native species diversity in systems not severely impacted by human activity. They are examined to learn about the historical condition of vegetation and associated biodiversity and the ecological processes that affected them (fig. 2). Reference conditions provide critical information about the range of variability of natural conditions, or at least of conditions much less influenced by human impacts than present or recent conditions provide. A study of earlier conditions provides insight regarding soil capabilities and potential vegetation, landscape structure, natural disturbance patterns
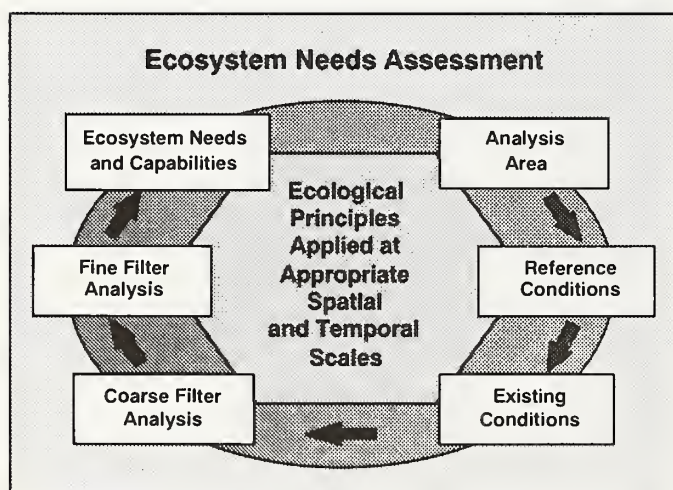
Figure 1.—Ecosystem needs assessment process for identifying ecosystem needs and capabilities in the context of ecological principles applied across spatial and hierarchical scales (from Kaufmann et al., 1994).
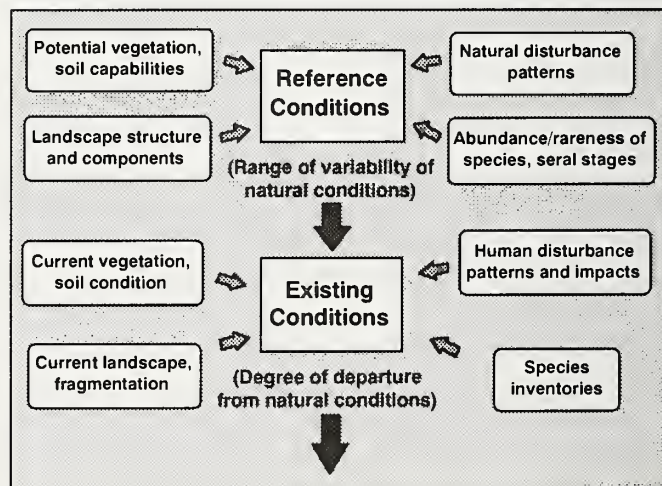
Figure 2.—Factors addressed in analyzing reference and existing conditions in the ecosystem needs assessment process.

that contribute to landscape structure, and the abundance or rareness of components of the system.

Reference information is often widely available (Kaufmann et al., 1994, Table 2). In a study of reference conditions on the Lincoln National Forest, we have assembled a large amount of information for characterizing the historical condition of the Sacramento Mountain ecosystem. Information sources include General Land Office surveys, historical timber inventories, early logging records, dendrochronological records of fire and insects, historical maps of fire occurrence and extent, etc. These information sources allow us to estimate historical forest extent, composition, and structure, and the extent and intensity of natural disturbance phenomena such as fire and insect outbreaks. While pre-European human influences may have been large in some areas, archeological evidence also may indicate relatively limited early human impacts in other areas, and in these areas knowledge of conditions at the time of European settlement may be especially instructive.

Information on existing conditions is available from more obvious sources such as existing inventory records, aerial photographs, etc. Increasingly these data are available in GIS formats that lend themselves to multiscale, spatially explicit analyses. The assessment process involves the development and use of three types of maps. Base maps characterize the biophysical environment, including both physiographic and environmental information. Maps of historical and existing ecosystem patterns provide an understanding of species and community distributions and disturbance events such as land use changes and fire, and their changes over time. Maps of historical and existing conditions must be developed in appropriate ways to avoid differences in criteria that confound map comparisons. Derived maps are often developed as research tools for examining and modeling species and community responses to disturbance, simulations of probable future ecological scenarios, etc.

The weakness of using only existing conditions in the assessment process is that existing conditions provide no or very limited insight into the impacts of management practices or other human impacts on ecosystem sustainability and conservation of biodiversity. It is incorrect to assume that

existing conditions indicate a sustainable, healthy basis for identifying desired conditions; they may, in fact, indicate the opposite. Thus the comparison of existing conditions with reference conditions is critical for determining the degree of departure of existing conditions in the landscape from historical conditions. Whether or not we use reference conditions as a template for future landscapes, reference information provides important knowledge needed to avoid pitfalls in management practices that often have led to poor landscape or ecosystem conditions such as unsustainability, reduced productivity, and reduced biodiversity.

Coarse-filter analyses are used to evaluate how well the existing landscape mosaic provides the mixture and spatial distribution of habitat types and seral stages expected under more natural conditions (fig. 3; Bourgeron and Jensen 1993). It is argued that the proper mixture and arrangement of vegetation in the landscape protects 85–90 percent of biodiversity (Hunter 1990, 1991). Thus the coarse-filter approach provides a basis for determining, for example, how much old growth should exist in an area, how it should be distributed spatially, and whether or not adequate amounts and appropriate spatial distributions of old growth presently exist. Using the old growth example, it is probably incorrect to assume that historical forested landscapes were entirely in an old growth condition, especially in regions influenced by large scale disturbances such as fire and wind. It is also
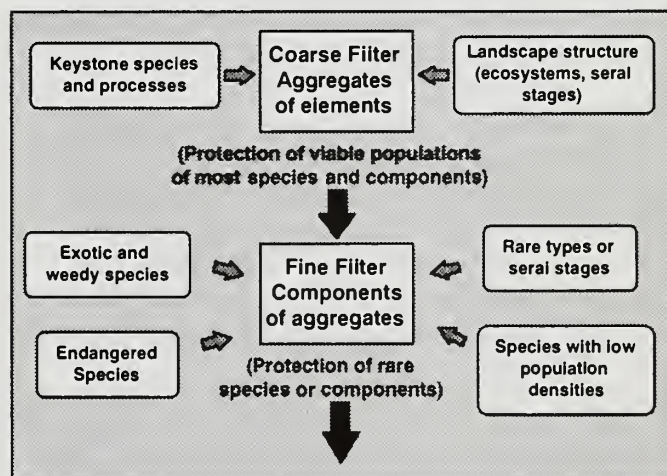
Figure 3.—Factors addressed in the coarse-filter and fine-filter steps of the ecosystem needs assessment process.

probably incorrect to assume that only 5 or 10 percent of historical landscapes was dominated by old forests, as often prescribed in Forest Plans. The coarse-filter analysis of reference conditions helps determine the extent of forested landscapes that were old-growth without intensive logging and unnaturally large scale catastrophic fires, and comparison with existing conditions helps determine if an ecosystem need exists to bring the old-growth component into closer alignment with the historic ecosystem condition.

The fine-filter analysis is concerned with specific components of ecosystems that are uncommon or rare. The usual concern addressed by the fine-filter analysis is rarity of specific species, seral stages, or habitat types. However, the process may be equally useful for assessing the introduction of exotic species or for evaluating how endemic species become weedy through changes in habitat conditions. In either case, the fine-filter approach focuses on ecosystem or landscape components not observed or measured by the coarse-filter analysis.

Underlying the analyses of reference and existing conditions with the coarse- and fine-filter approach are principles of conservation biology (Kaufmann et al. 1994; Grumbine 1992, 1994) and information and approaches from the other aspects of ecology previously discussed. These principles help assure that species, habitats, and processes are protected by focusing on sustaining ecosystem structure, composition, and function. The principles and analyses do not focus simply on one spatial scale such as a stand. Rather, the principles and analyses are applied hierarchically over space and time using approaches and ideas from landscape ecology, with precautions regarding the blending of information derived from and pertinent to the various scales. This increases our understanding of the impacts not only of past changes in forested ecosystems and landscapes, but also the likely future changes, particularly those brought about by management practices and population increases.

The outcome of the ecosystem needs assessment process is the identification of ecosystem needs. These needs focus specifically on the ecological features of ecosystems and landscapes that are found to need attention for conserving or restoring

the condition of these systems. They are not meant to address the economic and social elements that enter into decision deliberations. The advantage of the ecosystem needs assessment process is that it provides an evaluation of ecosystem and landscape well-being independent of economic and social concerns, and it allows for a specific focus on ecosystem sustainability and protection of biodiversity. Thus the ecosystem analysis process helps determine, for example, what should be done to ecosystems to provide or protect adequate mixtures of seral stages in the landscape, protect or restore riparian areas, restore critical habitat for threatened species, protect against negative impacts of introduced species, or guard against negative effects of urban encroachment.

Ecological, social, and economic needs are blended in the decision-making process (Kaufmann et al. 1994). It is in this process that the consequences of various courses of action are considered. The use of ecological guidelines in making decisions helps focus on meeting economic and social needs in ways that lead to biological integrity of ecosystems and ecological, economic, and social sustainability (fig. 4). This approach also helps identify the trade-offs and ecological costs of operating outside the ecological capabilities of ecosystems (Allen and Hoekstra 1994). These include the loss of species, degradation of environments, social dissatisfaction, and economic instability.
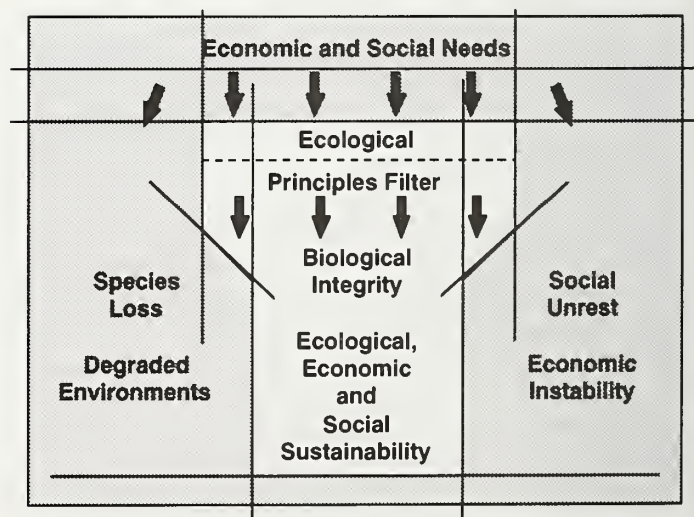
Figure 4.—Consequences of meeting economic and social needs in ways consistent with or inconsistent with ecological principles (from Kaufmann et al., 1994).

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SILVICULTURE BASED ON AN ECOLOGICAL APPROACH FOR LAND STEWARDSHIP

The ecosystem needs assessment process often may identify specific changes recommended in the landscape to maintain or improve the forest or landscape condition. The adjustments may involve treatments of structure or composition of forest stands that would contribute to the restoration of healthy conditions or that would assure production of goods and services while sustaining the structure and function of healthy ecosystems.

Clearly the context for silviculture has changed. It is no longer acceptable for forest management practices to focus on wood production without considering the long-term consequences related to ecosystem sustainability. On the other hand, standard silvicultural practices such as tree removal and the use of prescribed fire may be entirely appropriate tools to accomplish ecosystem goals, provided they are used innovatively to meet prescriptions for forest stands based upon specific ecological goals and maintaining sustainability. These innovations may include, for example, live tree retention, aggregation of harvest areas to allow higher proportions of interior species, manipulations conserving the forest/stream relationship, and evaluations based upon residual diversity rather than residual stand density (Franklin 1989; Swanson and Franklin 1992). Thus ecosystem-based silviculture may result in significant on-the-ground treatment of forest stands where the primary reasons may involve non-traditional factors such as conservation of habitat types or seral stages, restoration of landscape components and processes, or emphasis on natural disturbance processes at both large and small scales.

The challenge to everyone concerned with the management of forested ecosystems is to determine how silviculture can and must play a role in regulating the conditions of forest systems such that their ecological integrity is conserved or restored, and where possible to provide for the safe production of useable goods from those systems. While to some degree and in some locations this shifts the traditional commodity-oriented goals of silviculture to a more secondary role than in the past, the silviculture profession provides many of the tools for accomplishing the changes identified in assessment processes as necessary for sustaining ecosystems for the future.

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Forest Ecosystem Health in the Inland West

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Abstract.—For the past four years, American Forests has focused much of its policy attention on forest health, highlighted by a forest health partnership in southern Idaho. The partnership has been hard at work trying to better understand the forests of the Inland West. Our goal has been to identify what is affecting these forests, why they are responding differently to climate stress than they did in the past, and what needs to be done to improve their health and resilience. Findings to date suggest that disruption of forest ecosystem processes and functions has significantly altered the natural role of fire in the region, particularly in the low-elevation, long-needled pine forest type. The result is millions of acres of unhealthy forest that do not meet the needs of society, and according to several scientists, may be on the verge of ecological collapse. The expansion of our early work has led to several features in regional and national media, and opportunities to share our findings and better inform interested members of Congress. A national survey on forest management commissioned late last fall gives us an indication that the public is generally supportive of management rather than letting nature take its course. However, public perceptions with respect to forest health and the role of fire suggest a need for more information and education on these issues. With the current volatile debate on salvage logging after the 1994 fires raging throughout the West, there is a considerable need to continue to raise awareness on forest health within the federal agencies, with the general public, and with policymakers.

For the past four years, a Forest Health Partnership consisting of American Forests, Boise Cascade Corporation, the Boise National Forest, the Idaho Department of Public Lands, the Intermountain Research Station of the Forest Service, and the University of Idaho has been hard at work trying to better understand the forests of the Inland West, a huge geographic region that stretches from the coastal ranges to the Plains; from Canada to Mexico. Our goal has been to identify what is affecting these forests, why they are responding differently to climate stress than they did in the past; and what needs to be done to improve their health and resilience.

As most people are aware, the forests in this region are discontinuous and spread out, often in remote locations and harsh environments. Many of them, including many of the long-needled pine forests, are on the edge of forest adaptation, adjoining either deserts, grasslands or high alpine areas, and major environmental or ecosystem shocks could change them dramatically—even to non-forest.

Throughout the region, one can find forest sites where the presence of dead and dying trees is the most dominant and visible feature. These sites pose a critical wildfire risk, and the prospect of losing the entire forest stand looms large. Even where they look outwardly healthy, Inland West forests may be at serious risk. Dense stands of trees, often representing a much higher percentage of fir trees than what existed in pre-settlement times, occupy much of this landscape.

And we must keep in mind that when we are talking about forests, we're talking about entire complex ecosystems. A forest with its major vegetative component—trees—seriously out of balance

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cannot have normal stream flows, nutrient cycles, or wildlife habitats. The fact that these forests exist in a condition that today offers high recreation and environmental value is important. It is also subject to dramatic and sudden change. If we prize these values today, we need to consider how best to maintain them through our actions, because time is not on our side.

One of the major achievements of our Forest Health Partnership has been a series of reports and findings that are clarifying the urgency of forest ecosystem health problems, not only on the Boise Forest, but throughout the Inland West. Results also document the great need for effective management responses.

A June 1–3, 1993 Forest Health Symposium, "Forest Health in the Inland West," held in Boise, Idaho, outlined the nature of the emergency. Participants concluded that over-dense tree stands, species composition shifts from pine to fir, fire suppression policies, and past timber harvest practices were the primary, underlying causes of deteriorating forest health. They also recommended the use of prescribed fire and thinning through timber harvest, as urgently needed measures to reduce fir species, increase pine species, and restore ecosystem resilience (Adams and Morelan 1993). Most of the speakers equated the concept of forest health to ecosystem health, but others challenged the Forest Service to look beyond trees and their condition to "think for a minute about the entire forest ecosystem—the soil, the wildlife, the watershed, the fisheries" (Gehrke 1993).

In late August 1993, American Forests hosted a policy analysis of the Boise's Forest Health Strategy. This analysis was a follow-up to the June Symposium. A group of interested citizens, organizations, agencies, and partners gathered to discuss the Forest Health Strategy. They generally validated the strategy, but they also urged the Boise to merge the forest health strategy into a broader forest ecosystem health approach. The group strongly endorsed adaptive management principles for application in refining the forest health strategy (Sampson 1993).

The partnership convened a workshop in Sun Valley, Idaho, in November 1993, to assess the current state of scientific knowledge about the health of forests of the Inland West. The workshop brought together a diverse group of scientists and forest managers to produce a current, accurate, and credible synthesis of information about forest ecosystem health (Sampson et al. 1994). Workshop participants agreed that in many areas of the Inland West, forests across large landscapes are dying faster than they are growing (O'Laughlin 1994). Participants also agreed that without application of needed silvicultural treatments within 15–30 years, including prescribed fire, and commercial and precommercial thinning, there is great danger that over the next century the region's forest legacy will be one of large, uniform landscapes recovering from wildfires and other ecosystem setbacks on a scale unprecedented in recent evolutionary time (Covington et al. 1994). Another key observation was that high fuel loads made up of largely dead and dying trees, resulting from the long absence of fire, result in fire intensities that cause enormous damage to soils, watersheds, fisheries, and other ecosystem components (Sampson et al. 1994).

Sampson et al. (1994) pointed out that the question of risk is at the heart of options facing people concerned with Inland West forests. They also stated that the current ecological conditions in the forests of the Inland West lead to the conclusion that ecosystem management will demand increased management. All participants agreed that the costs and risks of inaction are greater than the costs and risks of remedial actions, and that the challenge to managers on these threatened forests is to provide preventive treatment as a means of protecting ecosystem resources. Finally, participants accepted the concept of "historical range of variability" as useful in determining ranges of desired future conditions, and in establishing limits of acceptable change for ecosystem components and processes (Morgan et al. 1994).

This is consistent with the mission of American Forests, which for 120 years has been a champion for forest conservation based on the use of the most current science and public values. Obviously, over the years, both science and public values have changed, and so has our approach.

But some things stay pretty much the same—including our magazine, which has just celebrated 100 years of continuous publication.

One of the major goals of American Forests in recent months has been to bring the Inland West forest health situation to national attention. Along the way, we've identified some principles that we think are useful in thinking about forest health—in all regions of the world. First, we must recognize the major paradigm shift that has taken place in describing forest ecosystems. Instead of speaking about "natural balance," "equilibrium," or "climax conditions," ecologists today talk more about constant change, and the chaotic nature of that change. We also feel that any approach, to be successful over the long term, has to understand the adaptive nature of management, and the possibility that what we know today could significantly change as we go along, learn more, and watch forests respond to the combination of management intervention and environmental change. We are also convinced, however, that new federal policies are needed to allow federal forest managers to undertake truly adaptive ecosystem management, and to build the collaborative relationships at the forest level that are needed to institute truly successful management.

Another part of our recent work on forest health came about through the hearings of the National Commission on Wildfire Disasters, which was chaired by Neil Sampson of American Forests. In the Commission's field reviews, which extended right up to the Los Angeles firestorm of 1993, a consistent message was heard from land managers and fire fighters alike. If these forests are over- protected from fire, and under-managed to reduce fuels, the result is catastrophe. This is particularly difficult in the many areas where urban growth adjoins the forest. Even in areas where the dominant character of the land remains essentially rural, the presence of homes and other structures makes firefighting an enormously complex and dangerous task. The basic conclusion of the Commission was that the dry forests in the Inland West are going to burn. The question is not whether, but when. And in today's forest condition, virtually any fire will flash to the crowns of the trees and kill most, if not all of the stand. This isn't a normal fuel condition, and you won't have normal wildfire behavior. It is no coincidence that so many of the 1994 news stories quoted people as saying that they "never saw one behave like this before."

One of the major public policy challenges, clearly, is that the costs of wildfire suppression are
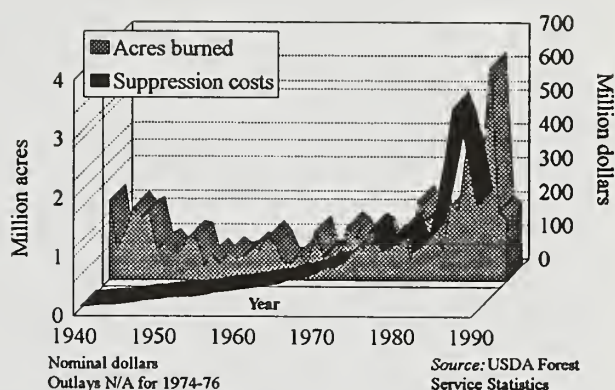
Figure 1.—Wildfire acres burned in 11 western states and Forest Service fire suppression outlays for the U.S., 1940–90.

rising dramatically. Although there is a great deal of annual variation, the recent trends are steeply upward, and the near $1 billion federal fire suppression cost in 1994 is only the beginning of what could continue to be a rising public obligation (fig. 1). The Commission's conclusion was that, unless forest health was addressed quickly, by a major change in management approach on the federal forests, these costs would keep trending steeply upward (National Commission on Wildfire Disasters 1994).

The other side of that coin, however, is that there are solutions today that were unavailable only a few short years ago. The high price of wood makes helicopter logging feasible in many places, for example, even when the logs removed are only a thinning cut composed largely of dead and dying fir trees. The completed job will often be almost invisible, particularly where careful slash disposal and cleanup has been done. The forest will look virtually untouched, but it now has a chance to thrive, and to handle a wildfire without losing the overstory of valuable ponderosa pines. These kinds of results are often easier to achieve when a special kind of contract—called an end-results, stewardship contract—can be used instead of a timber or salvage sale (Sample and DiNicola 1994). These contracts, which have been tested on several western forests, will need to be authorized in federal law before they can be more widely used in the treatment of federal forests.

One challenge, of course, has been to make the forest health situation known to a national audience, including a skeptical Congress. Doing that required more than anecdotal evidence, and that is where the forest health partnership focused its efforts. Forest Service researchers documented the history of some forested plots, where evidence supporting forest composition extended backwards over four centuries. In a research plot on the Boise National Forest, for example, land that supported a savannah forest of 25–30 pine trees per acre for centuries is now trying to grow over 550 mixed pine and firs (Sloan 1993). Over half those trees are firs, and over half are dead. This is a change directly related to fire suppression, which is directly connected to the settlement of the region in the late 19th Century. Pioneers eliminated Native American fire usage, grazing livestock reduced the carpet of fine fuels that carried summer fires over huge areas, and settlers put out every fire they could handle, in order to protect their property. Fire suppression may have become much more organized as the Forest Service and state agencies gained capacity, but the attempts to eliminate wildfire from western lands started with the first wave of settlers, and has been effective in keeping fire out of some of these systems for over 100 years now (Pyne 1982).

The importance of fire exclusion in these systems can be illustrated by illustrating the way carbon is cycled through them, and comparing that to other types of forest. In warm, moist climates such as that which grows the great Douglas-fir forests of the Pacific Northwest coastal region, carbon is captured into wood by forest growth, and a very high percentage of that carbon is recycled out of the forest through decomposition. Organisms of all types live in and on the wood that falls to the forest floor, and although the large pieces rot slowly, most of the carbon is eventually recycled in this manner. Fire enters these forests very infrequently, maybe every 250 to 1,000 years, and recycles the rest of the growth. Over long enough time periods, the carbon cycle is probably fairly well balanced in this manner (fig. 2).

In the cold, dry environments of the Inland West, however, microbial decomposition is very limited. These climates are so cold in winter and dry in summer that microorganisms don't get much time to work effectively. Wood that drops to the ground
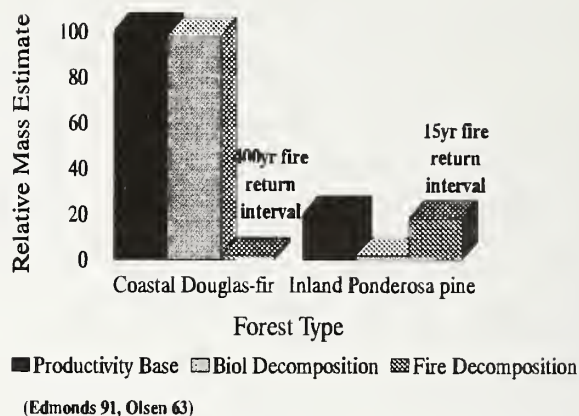
Figure 2.—Base productivity/decomposition.

may lay there for decades, and layers of pine needles and bark flakes build up around trees. In these systems, fire has historically provided the carbon recycling device. Before the region was settled, fire visited every 10–20 years or so, burning the fuels on the forest floor and recycling the carbon on a regular, but low-intensity basis (Agee, 1993). These ground fires killed small trees, but left most of the large ones unharmed. Thus, over time, a forest of fire-tolerant species such as pine or larch dominated much of the area.

Fire also liberated nutrients that were essential to all living things in the soil and forest, as well as favored those species that had grown to depend on fire as part of their life cycle. Thus, many of the forest's essential functions were changed dramatically as the forests continued to "miss" their normal fire cycles. A forest that has missed 6 or 8 wildfire cycles in the Inland West will now have huge carbon reserves awaiting recycling. In addition to huge loads of dead fuels in the trees, it may have larger-than-normal carbon supplies on the soil surface and in the top soil layers (fig. 3). When such a forest burns today, instead of a simple recycling of carbon that keeps both the aboveground plant growth and the soil carbon within normal ranges, the intense heats generated can result in significant soil carbon losses. This may translate into a damaged soil that cannot recover normally from the heat's damage, and thus, a forest ecosystem that may not be able to restore itself.
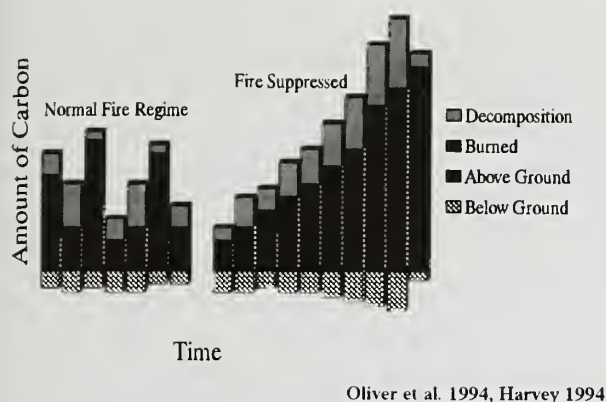
Figure 3.—Forest carbon cycle schematic.

The results of fire suppression show up in many ways, as researchers look to the forest for clues as to what is happening, and why. University of Idaho researchers, for example, looked at available timber survey records, which documented a major species shift in Idaho forests over the last 40 years (fig. 4) (O'Laughlin 1993). Ponderosa and western white pine are rapidly dwindling within Idaho forests, while Douglas-fir, true firs, and lodgepole pine are rapidly increasing. This forest has been changing rapidly through the last few decades.

We studied the data on moisture conditions, as reflected in the snow surveys taken on major forest watersheds by the Soil Conservation Service, and compared spring snowpack conditions with the available Forest Service data on insect damage and wildfire extent (fig. 5). What we saw was that when

moisture stress rose in the 1980's, the forest responded far differently than it did in earlier droughts (Sampson 1992), signalling that something different was happening this time, and raising the question "why?"

The papers from the Sun Valley workshop are contained in Volume 2, issues 1–4, of the *Journal of Sustainable Forestry*, and a hardcover book of those papers entitled *Assessing Forest Ecosystem Health in the Inland West*, is available through American Forests or the publisher, Food Products Press (Sampson and Adams 1994). The bottom-line conclusion from the workshop is critical. Any course of action in resource management entails risk—costs are usually immediate and certain; outcomes are usually uncertain. But today—given the situation in these forests—the costs and risks of doing nothing are greater than the costs and risks of taking action. It is promoted by some scientists, and widely believed in the environmental movement, that leaving wildland forests unmanaged and untouched is a way to protect values such as biological integrity and ecological protection. In a significant departure from that idea, which has attracted much controversy and debate, the scientists at Sun Valley said that the risks of severe ecosystem damage from doing nothing should be considered, and that they outweigh the risks and costs of treatment.

Our workshop report was given some publicity when it was released in March of 1994, but not all that much attention was paid until the wildfires of the 1994 summer began to break out. Then, tragi-

Figure 4.—Change in Idaho softwood growing stock volume on timberland for selected species, 1952–1987.
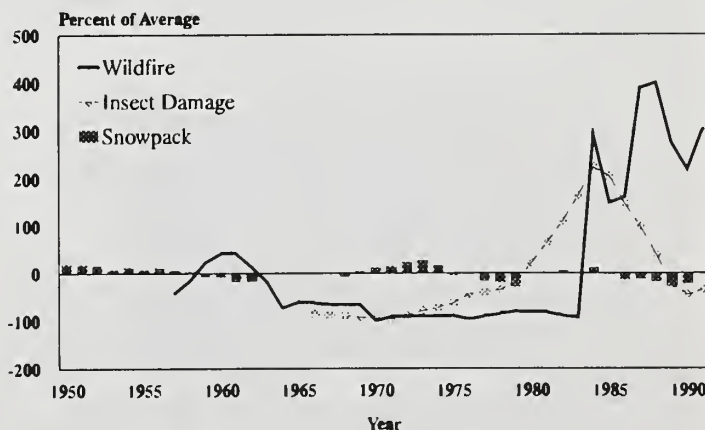
Figure 5.—Boise National Forest, forest health indicators.

cally, came the disaster on Storm King mountain, where the death of 14 firefighters brought the human costs of the wildfire challenge directly into every home in America.

That attention galvanized serious journalistic investigations, such as the MacNeil-Lehrer Newshour, which could take 12 minutes of national TV time to try and explain a situation that is too complicated for 30-second soundbites (*See* Knudson et al. 1994). Most importantly, this kind of media allowed time to point out that, for many forests where extreme risk exists, there are also enormous values that can be protected if proper actions are taken. Millions of acres of federal forest are now growing trees that are more than half-way toward an old-growth ponderosa pine condition that could mimic what the pioneers found. But these pines are surrounded by smaller trees, and fuels reach from the ground to the top of the trees. If a wildfire starts now, it will climb those dead, dry branches and set this system back 100 years or more. The hopes of an old-growth pine forest will be lost, many forest values will vanish for years, if not decades, and managers 100 years from now could be faced with another even-aged pine stand that will need to have intensive management to avoid another wildfire that kills everything back again.

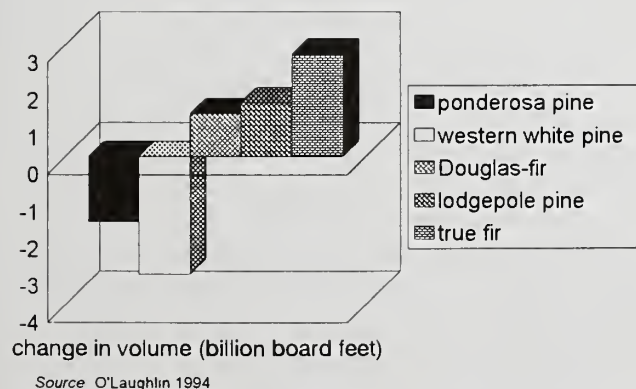But if those forests can be thinned, and the logging slash carefully burned, many areas can be set on the path to long-term forest health. Nutrient recycling will start up again with the slash burning, and a more normal carbon cycle will have been created by removing excess wood from the forest both through the thinning harvest and the cleanup fires. In some places, prescribed fire can be used without first thinning the trees and reducing the amount of fuel present. This is a difficult and risky treatment, but may be the answer to starting the forest health restoration process where the conditions are right.

Unfortunately, there are cultural and legal obstacles to the widespread use of prescribed fire. Although prescribed fire is accepted in the Southeast, events early this century kept it from being used in the Inland West. The light burning controversy of the 1920s, an argument over using prescribed fire as the Native Americans did, was won

by advocates of fire suppression, aided by public fears from early fires such as the 1910 Big Burn in Idaho and surrounding states (Pyne 1982). Clean air regulations created to protect human health set allowable smoke levels during a period when fire suppression masked actual baseline levels of smoke. Prescribed burns have the potential to create higher than legal amounts of particulate matter from smoke, and there are serious and legitimate health concerns about these added pollution levels. In large fires—fires that are likely much larger and hotter than historical fires for the region—episodic pulses of smoke threaten the health of communities downwind. Scientists are hard at work trying to show that frequent low-intensity fires such as prescribed burns produce the equivalent or less than less frequent stand-replacing fires over time (Schaaf 1995). Policymakers will need to look hard at these tradeoffs in relation to the Clean Air Act and state air quality regulations. Prescribed fires presumedly produce less smoke overall, and are manageable to mitigate health risks. Currently, the Western States Air Quality Resources Council, an umbrella group for local and state air quality regulators in the West, is attempting to take the lead on this issue (*See* WESTAR 1995).

These kinds of options were discussed at a September, 1994, conference in Spokane, Washington, and, again, given good discussion in the region's media (*See* Danielson and Sampson 1995; Knudson et al. 1994). Obviously, there are people who do not agree with these recommendations, and who still argue that the greatest danger comes from taking action to treat sick forests. Their voices have been heard by the public as well. Mainline media are quick to pick up on any controversy that exists.

As fall weather signalled the end of the 1994 wildfire season, an estimated 3.8 million acres of forest had been burned, and the controversy that made most headlines was over whether or not to salvage the dead merchantable timber from that land. The Forest Service, who were faced with most of the problem, are still caught in that controversy, which has now moved to the Congress and become even noisier and more divisive.

Most conservationists and managers agree that salvage is primarily an economic activity, and managers should be very conservative in applying

it to post-fire management. Salvage operations, either post-fire, or after other disturbances such as after insect-caused mortality, are valuable for economic reasons. They supply wood to mills that are now starved for raw material, and benefit local economies. More importantly, much of the money generated from salvage can and should go back to restoration work in unhealthy forests. Because of the ability for salvage sales to offset the cost of restorative treatments such as thinning, watershed rehabilitation, or prescribed fire, salvage is an important tool in overall restoration of forest health in unhealthy landscapes.

The forest health focus should be on restoration forestry, which is done mostly through treatments other than salvage. Although we have identified salvage as useful to the forest products industry and to offset costs of other treatments, it should be clear that a strategy focused on chasing volume of fire-killed timber salvage alone is wasting political energies, will not solve forest health problems, and disrupts managers and forest interests from working together to address real forest health problems.

The policy trap that we face is that unless pre-fire treatments can be increased, larger, more intense, stand-replacing wildfires are certain. This means more and more fire-killed timber to fuel salvage controversies, and less ability on the part of the agencies or the woods-working industries to apply preventive treatment to a shrinking base of green stands that could survive future fires if properly treated. So—the more that salvage dominates the forestry agenda, the more salvage there will be to do. Until, of course, most of the untreated areas are burned over. Then, the 21st century forestry will face the challenge of protecting young recovering forests, with few, if any, timber receipts to help fund the work.

For the most part, at American Forests we tried to stay out of the salvage battle, which we believe ought to be waged locally by looking at each individual situation and making sensible decisions in consultation with affected people. Every situation is different, and there are enormously important values at stake that must be considered. We chose, instead, to launch a three-year public education campaign, because we think the problem is going to be with us for a very long time, and a far

greater level of public understanding and support is going to be needed before real solutions begin to emerge. If we allow millions of untreated acres to suffer needless wildfire damage, and spend our energy fighting over salvage options, we will have missed the entire point, and billions of dollars in public money, as well as enormous environmental values, will be wasted as a result.

We started this educational effort by commissioning a public opinion poll on the subject. Our rather simplistic notion is that, if you are going to set out to affect public opinion, it would be nice to know where you stand at the start. We commissioned the public opinion firm of Frederick/Schneiders in Washington, who polled a sample of 1,000 registered voters across America, for national data with an estimated error range of 3 percent. What we found is, we think, both interesting and important (American Forests 1994) (fig. 6).

The first question we asked was, how would you describe the condition of the national forests across the nation, as well as in your region? Interestingly, almost three-quarters say they think their region's forests are healthy, even in the Inland West where the problems are so visible. On the other hand, they are less positive about forests as a whole. Forest health is a problem, they say, but its somebody else's problem. That is an attitude we need to change in several regions. The problems are at home, as well, for much of the American public.

We then tested voter awareness of the wildfire situation, asking if they thought 1994 experienced more, the same, or less wildfire than average. Here, half the people got it right, and almost two-thirds
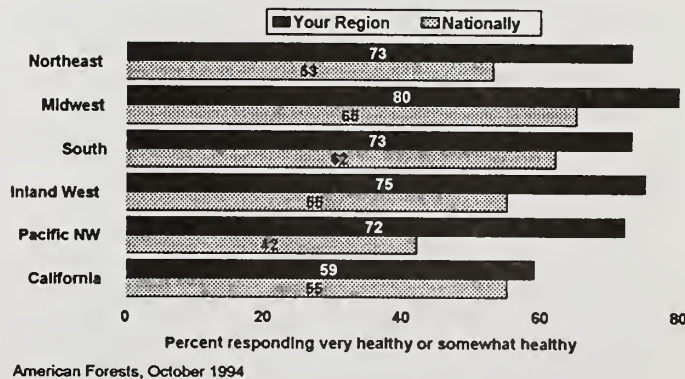
Figure 6.—What is the condition of national forests in your region and across the U.S.?

of westerners recognized that 1994 was a high fire year. In case you think these percentages are awfully low in the face of all the media publicity, rest assured that our pollster tells us that when half of the voters recognize something, that's significant. Clearly, however, the public does not yet recognize the connection between wildfire and forest health. Even westerners who knew that wildfire impacts were high in 1994 still rated their region's public forests as "healthy." In other words, the connection between unhealthy forests and major wildfire risks is not widely known.

One of the questions tested the controversy over whether we should impose human management on these forests, or let nature take its course. Here, 52 percent of the people came out in favor of management intervention, and that opinion was, again, most widely held in the West.

There have been suggestions that timber harvesting should be completely stopped in the National Forests. We checked that idea, and found 47 percent of voters supporting the continued harvest of timber, with 44 percent agreeing that timber harvest should be eliminated. Again, there were significant regional differences of opinion, with almost two-thirds of the people in the Pacific Northwest supporting timber harvest on federal forests.

After explaining what thinning was supposed to accomplish in terms of restoring forest health, we asked if people favored its use as a forest treatment. A higher percentage (51 percent) support thinning, but again, there are strong regional differences in the support for this idea, with 70 percent support in the West.

Returning to the wildfire question, we asked whether the Forest Service should try to extinguish all fires or let some burn. What we discovered is that public attitudes still favor extinguishing all wildfires, by a 55 to 36 percent margin. Interestingly, that point of view was particularly strongly held by the women polled in the sample.

Even after explaining how prescribed fire could help forests, people are still not certain that it is a good idea. They agree that it should be used, by a margin of 49 to 42 percent nationally, but only in the Inland West was there as much as a two-thirds majority favoring the use of prescribed fire as a means of improving forest health. If forest manag-

ers believe that the increased use of prescribed fire is important in these forests, they have a significant public education challenge to address.

Over half (51 percent) of the respondents favored the salvage of dead trees following wildfires. Again, the regional differences of opinion across America were striking, with support for salvage strongest in the western regions. When asked whether appeals and other legal delays should be shortened to facilitate salvage, however, public opinion was split 45 to 43 percent. Clearly, attempts to limit appeals or shorten review processes will need to be done cautiously and explained well to the public and, even then, should be expected to meet stiff opposition. The current controversy over the salvage amendments in the Appropriations Bill reflects the divisions on this issue.

The most opposition will be encountered when forest managers propose to build roads into roadless areas. People oppose building roads into roadless areas by a margin of 55 to 40 percent at the national level, and that general opposition extends into all regions. People value roadless areas, and so long as they think these areas are safer without roads, they will make that opposition felt. Where managers feel that a roadless area faces a high risk of destructive disruption unless it is treated, and that road access is essential to that treatment, they will have to explain the situation openly in terms of the risks and losses incurred in building roads versus the risks and losses likely if the area is left untreated.

When asked whose opinion they most trusted about forest management questions, 43 percent of Americans identified university scientists as having high credibility. Federal agency and environmental organization scientists are trusted by more people than timber company experts, except in the Pacific Northwest.

Finally, since this forest health effort of ours is tied to public policy and federal legislative proposals, we asked people whether or not Congress should write prescriptive legislation setting out the details for federal forest managers, or whether they should give the agencies more flexibility to manage in response to local situations. Here, the most overwhelming public consensus in the survey emerged. Congress should provide policy tools

and guidance—not forest management prescriptions—say an overwhelming 74 percent of Americans.

Part of the reason for that view may be based on the trust that Americans hold in public agencies. You will hear from some advocacy groups that the public doesn't trust the Forest Service. That's false. Public trust in the Forest Service is high. Three-fourths of the sample say they have a "very favorable" or "somewhat favorable" impression of the agency. Only 8 percent have an unfavorable rating, and 19 percent say they don't know. Other agencies and types of organizations were also tested. If you are interested, a full set of the questions and responses used in this poll can be purchased from American Forests.

This poll shows that Americans do not have a solid grasp of how forests work, especially the linkages between forest health and the role of fire in the forest. Changing that is perhaps the major educational challenge we face. However, while all this information on public opinion is very helpful and interesting to those of us who are working to shape public policy, the fact still remains that it does little to solve the forest health situation—or the risk of losing significant values—over millions of acres of western forests.

Those lands, so highly important for so many reasons, to so many people, deserve better care than we have been willing—as a public—to give them. Over millions of acres, managers need to be able to respond more quickly to fast-changing conditions. If we continue to spend all our time in preparing studies and fighting over whether or not to address these treatment needs, the natural forces such as wildfire will take those decisions out of our hands, certainly for many years, perhaps, in the most seriously-damaged places, for centuries. These choices aren't easy, but they are critical, and time is not on our side. Forest health must become the new rallying cry for public forest management well into the next century.

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Role of Disturbance

Disturbance Regimes and Their Relationships to Forest Health

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Abstract.—While planners deal with landscape issues in forest health, silviculturists deal with the basic units of the landscape, forest stands. The silviculturist manipulates small-scale disturbances and needs appropriate management indicators. Disturbance agents and their effects are important to stand development and are therefore useful as management indicators. More studies are needed to improve our understanding of the spatial and temporal patterns associated with various agents. We propose use of a disturbance profile to quantify small-scale disturbance regimes. This multivariate descriptor can assist making decisions on where, when and how to mimic, promote, suppress or tolerate natural disturbance.

INTRODUCTION

New attitudes and concerns for maintaining healthy forests have made planners and silviculturists more aware of the importance of natural disturbances in shaping forest landscapes and stands. Fire, insects and pathogens are no longer considered necessarily undesirable and are now recognized as performing valuable ecological functions and even promoting ecosystem health (Haack and Byler 1993; van der Kamp 1991). Small-scale natural disturbances induced by insects or pathogens at the gap or stand levels could even be used to achieve management objectives (Lundquist 1995b). However, such use of small-scale disturbance requires an good understanding of the spatial and temporal characteristics (disturbance regimes) of vegetation response and recovery (Lundquist 1995a, 1995b, 1995c). For describing and modeling disturbance regimes at the stand level, we have developed the concept of a multivariate, spatially-explicit disturbance profile

(Lundquist 1995b). This tool can assist silviculturists in making site-specific decisions on where, when and how to mimic, promote, suppress or tolerate natural, small-scale disturbances.

A HEALTHY FOREST

Forest health can be viewed from a number of different perspectives. The concepts of "tree health" and "stand health" are generally understood as complements of traditional tree and forest pathology. A healthy tree is one without damaging injuries or diseases, and a healthy stand is one without devastating infestations. Here, we use the term "forest health" in the sense of ecosystem health from the utilitarian perspective of satisfying management objectives as well as the ecological perspective of maintaining natural processes and structures (Kolb and others 1994; Shrader-Frechette 1994). Although the analogy of forest health with human health is flawed, it still provides a useful metaphor. All concepts of "health" include two principles: an identified goal and a comparison to some normal standard. In medicine, the goal is determined by ethics as preservation of human life or dignity; the normal standards are determined by clinical studies of selected populations. In forestry,

the goal on public lands is determined by policy as ecosystem management for sustainability, integrity and diversity; standards and guidelines are proposed by resource specialists and set by managers. The challenge is to determine how these abstract qualities can be measured and what reference sites to use for establishing standards (but see Lemons 1985).

DISTURBANCE

Forest ecologists and managers recognize that disturbance, as well as site factors and competition, determine forest species composition and succession. Disturbance is more than the destruction of vegetation; it is an opportunity for release and re-organization (Holling 1992). Disturbance increases ecosystem heterogeneity and responds to it (Knight 1987). The repetition of overlapping vegetation patches of various sizes and ages across the forest landscape demonstrates that disturbance is frequently recurrent and ubiquitous (see Reice 1994). Disturbance is also scale-dependent; disturbance processes at a lower level of the ecological hierarchy produce the vegetation patterns observed at a higher level (Allen and Hoekstra 1992).

The spatial and temporal patterns associated with the repeated occurrence of a given disturbance agent define its regime (Pickett and White 1985; Pickett and others 1989). These patterns are described by means and variances in location, size and shape of affected area, frequency, synchrony, seasonality, duration, rotation and intensity of the disturbance, the severity of damage, and synergysim among agents. The disturbance regime of a specific agent is spatially and temporally keyed to a characteristic scale: e.g., windthrows at a gap scale and ice ages at a continental scale (Delcourt and others 1983).

The effect of disturbance on landscape dynamics depends on the proportion of the area affected and on the ratio of disturbance frequency to recovery time (Turner and others 1993). Small-scale and large-scale disturbances are distinguished not by the areal extent affected but by the resulting variation in stand age distributions across the landscape. Landscapes with small variation in age distributions over time result from disturbance regimes that operate at fundamentally small scales

(canopy gap to stand). Large-scale disturbances (i.e., introduction of exotic species) or significant alteration of a disturbance regime (i.e., suppression of low intensity fires) can induce catastrophic changes into the ecosystem.

Because forest insects and pathogens are sensitive to host distribution, size and physiological condition, which are relatively uniform within patches, they are primarily agents of gap- or stand-level disturbance. In analyzing or treating infested stands, the silviculturist needs to be especially mindful of their effects on tree reproduction, growth and mortality within stands. The planner, concerned with the landscape patterns, should be aware of how insects and pathogens modify long-term succession and induce stand replacement. Both levels of the ecological hierarchy are relevant to ecosystem management and forest health (Allen 1994). Both levels are influenced directly or indirectly, respectively, by the small-scale disturbances caused by insects and pathogens.

Because agents such as fire, stem rust, bark beetles, root disease and mistletoe spread by different means and cause different types of damage, they have distinctive disturbance regimes that vary by forest type and condition. These differences can be illustrated by examples pertinent to the forests of the Sacramento Mountains, New Mexico (Mescalero Apache Indian Reservation and Lincoln National Forest).

Fire in the Southwestern Mixed Conifer Forest

One of our study sites in the mixed conifer forest of the Sacramento Mountains is the Delworth plot. This mesic, south-facing stand of Douglas-fir, white fir, ponderosa pine, and southwestern white pine was logged in the 1930s and again in 1969. The canopy is multistoried and contains many large-size trees. All recorded fires occurred before 1879, at a mean interval of 10 years; and these fires usually occurred early in the growing season (Huckaby and Brown 1995). This pattern of frequent, low-intensity fires in the previous century and their relative rarity in this century is typical of fire regimes in the Southwest (Swetnam and Baisan 1995). In contrast to the earlier low-intensity fires

which cleared undergrowth and maintained open stands of large-size trees, most recent fires in the surrounding forest have been high-intensity, stand-replacing crown fires. Fire regimes are influenced by forest conditions and management practices which affect fuel loading. Although fire has not occurred recently at the Delworth site, stand density and composition are suitable for a damaging fire.

Stem Rusts of Pine

The most important stem rust in the Sacramento Mountains is the recently introduced white pine blister rust (*Cronartium ribicola*). Because the outbreak is still expanding, the character of its disturbance regime has not yet been established here (Geils 1995). However, comandra blister rust (*C. comandrae*) in the lodgepole pine forests of Wyoming, a native rust with a well described epidemiology, can illustrate its likely spatial and temporal behavior (Jacobi and others 1993). Spores that infect pines are produced on an alternate host species (comandra) and wind-dispersed to pine hosts when suitable environmental conditions of high humidity exist. Incidence is high where pine hosts are in close proximity to alternate hosts (<200 m); moderate incidence levels occur many kilometers downwind of alternate host populations. Episodes of severe infestation appear at irregular intervals but are frequent enough that serious outbreaks can occur each decade. Infected trees may become girdled by a rust canker; girdled trees are killed or spike-topped. Where alternate hosts are in close proximity to the pine, the disease appears to have a contagious distribution on the pine; but where spores have been dispersed over a long distance, distribution on pine appears random. Local features of the disturbance regime of stem rusts result from interactions of host distributions, landforms, and meso-scale climate. These factors in the Sacramento Mountains are favorable for the severe outbreak of white pine blister rust developing there.

Bark Beetles

Bark beetles (Scolytidae) are important mortality agents of pine and other conifers throughout the southern and western United States (Schowalter and Filip 1993). At endemic population levels, mortality is usually restricted to weakened, diseased, or otherwise stressed single or small group of trees. Upon emerging from a brood tree, adults disperse to either nearby or distant trees. Epidemics arise when significant amounts of the preferred host become stressed by droughts, windstorms, or biotic agents such as mistletoe or root disease. When these conditions comprise a large proportion of the forest, outbreaks occur. During expanding outbreaks, beetle populations increase to numbers sufficient to kill trees which would have otherwise not been attacked. Disturbance regimes are determined by the abundance, distribution, size, and condition of the hosts; weather, predators and parasites also influence the timing of outbreaks. The roundheaded pine beetle (*Dendroctonus adjunctus*) is now epidemic in the Sacramento Mountains; the previous outbreak occurred in the mid–1970's (Parker and others 1975).

Root Disease

Root diseases are caused by various fungi (e.g., *Armillaria*) which spread by root contact, root-feeding beetles, rhizomorphs or spores (Shaw and Kile 1991). Although infected trees eventually die, mortality is usually precipitated by other agents (wind or bark beetles). Although random individual trees may harbor and die of root disease, distinctive root disease pockets are common in some forests. These mortality pockets increase slowly, except where expansion is accelerated by partial cutting, and persist for decades, even following stand replacement. Proliferation and extinction of pockets is rare. Trees differ in their mortality rates from root disease by species and age; therefore root disease disturbance regimes are strongly influenced by stand composition and structure. Root diseases are important mortality agents in the Southwest (Wood 1983), and were commonly observed on the Delworth site.

Mistletoe

Dwarf mistletoes (*Arceuthobium*) spread primarily by short-range (<20 m), ballistic dispersal of seeds; rare long-distance dispersal (kilometers)

which establishes new infection centers is effected by birds (Hawksworth and Wiens, 1995). As the infestation builds within centers, severely infected trees are stunted, broomed, topped, and eventually killed. Mortality rates accelerate exponentially as the mistletoe population increases. Because of its long life-cycle, centers expand only meters per year; nonetheless, well-scattered seed trees with mistletoe infections can re-infest a regenerated stand after only several decades. The distribution and abundance of mistletoe is strongly influenced by the fire regime and management practices. Mistletoe is very abundant and damaging in the Sacramento Mountains (Hawksworth 1959; Hessburg and Beatty 1986).

Other Disturbances and Interactions

Fire, stem rust, bark beetles, root disease, and dwarf mistletoes are not the only natural disturbance agents that affect forest stands of the Sacramento Mountains; decay fungi and defoliating insects (e.g. western spruce budworm) are also locally or occasionally important. The predisposing factors, damages, dynamics and interactions with other agents of each of these disturbances are different and complex. Root disease and dwarf mistletoe are persistent and by weakening trees often predispose those trees to attack by bark beetles. Trees broomed by mistletoe or recently killed by other agents provide fuels to carry fire from the surface to the canopy; but devastating crown fires can eradicate mistletoe from a stand (Alexander and Hawksworth 1975). The dynamics of mistletoe infection centers are intermediate between the sudden appearance of bark beetle spots and long-term site occupancy of root disease pockets. Southwestern white pine which is less damaged by fire, bark beetles, root disease and dwarf mistletoe had often filled-in following the mortality of other species from these agents and had therefore formed a buffer on their spread. By removing the southwestern white pine, blister rust may have an indirect effect of increasing the activity of other disturbance agents.

These complex relations can be quantified as a disturbance pathway composed of a predisposing factor, mortality agent, and tree response (Lundquist 1995a). Associations and sequences of

pathways are recognized as networks and the importance of various pathways determined by the frequency with which they occur. Because different agents are associated with different spatial and temporal dynamics and interactions and because multiple agents are active in most forest stands, disturbance can not be treated as a single, generic process that simply kills trees uniformly over a given area at a certain return frequency. Managing stands and landscapes requires a site-specific knowledge of the effects and dynamics of the various disturbance agents which determine forest health.

A MANAGEMENT INDICATOR

The principal difficulty in relating the complex regimes and interactions of these disturbance agents to forest health is the lack of a suitable, quantitative, management indicator. Measures of stocking and commercial volumes appropriate for timber production are not adequate where the management goals are sustainability, integrity, and diversity. We have identified five attributes required of a satisfactory metric for relating disturbance and forest health:

1. sensitivity and responsiveness to effects of disturbance and recovery;
2. relationship to patterns and processes on the scale at which silviculture is practiced;
3. provides linkage to higher and lower spatial scales;
4. indicates the status and trend of resource values and ecological functions; and
5. reflects and responds to management activity in modeling exercises and implementation.

Research Strategy

The management indicator we propose is the disturbance profile (Lundquist 1995b). Our current research studies with the disturbance profile includes development of survey methods, summary and analysis procedures, descriptive and predictive models, experimental verification and management implementation (Lundquist and others 1995). Beatty and others (1995) describes the methods used to collect data and compute the

disturbance profile; Lundquist (1995b) describes application of the profiling technique. Here, we introduce a basic strategy for integrating the spatial patterns and dynamics of multiple disturbance agents, vegetation responses and their interactions.

Disturbance Profile

The disturbance profile is a multivariate descriptor of distributions of live vegetation, canopy density, course woody debris and disturbance pathways within a forest stand (for detailed examples see Beatty and others 1995 or Lundquist 1995b, 1995d). The specific variables which quantify vegetation, canopy structure and composition, woody debris, and disturbance pathways are chosen for their relevance to the ecological patterns and processes at the gap and stand levels. These variables are also screened to determine their utility for tracking the effects of specific silvicultural treatments on stand dynamics and resource values. The selection of variables is also guided by an identified management objective; these objectives and variables provide specific definition to the general goals of sustainability, integrity, and diversity. The designated management objective also helps identify the population from which standard norms can be determined. In the study we are conducting on the Sacramento District the objective is "enhance habitat for the small mammal prey of the Mexican spotted owl." The disturbance profile is designed to be a silvicultural tool for monitoring and projecting the trends and effects of small-scale natural disturbances and their responses to management intervention.

We use a multi-scale approach for studying disturbance to develop an understanding of the underlying ecological processes at the gap level and to determine the distribution patterns of vegetation, canopy, and woody debris at the stand level. Small-scale disturbance is emphasized because associated predisposing factors and agents are more easily subjected to silvicultural treatment and because cost-benefit risks are more predictable and favorable. The dynamics and interactions of small-scale disturbance agents usually determine the patterns of stand heterogeneity and development and may influence vulnerability to a stand-replacing event.

The multi-scale approach to developing the disturbance profile involves two phases. First, we intensively study disturbance and recovery to observe the initiation, expansion and recolonization of canopy gaps on a series of 4 ha plots. This observation scale and extent is appropriate for the important disturbance agents such as fire, stem rust, bark beetles, root disease, and mistletoe. Then, we extensively survey a number of stands (10 to 200 ha) to determine the distribution patterns of gaps (and subsequent re-vegetated patches) by cause and age. These surveys provide detailed information on how various gaps and patches are interrelated and integrate into the stands designated by silviculturists for management. Distribution patterns of vegetation, canopy gaps, woody debris, and mortality agents are characterized in both of these exercises with spatial statistics and methods adapted from landscape ecology.

The field data collected during the intensive plot study and the extensive stand survey provides spatial and temporal information on 1) live trees and regeneration (vegetation), 2) horizontal canopy structure (gaps), 3) snags, logs, and stumps (coarse woody debris), and 4) biotic and abiotic mortality agents and associated predisposing factors (disturbance pathways). Vegetation, gaps, and coarse woody debris are the basic structures which comprise the stand as seen from resource and ecosystem management perspectives. The disturbance pathways identify the dominant processes active in the stand and therefore indicate likely trends of future development.

Disturbance Profile for Forest Health

The disturbance profile provides a operational method for defining forest health and determining how well a stand or proposed treatment meets forest health goals. The disturbance profile is intentionally constructed from measurable variables which reflect those ecological processes and structures related to sustainability, integrity, and diversity. Key to identifying the specific variables which comprise the profile is recognition of the management issue or context from which forest health is to be judged.

Forests are evolving biological systems with complex and ever-changing dynamics and struc-

tures. Knowledge of the range of variation in pre-settlement stands and of contemporary, unharvested stands is useful for indicating previous and potential realizations of forest conditions. But these conditions are not necessarily required or appropriate in the sample population which typifies the healthy forest stand. Reconstruction techniques provide only a portion of the description of disturbance regimes; relict, unharvested stands may persist as such because they were atypical. Most stands that have not been cut or grazed have nonetheless been subjected to suppression of fire or pests or indirectly affected by these activities in adjacent stands. One would not use the range of cholesterol levels from Eskimo populations to set the normal range for an American white male (see Beatty and others 1995). An overmature stand of climax species may not be appropriate standard for rating the health of spotted owl habitat on the Sacramento District. Finally, there are important differences in the disturbance regimes of various agents which have subsequent consquences on stand development.

Although there may be no universal standard conditions represented by some imaginary "undisturbed" stand for determining forest health, there are stands which can be recognized as desirable conditions for specific management objectives. Because these objectives can include ecological functions as well as commodity production, healthy forests in the broadest sense can represented by these stands. The disturbance profiles of these reference stands provides a standard and range of variability for assessing other stands or tracking their performance following treatment. By choosing stands which meet specific criteria of sustainability, integrity, and diversity as a standard, the profile can relate these qualities to the dynamic processes and complex patterns of various small-scale disturbance agents.

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Disturbance and Canopy Gaps as Indicators of Forest Health in the Blue Mountains of Oregon

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Abstract.—Disturbance profiles, indices based on both spatial and non-spatial statistics, are used to examine how small-scale disturbances and the resulting canopy gaps disrupt ecosystem patterns and processes in selected stands in the Blue Mountains of Oregon. The biological meaning of many indices remains undefined for small scale disturbance phenomena, but their disturbance profiles could eventually be used to assess current and desired forest conditions and suggest actions to meet specific management objectives. These profiles can be determined for plots representing desired conditions associated with specific management objectives, to establish a range of variability for forest health indicators, and to monitor the progress of disturbances used as silvicultural tools.

DISTURBANCE AND CANOPY GAPS

Canopy gaps are discrete openings in forest canopies caused by small scale disturbances (Watt 1947). Most natural, small-scale disturbances are so well integrated into community dynamics that they are considered keystone processes for maintaining the health or integrity ecosystems. Tree mortality and the resulting distribution of gaps, snags, coarse woody debris, and recolonizing vegetation are important factors in determining biodiversity, wildlife habitat, scenic quality, recreation opportunity, timber volume, water yields, and various ecological functions. Canopy gaps and the agents that cause gaps influence many different forest resource values. They reduce timber production by reducing stand uniformity and create forecasting and scheduling problems by causing miscalculations in prediction models.

Gaps may also positively influence other ecosystem components, such as wildlife species, by increasing the amount of available habitat for organisms dependent on coarse woody debris, openings, or edges.

Gaps in the forest canopy created by disturbance agents harbor the preponderance of coarse woody debris in a typical forest stand. These logs, stumps, and snags are key habitat components for many species comprising the primary cavity-excavating guild of birds and the small animal fauna of these forest sites. Chickadees, nuthatches, voles, mice, chipmunks, and other species of these groups contribute to biodiversity and biomass of a forest site and also play an important ecological role as prey of predatory wildlife species that are often rare or sensitive. Quality habitat for the primary excavators and small mammals is often defined by the availability of specific kinds of coarse woody components. Thus, forest canopy gaps, their origin, and the structure and composition of their interiors can directly impact the biodiversity of forest landscapes.

With an increasing understanding of small-scale disturbance these natural processes could be used as additional silvicultural tools for generating and maintaining desired future conditions. These conditions include species composition, stem density, tree size, type and abundance of snags and

logs, and canopy structure. Small-scale disturbances are particularly useful for increasing within-stand diversity and decreasing large-scale pulses in mortality and regeneration.

FOREST HEALTH

What is forest health? The answer to this question will, in large part, determine how we measure and quantify indicators of health. No matter how one defines it, or even if one agrees with the concept, the term "forest health" is now used almost daily in discussions about natural resource management because it is something that almost everyone can identify with. We know what it is to be healthy ourselves and we want our forests to be healthy as well. One way of measuring forest health would be to look at the ability of a forest to meet management objectives. Under this approach, a healthy forest could be described in this way: "A desired state of forest health is a condition where biotic and abiotic influences do not threaten resource management objectives now or in the future" (U.S. Department of Agriculture, Forest Service 1993).While this definition can be considered highly utilitarian, other definitions focus more on aspects of ecosystem function. In this viewpoint, a healthy forest is an ecosystem in balance; a fully functional community of plants, animals and their physical environment (Monnig and Byler 1992) where the major components of ecosystem function vary within a range of known, specified parameters.

The most useful and popular definitions seem to combine the two views. In essence, we design our management goals to include, or be dependent on, functional ecosystems. The challenges we face are to define and measure the indicators of forest health, as well as the attributes of functional ecosystems, that will be useful in helping us recognizes when forest and stands are unhealthy and why.

Early attempts to describe forest health in the Blue Mountains of Oregon were at a landscape scale so the indices used to describe and quantify indicators of forest health were selected and designed to be appropriate for that scale. The results of one of the early attempts at forest health analysis

are documented in the Blue Mountains Forest Health Report, "New Perspectives in Forest Health." In it the authors reported that the health of the forests in the Blue Mountains was declining. The effects were obvious: dead and dying trees. The causes were ascribed to 'decades of fire exclusion, selective harvesting of early and mid-seral trees, livestock grazing, and little influence on . . . biodiversity and long-term site productivity.' (Gast 1991). Indices used in the report were: insects and diseases, watershed health (measure of impacts by grazing), fire, long-term site productivity, and biodiversity, (table 1). Those stands with large and increasing populations of insects and diseases, a Class III rating for watershed health, increased risk of catastrophic fire, and biodiversity structure outside the range of natural variation, were considered unhealthy. Range of natural variability is a description of ecosystem composition, structure, and processes of an area, had it been minimally influenced by humans (ECOMAP 1993). This concept is tied closely to that of the functional ecosystem as it is viewed in forest health definitions. Predictive simulation models can also play a role in assessing the temporal range of natural variability, that is, how the ecosystem will change over time (Kaufman 1994). This method for assessing forest health is useful in showing, on a landscape scale, the location of forest health problems but it does not provide an analysis tool useful for assessing, predicting, or monitoring the impacts of disturbance agents at the stand level.

As part of a larger research project examining disturbance and canopy gaps in the West, the study I would like to report on here was designed to use several indices simultaneously to examine

Table 1.—Forest health profile indices for the Blue Mountains, Oregon.

Index	Units of measurement
Insects and Diseases	Acres of defoliation/Acres of mortality
Watershed condition class	Class I/Class II/Class III
Fire	Percentage of true fir/Mixed age structure/Dense, suppressed
Long-term site productivity	Not degraded/Generate products in perpetuity
Biodiversity	Ages/Structural configurations/Species combinations

how diseases, insects, anthropogenic activities and other canopy gap-forming disturbances change the structure and function of ecosystems at the stand level. One of the primary objectives was to see if this system could be used as a way of measuring indicators of forest health at a lower spatial scale than that of the Blue Mountain Report. Forest health can be described and assessed at multiple scales. For the work reported here, the focus is at the stand and tree level, even though we realize that, in order to deal with forests health issues in a holistic way, they must be described at the landscape level through vegetation mosaics and ecosystems processes. Because of our interest and expertise in identifying meso-scale disturbances, the scale we selected was that of the stand, the domain of the silviculturist.

DISTURBANCE PROFILE

Silvicultural management of stands for forest health objectives will require new methods of inventorying and characterizing forest stand attributes. According to Lunquist, Geils, and Negron (1995), these attributes must be: 1) sensitive and responsive to the effects of disturbance and recovery, 2) relate to patterns and processes for the scale at which silviculture is practiced, 3) provide linkage to higher and lower spatial scales, 4) indicate the status and trends of resource values and ecological functions, and 5) reflect and respond to management activity in modeling exercises and implementation. A disturbance profile is a combination of spatial and relational statistics (referred to here as indices) describing relationships between, among others, canopy density and structure, disturbance agents and their interactions, dead woody material such as snags and logs, and recolonizing vegetation. It is, therefore, a spatial and temporal description or fingerprint of the stand and gives us another tool to visualize an extremely complex system. Multivariate statistical methods are used to compare and contrast disturbance profiles among forest stands and to establish range of natural variability for various management objectives (Lundquist 1995). Disturbance profiles can be compared to a test used to measure human health known as a blood profile, a test that we are all familiar with from physical check-ups

Table 2.—Blood chemistry profile.

Test	Result	Reference range
Glucose	98	70–115 mg/dl
Urea Nitrogen	17	7–25 mg/dl
Creatinine	1.1	0.7–1.4 mg/dl
Bun/Creat Ratio	15.5	10–24
Protein, Total	7.0	6.0–8.5 g/dl
Uric Acid	4.6	4.0–8.5 mg/dl
Iron, Total	127	25–170 mcg/dl
Cholesterol, Total	194	<200 mg/dl
Cholesterol, HDL	31	>45 mg/dl
Cholesterol, LDL	133	<130 mg/dl

(table 2). In much the same way that a blood profile measures different blood components and compares current levels with a range of acceptable or optimum values, the disturbance profile looks at certain stand and gap components and compares them to a range of expected values. In order to make a meaningful diagnosis of the state of human health doctors need to know what the acceptable range of values is for each specific variable. So to when we attempt to estimate the health of stands we need to know whether or not the idex values we measure fall within an acceptable range, a natural range of variability. As used in disturbance profiles, range of variability could indicate minimum and maximum values acceptable for a specific management objective or the range of those variables we measure in functional ecosystems. One way to obtain this information would be to compute disturbance profiles for unmanaged, but disturbed, stands and determine the range of natural variability associated with natural disturbance regimes.

BLUE MOUNTAIN PLOTS

In order to test the utility of the disturbance profile concept, four 4-hectare areas (200 m × 200m), called plots, were established in the Five Points drainage northwest of the town of La Grande, Oregon in the Wallowa-Whitman National Forest. We then gathered data on four classes of indicators that we thought would be useful in establishing a forest health disturbance profile, canopy density, disurbance pathways, dead and down wood, and recolonizing vegetation.

Each plot was overlain with a 5m × 5m grid and at each grid coordinate an instrument called an optical densiometer was used to make estimates of canopy density. Variograms generated from these readings were used to compose two-dimensional diagrams of canopy density called patterned isopleths or gapograms. Threshold levels for differences in canopy density were set during data analysis to mimic stand conditions so that the openings indicated on the gapograms would relate to canopy gaps we could identify in the field. The units of measurement for this element of the profile are: canopy density and gap location, size, and shape.

After gapograms for each plot were generated they were used to locate individual gaps on the ground. An interdisciplinary team composed of forest pathologists, entomologists, wildlife biologists, and foresters then navigated to each gap, marked the gap boundary, and determined the disturbance pathway or pathways which had created that gap. The etiology of canopy gaps can be complex because cause / effect relationships are often not obvious. Two or more disturbance agents commonly interact to cause gaps. Measurements for this component were: predisposing factors, killing agents, and tree response. Each gap was also inventoried for dead and down woody material and recolonizing vegetation. The measurements for woody material included species, decomposition class, dbh of snags, and length of logs. Measurements for recolonizing vegetation were: abundance (percentage of ground covered) by vegetation layer.

Since the results of the fieldwork were not yet available we were unable to compose a profile for these paticular stands. When we do, however, we feel that the resulting disturbance profiles will serve as useful sources of values for ranges of natural variability of our selected indicators in unmanaged, disturbed (except by recent fire events) stand in the Blue Mountains.

MANAGEMENT USE

Managers will eventually be able to use disturbance profiles to help establish forest plan standards and guidelines . Ranges of index values would have to be constructed for various re-

Table 3.—Disturbance profile.

Disturbance Index	Actual Value	Range of Natural Variability
Dominance	2.23	2.0–2.3
Canopy density	45%	0–60
Fractal dimension	2.56	2.5–2.7
Number of gaps	23	18–30
Contagion	3.5 (high)	2.5–3.0
Average gap area	16	15–20
Variogram range	450	400–500
Number of edges	40	50–75
Number of gaps	21	25–40
Shannon Weaver index	2.45	2.0–5.0
Shrub vegetation layer	80% cover	60–90

sources. The desired future condition for maintaining these resources might require forest landscapes or stand that have a certain combination of index values (profile) falling within the range of natural variability as described in the forest plan, (an example of a profile with hypothetical values for ranges of natural variability is provide in table 3). Existing stands would then be inventoried for actual values in each index and the existing and potential suite of disturbance agents. Disturbance network models would then be consulted to determine what manipulations could be done to make adjustments to the index values to more closely bring the stand towards the desired future condition

We believe that in the near future, application of the disturbance profile concept will be a useful tool for land managers interested in maintaining healthy, functioning ecosystems through the use of natural disturbance agents. In the future we anticipate using other technology such as remote sensing, among others, that will make gathering the necessary inventory data to develop disturbance profiles more expeditious.

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Allegheny National Forest Health

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Abstract.—Since 1985 72 percent of the forest land on the Allegheny National Forest has been subject to at least one moderate to severe defoliation from any of three native or three exotic agents. In addition, droughts affected the forest in 1972, 1988 and 1991. As a result, at least 20 percent of the forest shows tree mortality in from 10 to 80 percent of the overstory trees. Sugar maple is the most seriously affected species. The impacts of this mortality are compounded by the impacts of up to 70 years of overbrowsing by white-tailed deer.

Long-term silvicultural research studies were reexamined and showed that most of the sugar maple mortality is occurring in sapling and pole–size stems, mortality is worse on dry than on wet sites, and even–age silvicultural treatments, especially thinning, are associated with reduced amounts of mortality and reduced rates of mortality.

INTRODUCTION

The Allegheny National Forest (ANF), a half-million acre tract of largely forest land on the unglaciated portion of the Allegheny Plateau in northwestern Pennsylvania, was established in 1923. Early surveyor's records suggest that the original forest consisted primarily of American beech, *Fagus grandifolia* Ehrh., (44 percent) and eastern hemlock, *Tsuga canadensis* (L.) Carr (20 percent). Sugar maple, *Acer saccharum* Marsh., red maple, *A. rubrum* L., and white pine, *Pinus strobus* , each represented 5 percent, and black cherry, *Prunus serotina* Ehrh., represented only 0.8 percent of the trees recorded in these early surveys (Whitney 1994). Wind, including tornadoes, was the primary natural disturbance, along with drought and ice (Bjorkbom and Larson 1977). Fire, both natural and anthropogenic, was also a force, especially near river drainages (see, for example, Lutz 1930). Browsing by deer and hare, defoliation by insects, and

forest diseases were also undoubtedly part of the natural disturbance regime of these forests.

The forests of the Allegheny Plateau region were harvested lightly for selected species and products throughout most of the 19th century. With the onset of the Industrial Revolution near the close of the 19th century, however, harvesting practices changed, and final removal cuts with very complete utilization took place across the region from about 1890 to 1930, creating a significant regional age-class imbalance (Marquis 1975). In 1993, 75 percent of the forest land base on the ANF contained stands between 60 and 110 years of age (U.S. Department of Agriculture Allegheny National Forest 1993).

These even-aged second growth forests contain a diverse mix of species, often stratified vertically and by diameter. The Allegheny hardwood, or cherry-maple type, for example, is dominated by the shade-intolerant black cherry, which survives only in the largest diameter classes and codominant or dominant crown classes. Red maple, the birches, *Betula lenta* L. and *B. alleghaniensis* Britton, white ash, *Fraxinus americana* L., and other species of low to intermediate tolerance are most frequently found in the mid- to largest diameter

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classes and codominant crown positions, while the shade tolerant sugar maple and American beech, of the same age as the other species, persist as saplings and small poles in intermediate and suppressed crown positions. When species from the most shade-tolerant group are found in the main crown canopy and largest diameter classes, they are often holdovers from the previous stand, regenerated after mid–19th century partial cuts.

The turn-of-the-century cutting brought about dramatic changes in the species composition of this forest. Black cherry, only 0.8 percent of the presettlement witness trees, represents 28 percent of the trees in today's forest. Red maple has increased from 5 to 25 percent, and sugar maple from 5 to 13 percent (Lois DeMarco, personal communication).

Another important change occurred as the second-growth forest developed. White-tailed deer, *Odocoileus virginianus*, which had been nearly extirpated from Pennsylvania during the turn-of-the-century harvest period, were protected by the Pennsylvania Game Commission beginning in 1907, and the herd made a remarkable recovery. By 1929, scientists were noting losses in the shrub layer of the forest (Pennsylvania Game Commission 1991). Since that time, deer herds have been above the target level established by state game managers for the region, with the exception of two brief periods in the 40's and 70's associated with severe winters (Redding 1995).

Deer browsing has had a major impact on forest understories, regeneration development and wildlife habitat (Tilghman 1989, Jones and others 1993, deCalesta 1994). Regeneration of species dependent upon advance regeneration, as many of the second-growth species are, is frequently absent. Other species that interfere with the establishment and survival of natural regeneration by casting dense shade at the forest floor level (Horsley 1991, 1993) fill the growing space vacated by browsed seedlings. These plants include hay-scented and New York fern, *Dennstaedtia punctilobula* and *Thelypteris noveboracensis*, grasses and sedges, beech root suckers, and striped maple, *A. pennsylvanicum* L., seedlings. These effects occur in both managed and unmanaged forests, and have severely impacted natural regeneration processes in the two major old-growth blocks within the ANF (Hough

1965, Bjorkbom and Larson 1977, Whitney 1984, Walters and Nowak 1993).

FOREST HEALTH CONCERNS SINCE 1985

Since 1985 management challenges on the ANF have been increased by the activities of a series of natural and exotic agents. Native defoliators (elm spanworm, *Ennomus subsignarius*, cherry scallop shell moth, *Hydria prunivorata*, and forest tent caterpillar, *Malacosoma disstria*) have defoliated 385,000 acres moderately to severely since 1991. Exotic defoliators (gypsy moth, *Lymantria dispar*, and pear thrips, *Taeniothrips inconsequens*) and an exotic insect/disease complex (beech bark disease, *Cryptococcus fagisuga* and *Nectria* spp.) have affected 317,000 acres since 1985. Figure 1 shows portions of the ANF that have been moderately to severely defoliated from one to four times between 1985–95. Only 28 percent of the ANF has not received at least one moderate to severe defoliation. The last 10 years included two droughts, 1988 and 1991, a killing frost on Memorial Day 1992, and both unusually snowfree and unusually snowy winters. And finally, although effects have not been documented, the atmospheric deposition on the ANF's unglaciated and often base-cation poor soils is quite acidic. Collectively, these agents—insects and diseases, droughts and other climatic extremes, and soil-site conditions—have led to the decline of many tree species.

During the 1985–95 decade, personnel of the USDA Forest Service, Northeastern Area State and Private Forestry, Forest Health Protection group working with personnel of the Allegheny National Forest have sprayed more than 248,000 acres with insecticides to reduce defoliation by gypsy moth, elm spanworm, and forest tent caterpillar.

MORTALITY AND MANAGEMENT RESPONSES

Despite these significant efforts to protect the forest from defoliation stresses, the forest has experienced both sudden and gradual tree mortality. During the droughty summer of 1988, for example, tree mortality in the oak type occurred almost overnight in mid- to late-August, especially

Allegheny National Forest

Defoliation

1 year ▨

2-4 years ■
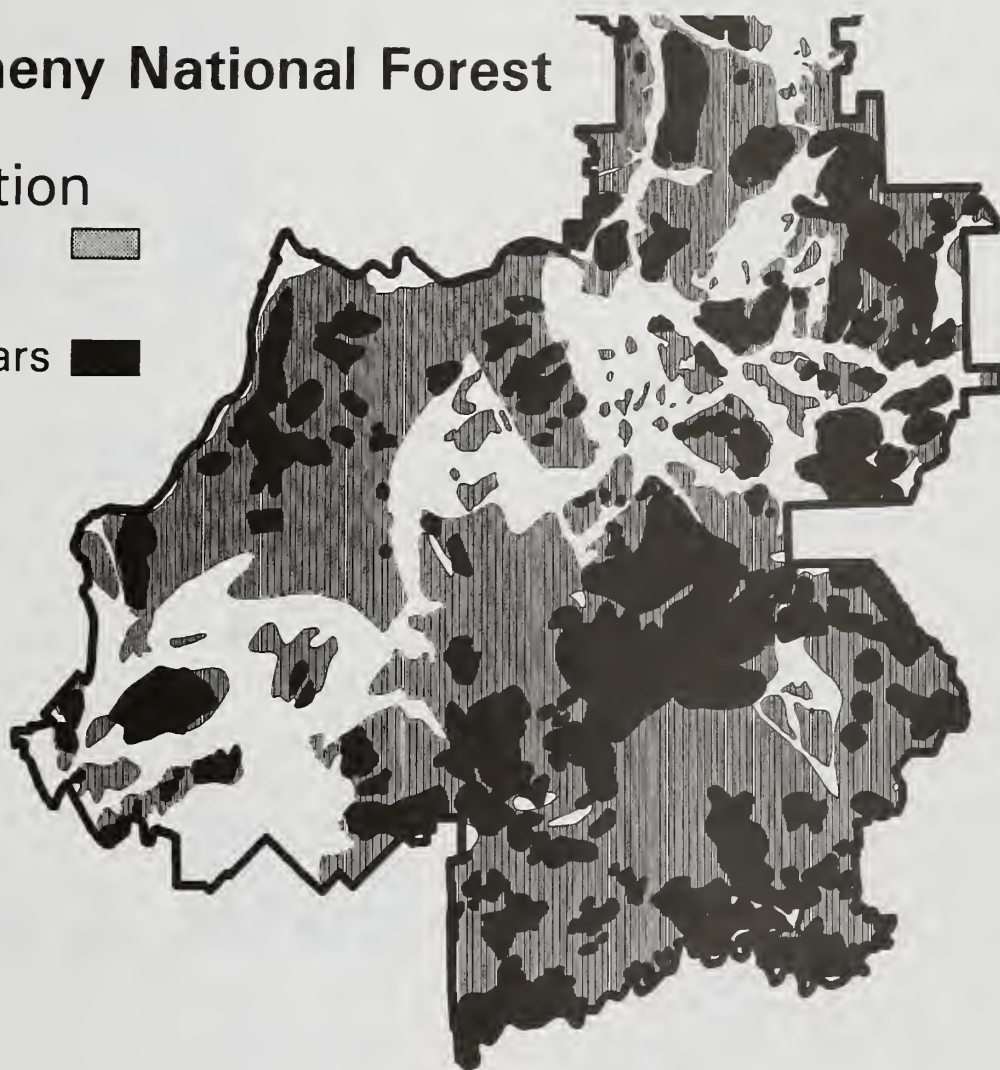
Figure 1.—Map of the Allegheny National Forest showing areas that experienced moderate to severe defoliation from 1 to 4 times during the decade 1985–94.

in areas defoliated by gypsy moth in previous years. Approximately 108,000 acres have suffered from 10 to 80 percent tree mortality since 1985.

During 1994, color infrared photography was used to identify the sites of current decline. Results indicated that approximately 90,000 acres are currently affected. We have used inventory data collected on 12,000 of these acres during the summer of 1994 to characterize the current decline.[4]

Within the acres surveyed, 12 percent of the basal area was already dead, and another 16 percent was judged to be at risk with less than 50 percent crown remaining. Sugar maple was the most heavily

[4] McWilliams, William H.; Arner, Stanford; Nowak, Christopher A.; White, Robert; Stout, Susan L. in preparation. Characterizing impacts in declining stands of the Allegheny National Forest. Res. Note. Radnor, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station.

impacted species, 28 percent dead and 31 percent at risk. White ash (27 percent dead and 20 percent at risk), beech (12 percent dead and 17 percent at risk), birch (14 percent dead and 4 percent at risk), and red maple (8 percent dead and 13 percent at risk) were other important species with mortality. Within the sugar maple group, mortality averaged about 14 ft^2 per acre, of which 12 ft^2 per acre was in trees of less than 15" diameter at breast height. Rates of mortality were actually highest in the largest size classes, but these represent less than 1 percent of the sugar maple in the sample.

Managers are particularly concerned about the implications of these declines for forest regeneration. In some places, the increased light reaching the forest floor as a result of the recent defoliations and crown dieback has resulted in increased establishment and growth of tree seedlings. Only 8 percent of the stands in the 12,000-acre sample had adequate tree regeneration, including shade-tolerant saplings of sufficient health to leave as part of a new stand. But in many places, the beneficiaries of increased light have been ferns, grasses, and sedges, and as mortality removes trees that could provide seed for natural tree regeneration, the management challenges increase. More than 70 percent of the stands in the 12,000-acre sample had fern understory stocking in excess of 30 percent, the level associated with interference with regeneration establishment (Marquis and others 1992). Allegheny National Forest managers commonly use intensive silvicultural practices—including herbicides, fencing, aerial fertilization of established seedlings, and individual tree seedling protectors—to overcome the barriers to natural regeneration. In addition, managers are working with scientists to identify appropriate management strategies for declining stands that do not require regeneration treatments.

As of spring 1995, environmental assessments to identify regeneration and, where appropriate, timber salvage responses to the mortality had been completed for 58,000 acres. Work is under way on environmental assessments for the remaining 51,000 acres known to be affected, and new photography and field reconnaissance will be used during the 1995 growing season to identify new or increased mortality.

RESEARCH RESPONSES

As the decline and mortality on the ANF accelerated, scientists looked for explanations and patterns. We used two long-term studies on the Kane Experimental Forest (KEF), a 1700-acre tract within the boundaries of the ANF on which research into forest management has been conducted since 1929, to examine the effects of silviculture on decline and mortality. We focused these analyses on sugar maple because it is the most significantly impacted species in the Allegheny and northern hardwood types, and because mortality first occurred in this species.

One study was designed to assess the impacts of even-age thinning to different residual relative densities on stand development. A series of two-acre treatment plots were installed on the KEF in 1973–75. Treatments were thinnings predominantly from below, and the original stand was an even-age, 55-year-old Allegheny hardwood stand. Treatments were accomplished through a combination of commercial and non-commercial removals. A complete description of the study can be found in Marquis and Ernst (1992) and Nowak.[5] During 1987, the vigor of individual sugar maple trees on these plots was assessed.[6] We reanalyzed the data from those plots that received thinnings to residual relative stand densities from 50 to 70 percent (Roach 1977, Stout and Nyland 1986) and control plots, to assess the impacts of thinning on sugar maple mortality. We used data from the inventories taken after treatment in the early 1970's, and measurements taken 15 years later, around 1990. These plots occurred across two toposequences typical of the ANF landscape. Comprehensive soil analyses were completed on all these plots during the mid–1980's (Auchmoody, L. unpublished data on file at the Forestry Sciences Laboratory, Warren, PA). We used these soil analyses to assign a soil drainage class to each of the study plots, enabling us to assess the impacts of soil drainage on sugar maple decline symptoms and mortality. Figure 2 shows decline

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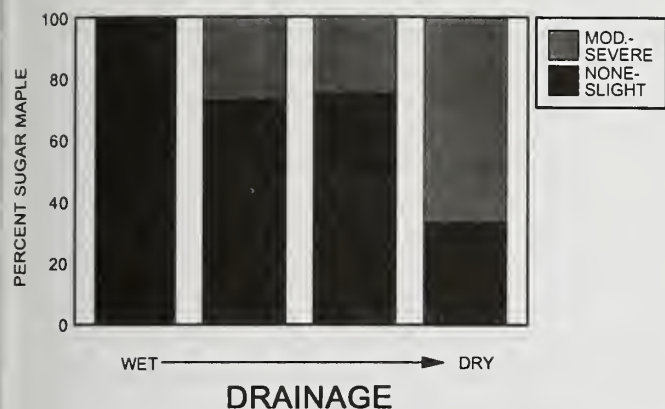
Figure 2.—Proportion of sugar maple trees showing decline symptoms in control plots from the Kane Experimental Forest thinning study, as a function of soil drainage. Each bar represents a 2–acre treatment plot.

Table 1.—Absolute and relative mortality of sugar maple in thinned and unthinned, 50–year–old Allegheny hardwoods, 15 years after treatment.

| Variable | Unthinned | | Thinned | | |
	n	mean	n	mean	p–value[a]
Number of stems					
Absolute (stems per acre)	6	286 (40)[b]	9	24 (19)	<0.01
Relative (percent of initial)	6	69 (19)	9	15 (11)	<0.01
Basal area					
Absolute (ft² per acre)	6	11.9 (6.3)	9	1.3 (1.4)	<0.01
Relative (percent of initial)	6	26.8 (7.8)	9	4.6 (3.7)	<0.01

[a] *p–values from t–tests between unthinned and thinned.*
[b] *Values in parentheses below each mean are standard deviations.*

Figure 3.—Relative mortality (proportion of post–treatment sugar maple basal area that died during the 15 years after treatment, 1973–75 to 1988–90) in thinned and control plots from the Kane Experimental Forest thinning study, as a function of soil drainage and treatment. Each bar represents a 2–acre treatment plot.

symptoms of sugar maple as a function of soil drainage in four uncut, control plots. Decline symptoms were higher on the drier soils. Wet soils had virtually no decline.

Figure 3 shows relative mortality, or the proportion of posttreatment sugar maple basal area that was dead after 15 years, in thinned vs. unthinned plots, across the toposequences. This figure shows that the soil drainage effect was much stronger in unthinned plots. Table 1 shows both absolute and

relative sugar maple mortality. In basal area, mean relative sugar maple mortality was six times less than the mortality in the unthinned plots (p<0.01). Relative mortality corrects for the fact that thinned plots had fewer trees at the beginning of the period.

Another study on the KEF was installed to test the effects of different silvicultural systems on stand development, growth, and yield. Three variants of uneven-age silviculture, two-age silviculture, and even-age silviculture were investigated. Treatments were applied to 4.9-acre plots during the winter of 1979–80 in four blocks of five treatments each. This study was installed in a multi-age stand resulting from a heavy partial cut during 1900. The study is completely described in Stout (1994). The analysis reported here is based on final measurements taken during the winter of 1995.

For this investigation, we pooled the plots that had received even-age or two-age treatments, and contrasted them with the plots that had received uneven-age treatments. Figure 4 shows the relative mortality (proportion of sugar maple trees left after treatment) in these two groups. Table 2 shows the values displayed in this chart, as well as the wide variation around the means. Differences are not significant but indicate a strong trend. As shown in Table 2, the differences are more nearly significant when expressed as proportions of basal area. The

large relative mortality when expressed as stems per acre reflects the fact that the mortality was most severe in small trees, which is consistent with the observations from the analysis of ANF mortality plots and with observations from the thinning study. Even-age and two-age treatments discriminate against smaller trees, while uneven-age treatments leave trees in all size classes, and smaller sugar maple trees have been more vulnerable to the stresses of the last decade.

Note that in this older stand, the rates of mortality are much greater than those in the younger, thinned stands. There are several possible explanations for this. Potentially the most important is the measurement period: data analyzed for the thinned stand were collected in 1990, before the worst mortality, and data for the silvicultural systems study were collected in 1995. Based on observations in both stands during 1995, however, we believe that mortality in the older stand is indeed higher than that in the younger stand. In addition to age, this may be because 17 of the 20 plots in the silvicultural systems study were on moderately to well-drained, or dry, soils.

LONG-TERM RESPONSES

The scale and severity of the decline and mortality in Allegheny hardwood forests has, frankly, surprised managers and researchers alike. We have focused on the dimensions of the problems on the ANF in this paper, but industrial, non-industrial private, and state agencies are experiencing similar problems. Although we have known that the species composition of our second-growth forests is quite different from the original forests of our region, they appeared to be healthy and vigorous until the last decade. The most serious challenge to their sustainability was posed by white-tailed deer browsing on regeneration. Understanding the ecosystem implications of the current decline, and designing a response that offers the best hope of sustaining these forests, will require a comprehensive program of research and adaptive management. Such a program is already beginning.

During the first week of June 1995, a team of scientists and managers from across the northeastern United States met to study the problem and design a comprehensive response. The team included pathologists, physiologists, silviculturists, entomologists, geologists, hydrologists, and managers from state, federal, and industrial landown-

Table 2.—Absolute and relative mortality of sugar maple in 90-year-old and older multi-age Allegheny hardwood stands treated with uneven and even-age silviculture, 15 years after treatment.

| | Treatment | | | | |
| | Unthinned | | Thinned | | |
Variable	n	mean	n	mean	p-value[a]
Number of stems					
Absolute (stems per acre)	12	28 (14.9)[b]	7	22 (13.8)	<0.44
Relative (percent of initial)	12	66 (11)	5[c]	59 (11)	<0.26
Basal area					
Absolute (ft² per acre)	12	9 (7.4)	7	8 (4.3)	<0.74
Relative (percent of initial)	12	62 (16.9)	5	53 (13.8)	<0.31

[a] p-values from t-tests between stands receiving uneven- and even-age treatments

[b] Values in parentheses below each mean are standard deviations.

[c] Two of the even-age stands received intermediate treatments. We have calculated absolute mortality by summing mortality for the two time periods, but there is not a comparable way to calculate relative mortality.
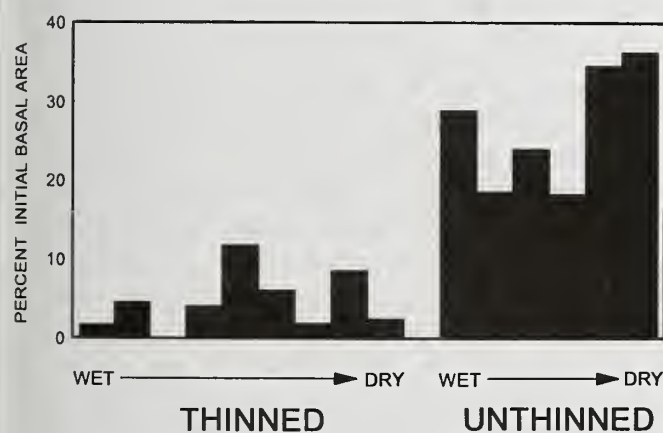

Figure 4.—Relative mortality (proportion of post–treatment sugar maple basal area that died during the 15 years after treatment, 1980–1995) in plots managed by even–age and uneven–age silvicultural systems from the Kane Experimental Forest silvicultural systems study.

ers. Insects, diseases, climate effects, nutrient depletion and soil effects, and anthropogenic stressors were all considered as contributing agents. Participants will design a series of studies that will assess both the patterns and processes associated with this decline. In particular, a coalition including all three branches of the Forest Service (National Forest Systems, Research, and State and Private Forestry), forest industry, and Pennsylvania state agencies is cosponsoring a spatial assessment. Information about soils, landform, recent and long-term management history, tree species composition, and defoliation history will be entered in a geographic information system to assess the scope of the problem across the northern tier of Pennsylvania and to detect correlations among these layers and current mortality. At the same time, other scientists will be working on a series of mechanistic studies to identify both causal factors and remedial strategies. Managers will remain heavily involved in this research, using early outcomes as adaptive management strategies.

Already this research has stimulated new understanding of the Allegheny hardwood ecosystem. Patterns of decline and mortality appear to have some association with patterns of glaciation in the region, in addition to the associations with soil drainage identified above. Calcium depletion, not previously studied in this region, has become an important hypothesis. Stand history, particularly shifts in the relative abundance of tree species, may have predisposed some tree species to their current declines. While the challenge of sustaining forests in the face of these declines is indeed a serious one, we anticipate learning a great deal about our ecosystem in the process of meeting this challenge.

ACKNOWLEDGMENTS

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Root Diseases: Primary Agents and Secondary Consequences of Disturbance

William J. Otrosina[1] and George T. Ferrell[2]

Abstract.—The fact that endemic root disease causing pathogens have evolved with forest ecosystems does not necessarily mean they are inconsequential. A pathogen such as the P group of *Heterobasidion annosum* has become an intractable problem in many Sierra east side pine stands in California because the fungus is adapted to colonization of freshly cut stump surfaces. The S group of Ha is wide spread among true fir forests in California and may be responsible for maintenance of endemic populations of the fir engraver bark beetle and for drought triggered, catastrophic outbreaks of this insect. Other diseases such as black-stain root disease are associated with certain root feeding bark beetles that are attracted to tree roots after site disturbances such as thinning. Fire may also affect various root disease fungi and their pathological behavior in longleaf pine through interactions with various soil factors as a consequence of previous land use.

INTRODUCTION

With the exception of "exotic" or introduced organisms, most forest tree pathogens have co-evolved with forest ecosystems and are normal components of forest stands. Many of these fungi have dual capabilities in that they can kill trees and decay wood. These attributes make such fungi key ecological agents that are responsible for structural diversity in forest stands. Their actions create openings in the canopy, recycle woody debris, and provide wildlife habitat through creation of snags, downed logs, and cavities (Franklin and others, 1989; Schowalter and Filip, 1993).

Root disease fungi can serve as primary agents of disturbance as well as secondary consequences of both invasive and non-invasive management activities. These pathogens respond to a wide range of disturbances, from fire exclusion to intensive timber harvesting and site preparation operations. Understanding how these fungi function and interact with other organisms under differing circumstances and stand management regimes is essential for attainment of sustainable forest productivity. To this end, we present examples of certain root disease causing fungi, their response to disturbance, and their role as disturbance agents.

ANNOSUM ROOT DISEASE

Heterobasidion annosum (Fr.) Bref. is a pathogen affecting temperate coniferous forests throughout the world. In the western United States, root diseases affect approximately 16.8 million acres of commercial forest land and annual volume losses may exceed over 2-1/2 times that due to forest fires (Kliejunas, 1995). In California alone, annual losses of 19.3 million cubic feet are attributed to *H. annosum* root disease.

Two biological species or intersterility groups (ISG's) of the fungus exist in western North America (designated S and P). Both the S and P ISG's readily colonize freshly cut stump surfaces by means of airborn basidiospore deposition on those surfaces. Stump surfaces may remain susceptible to colonization from 1 to 4 weeks after creation (Cobb and Barber, 1968). The spores germi-

nate, grow down through the stump wood, and colonize the stump and portions of its major lateral roots. Environmental conditions in many parts of the western United States may allow larger colonized stumps to remain infective for up to 50 years after initial infection. Thus, the disease may present itself 50 years after harvest of the original stand, creating mortality centers and gaps throughout the emerging ingrowth. This arises as a consequence of healthy root systems coming into contact with the fungal inoculum in the infected stump wood. The fungus then infects major lateral roots of previously healthy trees, causing root decay and eventual death of infected trees. Mortality can continue as root to root contact is made with adjacent healthy trees, creating ever widening gaps in the canopy. Details of the biology and ecology of this disease are presented in Otrosina and Cobb (1989).

Research has shown the S and P ISG's differ in their ecological, genetic, pathological, and host preference characteristics (Otrosina and others, 1992, 1993). The P ISG primarily affects pine, incense cedar, and juniper species. One hypothesis inferred from genetic data and field observations is the P ISG was endemic but rare in the western United States until timber harvesting was practiced on a large scale. The P ISG responds to this type of disturbance as a result of its competitive ability to colonize newly created stumps. Thus, increased levels of harvesting can lead to increased *H. annosum* root disease. Fortunately, mitigation of stump infection and colonization is accomplished by application of borax to stump surfaces within a few hours after harvesting. Unfortunately, supplies of borax may not be available in the future for various reasons.

On the other hand, the S ISG of *H. annosum* has different ecological and pathological characteristics. It primarily affects true firs (*Abies* spp.), *Sequoiadendron giganteum* (Lindl.) Buchhloz, and probably Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). There is strong evidence that this ISG is more widespread among true fir forests than the P group in pine (Garbellotto and others, 1992). One theory contends that *H. annosum* has been a common root disease pathogen in true firs at least since the last ice age (Otrosina and others, 1993). Recent data indicate that infections in true firs result

possibly from natural wounds (fire scars, insects, root breakage) in addition to freshly cut stumps (Otrosina, unpublished). Thus, *H. annosum* in true firs can act as a primary disturbance agent, causing root and butt rots and increasing susceptibility of affected trees to bark beetle attack by weakening host defenses (Hertert and others, 1975). These infected trees may serve as hosts for endemic populations of bark beetles like the fir engraver (*Scolytus ventralis* LeConte). During periods of protracted drought stress, insect outbreaks from these endemic centers can reach catastrophic proportions, causing widespread mortality at the landscape level (Berryman and Ferrell, 1988).

Fire prevention may be regarded as a disturbance in forest ecosystems that evolved with fire. In this context, *H. annosum* plays a role in ecosystems such as *S. giganteum* whereby exclusion of fire is responsible for decline in health of certain stands of this species in the Sequoia-Kings Canyon National Park. Shade tolerant firs comprising much of the ingrowth in these *S. giganteum* stands may be responsible for transmitting the fungus to the sequoia via root contacts with infected firs.[3] Normally, periodic fires would minimize the true fir component in these stands, ostensibly reducing the risk of transmission of *H. annosum*.

Because the S ISG of this fungus does not normally infect pines, speculations have been made regarding the role of this fungus in the maintenance of the ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) component of California mixed conifer stands in the central Sierra Nevada. Some butt rotted true firs in these stands, for example, may fall or blow down, exposing mineral soil for pine seed germination in the root ball area. The emerging pine seedlings growing in the resultant gap do not become infected because the S ISG is present in the fir root mass. Further research is needed relating to this suggested mechanism of gap dynamics in this forest type.

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BLACK-STAIN ROOT DISEASE

Black-stain root disease is caused by 3 host specific varieties of the fungal genus *Leptographium* Lagerb. and Melin. These varieties, *Leptographium wageneri* var. *wageneri* (Kendr.) Wingfield, *Leptographium wageneri* var. *ponderosum* (Harrington and Cobb) Harrington and Cobb, and *Leptographium wageneri* var. *pseudotsugae* Harrington and Cobb, are host specific to pinyons; ponderosa pines, Jeffrey pines (*Pinus jeffreyi* Grev. and Balf.), and other western "hard" pines; and Douglas-fir, respectively.

The fungus is spread from tree to tree through infected roots contacting fine roots of uninfected trees. This fungus is also capable of growing a short distance (about 5 cm) through the soil and infecting fine rootlets. Once infected, larger roots eventually become colonized by the fungus, blocking water transport. Trees quickly decline and die as a result of the infection or they become predisposed to bark beetle attack. Losses can range from isolated pockets of infection in affected stands to catastrophic reductions in stocking levels characterized by mortality centers that increase in size as long as susceptible trees are present. The reader is referred to Harrington and Cobb (1988) for details regarding these and other aspects of the disease.

Site disturbance is a major factor for initiation of this disease in Douglas-fir stands (Harrington and others, 1983; Hansen, 1978). Overland spread and initiation of infection in stands of Douglas-fir is a result of insect vectors, primarily root feeding bark beetles such as *Hylastes nigrinus* (Witcosky and others, 1986). In Douglas-fir, the beetles may be attracted to roots via chemical attractants given off by stressed or damaged tree root systems (Witcosky and others, 1987). Thus, disturbance resulting in damage to root systems such as during logging operations may increase risk of disease. Site factors such as soil compaction or poor drainage may also play a role in the disease, particularly in ponderosa pine (Wilks and others, 1985).

There are strong indications that insect vectors similar to those attacking Douglas-fir roots are also involved in overland spread and initiation of new infections in ponderosa pine (Cobb, 1988). Site disturbance may also be a factor in the development of black-stain root disease in ponderosa pine

stands, although causal relationships have not yet been established (Cobb, 1988). The root feeding scolytid *Hylastes macer* has been implicated as a vector of black-stain root disease in ponderosa pine (Goheen and Cobb, 1978). This insect probably responds to chemical signals given off by injured roots or stressed trees.

Site disturbance as a result of timber harvesting in ponderosa pine stands may increase insect vector populations, thus increasing the likelihood of the disease developing in some stands. We recently conducted insect trapping studies in clearcut and thinned stands to monitor populations of potential vectors of black-stain root disease. Our catch data indicates a rapid increase in catch of *H. macer* through the flight season in sites that were thinned or clearcut compared to adjacent, undisturbed stands (figs. 1 and 2). The thinned stands represented in figure 1 had severe black-stain root disease 3 years after thinning, characterized by continuing mortality and stocking that is well below desired levels. Further studies are now underway in ponderosa pine stands to determine effects of levels of site disturbance (thinning by mechanical shearing versus chainsaw felling) and

Pitfall Trap Catches from Devil's Garden
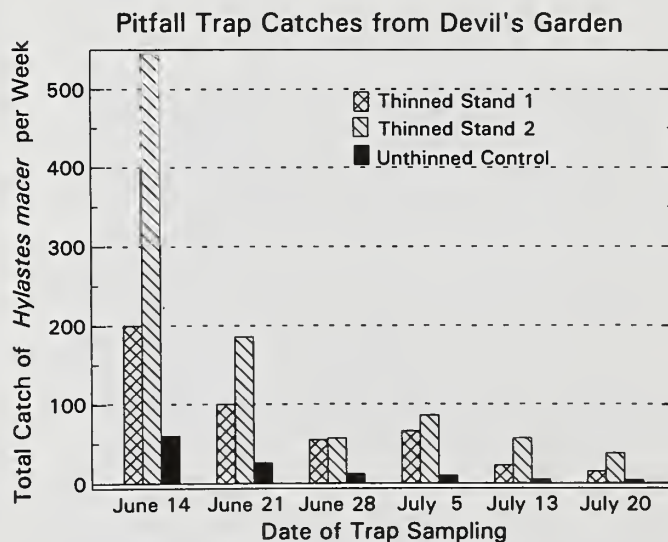
Figure 1.—Weekly pitfall trap catches of *Hylastes macer*, suspected vector of *Leptographium wageneri* var. *ponderosum*, in two ponderosa pine stands that have undergone thinning the previous season in the Devils Garden Ranger District, Modoc National Forest, California. Note the higher levels of insects trapped in the thinned stands (cross hatched and diagonal bars) compared to the undisturbed control stand (solid black bar) located within 0.5 to 1.5 kilometers of thinned stands.
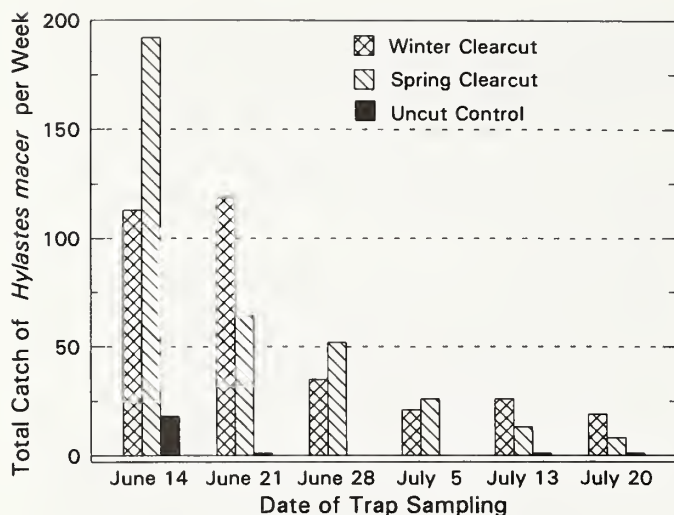
Figure 2.—Weekly pitfall trap catches of *Hylastes macer*, suspected vector of *Leptographium wageneri* var. *ponderosum*, in two ponderosa pine stands that were clearcut in winter (crosshatched) and spring (diagonal bars). Control stand (solid black bar) located about 100 meters from the clear-cut stands had much lower catch rates over trapping season.

timing of thinning (before or after bark beetle flight period) on insect vector populations and subsequent black-stain root disease occurrence in these stands.

EFFECTS OF FIRE

Many forest ecosystems have evolved with fire as a major factor responsible for maintenance of forest tree species and other vegetation. For example, in the southeastern United States coastal plain, periodic fire is essential for establishment and preservation of longleaf pine (*Pinus palustris* Mill.). However, the 60 to 80 million acres of land historically occupied by longleaf pine is now down to approximately 3 million acres. A large portion of these lands are currently used for other agricultural purposes or are planted to loblolly pine or other forest species.

While no research data is available at this time, past land uses may have a bearing on subsequent restoration of ecosystems such as longleaf pine. For example, the Savannah River Site near New Ellenton, South Carolina, under jurisdiction of the United States Department of Energy, with its forest lands managed by the USDA Forest Service in Region 8, have planted longleaf pine since the mid

1950's. The purpose for this and other pine species was to mitigate soil erosion on lands previously used for subsistence agriculture. Many of the stands now are about 40 years old and have been subjected to various prescribed fire regimes in addition to thinning and harvesting. A general increase in mortality has been observed in 30+ year old longleaf pine stands at the Savannah River Site. The major cause of mortality in longleaf pine on these sites is *H. annosum*. Recent preliminary studies on occurrence of root diseases in longleaf pine stands in the above age classes have revealed a relationship between recency of prescribed fire and increased mortality in burned versus unburned plots (Table 1). In addition to *H. annosum*, a high proportion of mortality trees sampled had various *Leptographium* species and bark beetle galleries associated with larger (> 5 cm diameter) roots of recently dead and dying trees in plots that have undergone prescribed burning within the last 3 years (Otrosina and others, 1995). The role of *Leptographium* in this ecosystem is unclear, however, some species are known pathogens of pines in the southeastern United States (Nevill and others, 1995) and may be responsible for declining stand health. While the prescribed burning regime was determined to be a "cool" burn, small lateral roots located within 5 cm of the soil surface had signs of damage, as determined by microscopic observations. Such damage was not observed on unburned plots.

It is not known at this time how various factors such as presence of *Leptographium*, root feeding bark beetles, thinning operations, fire regimes, various edaphic factors, and past land uses affect

Table 1.—Contrast in mortality and association of certain root infecting fungi in prescribed burned and unburned plots in a 30 year-old longleaf pine stand at the Savannah River Site.

	Burned plots	Unburned plots
Mortality (number of trees per hectare)	46	16
Percent *Heterobasidion annosum* recovered from sampled trees and stumps[a]	50	15
Percent *Leptographium* sp. recovered from sampled trees and stumps	45	20

[a]Percent *H. annosum* and percent *Leptographium* based upon 20 and 8 tree or stump root samples from the burn and unburned plots, respectively.

these longleaf pine stands. However, these associations raise suspicions and provide the impetus for further research. Questions such as: Does certain past land use history have a bearing on current observations of mortality and associated root infecting fungi? Does land use history and these biotic and abiotic factors interact in some way? Although longleaf pine ecosystems have evolved with fire, perhaps changes (as yet unknown) resulting from past land use events are affecting outcomes of stand developmental processes in an unexpected way. Answering these and similar questions may have relevance to "ecosystem restoration" projects in other situations as well.

CONCLUSIONS

Root disease causing fungi can respond to disturbances and changes in forest conditions and can act as primary causal agents of disturbance. In either case, they can be responsible for considerable losses in forest productivity, a consequence that cannot be ignored if we are going to utilize various products, recreational as well as commodities, derived from forests. At the landscape level, mortality due to diseases and insects may appear to be insignificant. However, because the stand is the unit on which we operate, losses and ecological changes brought about by diseases such as we have discussed do impact management plans. Forest stands are necessarily a part of management on a landscape scale and thus disease impacts must be considered wnen implementing overall large scale forest planning strategies.

There are considerable voids in our knowledge of the biology and interactions of these root disease causing fungi with forests. An understanding of root disease fungi and their interactions with various forest ecosystems must be obtained in order to avoid unacceptable outcomes as management plans are implemented. These organisms and the diseases they cause must be recognized as potent biological forces that can alter forest structure and can negatively impact productivity.

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Impacts of Southern Pine Beetles in Special Management Areas

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Abstract.—Southern pine beetles have had great impacts on wilderness and other special management areas. Infestations have spread and affected adjacent land, and they have disrupted the intended uses and goals desired for these areas. Coping with SPB in special management areas requires advance planning and management, then the use of new and integrated techniques for SPB risk reduction once the areas are established.

INTRODUCTION

The southern pine beetle (SPB), *Dendroctonus frontalis* Zimmermann, is the most destructive forest insect pest in the southeastern U.S. Four control methods are prescribed by the Final Environmental Impact Statement for the Suppression of the Southern Pine Beetle (USDA 1987): cut and remove, cut and leave, cut and hand spray, and pile and burn. These methods are efficacious in preventing the expansion of individual SPB infestations, but their effects on area-wide SPB populations is unknown. All four methods also involve felling trees, which can lead to conflicts with management restrictions in special management areas.

SPB IMPACTS IN SPECIAL MANAGEMENT AREAS

Wilderness

Prior to the enactment of the SPB FEIS, SPB control was allowed in wilderness. In Texas, 262 of 599 total SPB spots were treated in 5 wildernesses during a SPB epidemic in 1984–86. Total acres impacted was 1477, with 1392 acres treated. In the Kisatchie Hills Wilderness in Louisiana, 48 of 70

SPB infestations were controlled, with treatment on 3300 of 3930 acres impacted. SPB control in wilderness was very controversial, and various environmental groups filed suit in 1985 to prevent further action (Kirby 1986).

In 1987, the SPB FEIS established strict criteria for SPB suppression in wilderness. Treatment was allowed only to protect endangered species habitat or to protect susceptible pines on adjacent private or high value federal lands. For the endangered red-cockaded woodpecker (RCW), a SPB spot growth model must predict the infestation would impact essential clusters or critical foraging area within 30 days. Before control can be initiated to protect adjacent private land or high value federal land, the infestation must be within 1/4 mile of susceptible pines on the adjacent land, and a site specific analysis must predict the infestation would impact those pines.

The private landowner must also be willing to control SPB on his/her property. In all instances, the Forest Service must be assured of a reasonable chance of successful control before suppression may begin.

Though the possible impacts of limiting SPB suppression in large areas forested with pines had been discussed (Billings 1986, Smith and Nettleton 1986) and documented (Billings and Varner 1986), the effects of the new criteria were not evident until another epidemic began in Texas in 1992.

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Large infestations developed in all five wilder-nesses in Texas. The size and intensity of the infestations when they reached the 1/4 mile mark often made control difficult or impractical. Eigh-teen spots were treated to protect adjacent land, with treatment occurring on 126.4 acres in wilder-ness. Ten spots crossed over to private land, affecting approximately 205 acres, with another 456 acres harvested prior to predicted infestation. In Little Lake Creek Wilderness, 31 spots were treated to protect RCW clusters and critical foraging habitat, encompassing 274.2 acres. Total acres infested are given in Table 1. Approximate per-centages of Texas wildernesses impacted through FY 1944 are: Indian Mounds—3 percent, Turkey Hill —38 percent, Upland Island—14 percent, and Little Lake Creek—26 percent.

Current Conditions

In 1987 in Kisatchie Hills, a 7500 acre wildfire burned much of the 4000–5000 acres affected by SPB the previous two years. A study by Pearson et al. (1991) found that virtually no overstory canopy was present on the wildfire and beetle killed areas. Loblolly pines increased in the beetle killed only area, while pines were not present in the wildfire and beetle killed area. A visit by the author in April 1995 found loblolly pines 10–15 feet tall in the beetle killed only site, with scattered hard-woods mixed in. No overstory was evident in the beetle killed and burned area. Small patches of 2–3 foot tall pines were present, but the area appeared dominated by small oaks and yaupon.

In Texas wilderness, the large areas once domi-nated by pine which were killed by SPB are now characterized by standing and downed snags. Access into these areas is difficult and hazardous, and the tops of many snags have been snapped off

by high winds. The fire hazard is great due to the amount of woody material on the ground. Other areas which originally had a pine hardwood mix now have a open hardwood canopy mixed with pine snags. Little pine regeneration is evident in any of the beetle killed areas. Recreational use in these areas is extremely limited, though the poten-tial for solitude is very high.

Habitat Management Areas

SPB also has the potential to severely impact wildlife species requiring pines, such as RCW. RCW prefer older pines for cavity excavation (Conner and O'Halloran 1987) and foraging (C.Rudolph, pers. comm.), and these trees are also highly susceptible to SPB attack (USDA Forest Service 1993). At least 162 active cavity trees and 39 inactive cavity trees were killed by SPB in Texas from 1983–1993. Infestations can also destroy foraging habitat and lead to forest fragmentation, which may impact a variety of wildlife species, both positively and negatively.

Other Special Management Areas

Research natural areas (RNAs) have restrictions on SPB control similar to wilderness. Infestations have the potential to greatly reduce the pine com-ponent in RNAs as they have done in wilderness. Cain and Shelton (1995) found that areas infested by SPB in the R.R. Reynolds RNA in Arkansas are converting from pine to hardwood. The shade intolerant pine regeneration is shaded out by hardwoods and the standing dead pines. Hard-woods are expected to dominate the SPB killed areas in the absence of any other major disturbance. Scenic, botanical, and old growth pine management areas may also convert to hardwoods when SPB control and/or active management is limited.

Other non-Forest Service lands have had severe SPB impacts. The Big Thicket National Preserve in Texas has had many large infestations develop over the last three SPB epidemics. When estab-lished, the Preserve had approximately 51,000 acres of susceptible host type out of a total of 84,550 acres. Between 1975–86, 8,677 acres were impacted

Table 1.—Estimated total acres infested by SPB in Texas by fiscal year.

Fiscal year	General forest	Wilderness
1991	1,095	117
1992	2,689	2,130
1993	2,134	10,179
1994	174	96

by SPB (USDA 1987), and from 1992–1994 at least 3215 more acres were killed (Clarke and Ardoin, 1992, Clarke et al. 1993). Horseshoe Bend National Military Park in Alabama, the Natchez Trace Parkway, Fort Benning , GA, and many other federal lands with varying management emphases and goals have had significant SPB activity in recent years.

COPING WITH SPB IN SPECIAL MANAGEMENT AREAS

Desired Future Condition

The first step in dealing with SPB in special management areas (SMAs) is to identify the desired future condition (DFC) of the SMA. This should ideally be decided before the SMA is established. The DFC describes how the area should look in a specified timeframe, and is determined by the specific needs and potential uses identified during the SMA planning process. Once the DFC is set, the techniques required for SPB risk reduction and suppression which help reach the DFC can be designed. If it is clear that the necessary techniques are not available due to limitations in management activities imposed by management area emphases, then the area should be considered for reclassification. For example, the Four-Notch area in southeast Texas was proposed as a wilderness. The landscape consisted of primarily short-leaf and loblolly pine. In 1983, SPB infestations began to develop, but control was delayed due to the area's status as potential wilderness. A massive SPB infestation resulted, and as Coulson et al. (1986) note, the attributes which led to its selection as a wilderness candidate were lost as a result of the disturbance caused by SPB. The area was subsequently dropped for wilderness consideration.

Public involvement is very important in this process. The public must be informed of the possible consequences that can occur with SMA designation and restrictions in SPB suppression. For example, if a unique stand of old growth pine is located, the public must be aware that relegating the stand to wilderness or a RNA will not allow protection of the pines from SPB. If the pine component of a scenic or botanical area is considered valuable and desirable, then standards and guidelines for the area must allow for SPB suppression, and the public must understand why suppression is necessary. If letting nature take its course is the only DFC of an area, then SPB suppression is only required in emergency situations.

Set Boundaries Appropriately

Once a special management area designation is selected, it is important to set the boundaries appropriately. Boundaries should be drawn so as to provide access as needed, prevent adjacent overdevelopment, and avoid potential conflicts with neighboring private lands or other management areas. While it has been recommended that wilderness not be buffered (Phillips 1986), designating stands of mature, dense pine adjacent to susceptible pines on private lands as wilderness is asking for trouble. Common sense dictates that leaving a patch of general forest area between wilderness and private land in such situations will alleviate the threat of SPB populations in wilderness to pines on private land. Site-specific conditions and projected wilderness usage should guide boundary designation.

Manage Adjacent Areas to Reduce SPB Risk

When SPB suppression is limited in SMAs, the adjacent areas should be managed to reduce the risk of SPB. All SPB infestations should be quickly controlled. Pine basal area should be reduced, but pines should not be eliminated if susceptible pines on adjacent private land are nearby. Leaving some pines on adjacent GFA provides an opportunity to steer SMA populations onto GFA and away from private land, limiting the amount of suppression activity required in the SMA. Restoring adjacent areas to less susceptible pine species such as longleaf pine when appropriate can also reduce impacts. Ideally, the areas adjacent to wilderness should be defined use zones which limit development (Phillips 1986). However, the need to limit management and development next to wilderness must be balanced against the potential for insect and other destructive agents within wilderness to

affect adjacent lands. As conditions within wilderness or other SMAs change, so too should the management strategy for adjacent lands.

Strategies for SPB in Established SMAs

In the past, SPB management has consisted of spot suppression by one of the four techniques listed above, and SPB hazard reduction. Hazard reduction was usually not a top priority, but rather one of the needs listed to justify proposed management activities, such as clearcutting and replanting with off-site loblolly pine. In the future, particularly in SMAs, SPB management must incorporate true integrated pest management (IPM), utilizing a variety of suppression and hazard reduction strategies. Hertel et al. (1986) discuss IPM in SMAs, and the following is an update on new strategies.

SPB Inhibitors

Two SPB inhibitors are currently being tested for SPB spot suppression: verbenone, a SPB produced anti-aggregation pheromone, and 4-allylanisole (4-AA), a phenylpropanoid in the oleoresin of many pines (Hayes and Strom 1994, Billings et al. 1995). Freshly attacked trees and an uninfested buffer strip are treated in an effort to disperse the emerging and reemerging SPB and stop spot expansion. Early results with verbenone indicate that it works best on small infestations, and that treatment efficacy can be improved by felling infested trees. Semiochemicals may provide a treatment alternative to the four treatments currently utilized if efficacy can be established and EPA registration is obtained. Environmental groups have expressed interest in these compounds, and the use of semiochemicals may even be an option in wilderness. Small infestations could be treated before they expand and threaten adjacent private land. Otherwise, treatments involving felling would eventually be required. Inhibitors also show promise in the protection of high-value individual trees, such as RCW cavity trees.

Natural Enemy Maintenance

Natural enemies can have significant impacts on SPB populations, but as yet have not been shown to suppress infestations or epidemics alone.

Thanasimus dubius (F.), a clerid beetle, is the most common predator of SPB. Adults feed on adult SPB, while larvae feed on SPB larvae. Recent work by Reeve et al. (1995) indicates that clerids have an extended diapause, and may not emerge from trees until long after SPB have emerged. This extended diapause illustrates the necessity of leaving trees vacated by SPB during suppression treatments. In addition to protecting *T. dubius*, preserving these vacated trees also provides a resource for other wood-attacking beetles, which in turn provides an alternate food source for SPB natural enemies when SPB populations are low. Natural enemies may then be maintained in sufficient numbers to respond quicker to increasing SPB populations. Kroll et al. (1980) also recommend preserving vacated trees as nesting sites for woodpeckers. Woodpeckers feed on SPB brood in the bark, and can inflict heavy mortality on SPB populations.

Parasitoids can also impact SPB population levels. Some parasitoids can produce two generations for each SPB generation, but the adults may require supplemental feeding (Fred Stephen, pers. comm). Providing food sources for parasitoid adults may increase their efficiency.

Silvicultural Techniques

Silviculture has long been promoted as a way to reduce SPB impacts. Thinning, favoring more resistant species, removing high-risk trees such as lightning struck pines, and providing a hardwood-pine mix can all increase stand resistance to SPB (Belanger and Malac 1980, Brown et al. 1987). The impacts of other treatments such as prescribed burning are unclear. Conner and Rudolph (1995) give evidence which suggests that midstory removal in RCW clusters may increase the susceptibility of individual trees to SPB attack. While many silvicultural treatments may enhance long-term stand health and SPB resistance, they may temporarily or permanently increase individual tree susceptibility to SPB. Silvicultural activities should be evaluated for their potential impact on forest pest problems on a site-specific basis, and treatments should be scheduled when SPB populations are at low levels or after the main dispersal periods.

In special management areas, silvicultural options are often limited. Where felling is prohibited, girdling could be used to thin stands and to favor more resistant species. Prescribed burning could also be used to help regenerate longleaf where appropriate, and can also be used to thin young stands (Lloyd et al. 1995). Girdling could also be used to help suppress SPB infestations, as Dunn and Lorio (1992) report that SPB colonization was less successful above bark girdles than below. This technique might merit further research.

While neither silvicultural treatments, natural enemy maintenance, or use of semiochemicals alone can prevent SPB epidemics, a combination of these may reduce the severity of outbreaks and limit impacts, decreasing the need for suppression activity in SMAs.

SUMMARY

In the south, SPB will always remain a problem in areas where pine is a main or desirable component of the landscape. Coping with SPB in special management areas is best done at a site-specific level. Planners, silviculturists, and forest health experts must work together when designating SMAs, and when developing management strategies in those areas already established. Standards and guidelines for reducing susceptibility and suppressing infestations should be designed based on the desired future condition and predicted use of the SMA, the potential for adverse impacts to adjacent lands, and the management restrictions within the area. Public involvement is crucial, and they must be aware of the potential of SPB to positively or negatively affect the quality, appearance, use and structure of SMAs.

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Gypsy Moth Role in Forest Ecosystems: The Good, the Bad, and the Indifferent

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Abstract.—Despite a century of attempts to control populations of the gypsy moth, it remains one of the most destructive forest pests introduced to North America. Research has yielded valuable, albeit sometimes conflicting information about the effects of gypsy moth on forests. Anecdotal accounts and scientific data indicate that impacts of gypsy moth defoliation can range from inconsequential to devastating. When defoliation caused by the gypsy moth results in widespread mortality, successional patterns may be modified substantially and species composition may be altered. The most notable change in Eastern forests is a transition from oak dominated forests to those consisting largely of early successional species. Forest-level changes also modify habitats, thereby influencing populations including but not limited to birds, mammals, and invertebrates; but effects of the gypsy moth seem to be forest-specific and organism-specific. Attempts to limit the influence of gypsy moth defoliation by silvicultural methods appear to have promise in maintaining the overstory and possibly diversifying the understory, but it may be difficult to distinguish the effects of defoliation from the effects of thinning on vegetation as well as invertebrate populations.

INTRODUCTION

Since its accidental introduction near Boston, MA, in 1869, the gypsy moth (*Lymantria dispar* L.) has expanded its range in all directions, moving most notably southward and westward. Projections suggest that the expansion will proceed relatively unabated into varying forest types (Liebhold and others 1992). Roughly 80 % of the forests of North America is likely to experience some degree of defoliation. The earliest accounts of gypsy moth defoliation (Forbush and Fernald 1896) indicate the potential destructiveness of the gypsy moth, and information accruing since then also suggests that substantial changes in forests may be attributed to the gypsy moth.

Despite the numerous significant effects of gypsy moth defoliation, in this paper we will limit our

discussion to the effects on forest vegetation and forest arthropod communities. We will also address the use of silviculture to moderate the ecological or biotic effects of gypsy moth.

However, the numerous abiotic effects warrant mention. Among the less obvious consequences of gypsy moth are social, recreational and aesthetic problems such as reduced visitation due to an increased nuisance factor. Economic considerations are also important, because changes in the timber base can have negative ramifications for local economies. Effects of the gypsy moth on abiotic components, such as nutrient cycling, can cause irreparable changes in water quality and reduced soil productivity, and both can be detrimental to forested ecosystems. Studies in the Shenandoah Mountains of VA demonstrated an increased loss of cations from defoliated watersheds, exacerbating effects of acid deposition (Webb and others, unpublished data).

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EFFECTS ON FOREST VEGETATION

Overstory

Although many trees and shrubs may be utilized as a food source, gypsy moth larvae exhibit a distinct preference for certain species. Consequently, forest trees are categorized as "susceptible", "resistant" or "immune" to defoliation (Montgomery 1991, Twery 1991). The extent to which a forest is dominated by trees of each of these categories will then determine its relative susceptibility and vulnerability (Smith 1986). Stand susceptibility is described as the likelihood that defoliation will occur if the gypsy moth is present (Gottschalk 1993). Prior research indicates that pure stands of preferred food species such as oaks (*Quercus* spp.) are more susceptible to defoliation than mixed stands (Gottschalk and Twery 1989, Houston and Valentine 1977). Mortality of overstory trees occurs in direct proportion to defoliation (fig. 1), so the degree of stand susceptibility largely determines the extent of mortality.

A seminal work describing gypsy moth effects on forest composition and structure was published by Campbell and Sloan (1977). They found in-

creases in mortality among preferred overstory species, particularly when defoliation was not severe. In general, the loss of preferred species resulted in a subsequent forest that is less susceptible to gypsy moth. This was due primarily to the increasing dominance of red maple (*Acer rubrum* L.), considered resistant to the gypsy moth. This successional pattern characterizes many gypsy moth post-defoliated stands in the East.
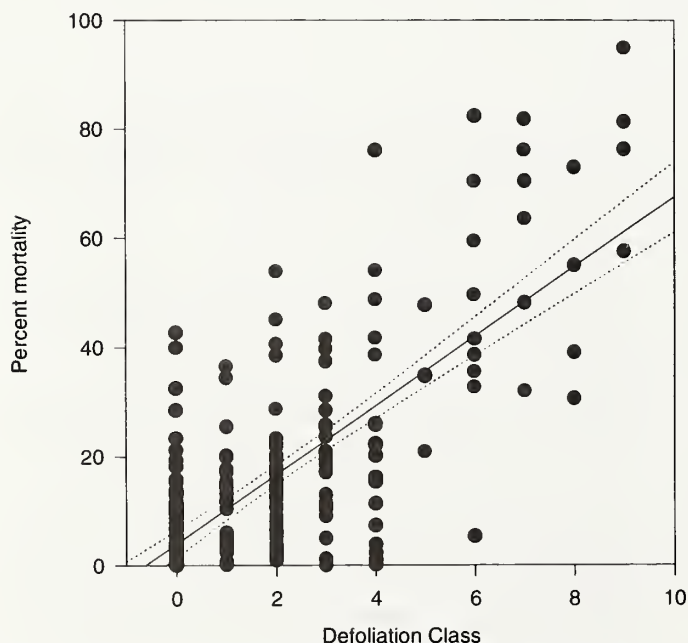
The most obvious forest structural changes caused by gypsy moth defoliation include loss of high canopy cover (>39 ft), increase in low canopy cover and an increase in shrub cover (Thurber 1992). Campbell and Sloan (1977), however, reported that repeated heavy defoliation resulted in changing stand structure and loss of vertical stratification. The structural changes from defoliation and mortality may present favorable consequences for wildlife, but can create stocking level and regeneration problems.

Gypsy moth may be contributing to the role of a regulator of forest ecosystems (Mattson and Addy 1975). Gypsy moth induced mortality preferentially eliminates low vigor trees (Campbell 1979, Houston 1981); hence removal of these individuals may help perpetuate a relatively healthy stand. Such mortality also resembles the effects of thinning from below. As such, a low to moderate level of mortality appears to have little effect on forest conditions. More recent findings from central PA Ridge and Valley plots that have undergone defoliation indicate crown position has a significant influence on amount of mortality (fig. 2). Similar to the findings of Campbell and Sloan (1977), this study indicates that suppressed and intermediate trees are more likely to suffer mortality. These results support the theory that gypsy moth mortality is similar to a thinning.

As Kegg (1973) maintains, however, defoliation effects are not equivalent to a thinning when high levels of defoliation lead to catastrophic mortality levels (>50 to 60% of stand basal area) (Fosbroke and Hicks 1989). Catastrophic mortality levels generally occur on only about 20 to 25% of the landscape (Herrick and Gansner 1987, 1988, Gottschalk 1993).

Figure 1.—Regression line (with 95% confidence interval) showing the relationship between percent mortality of stand basal area and defoliation class (Feicht and others 1993). Increasing class is equivalent to increases in defoliation ranging from <30% (class 0) to 4 years of > 60% defoliation (class 9).

Understory and Regenerating Species

As with any disturbance causing extensive mortality, areas that have experienced defoliation
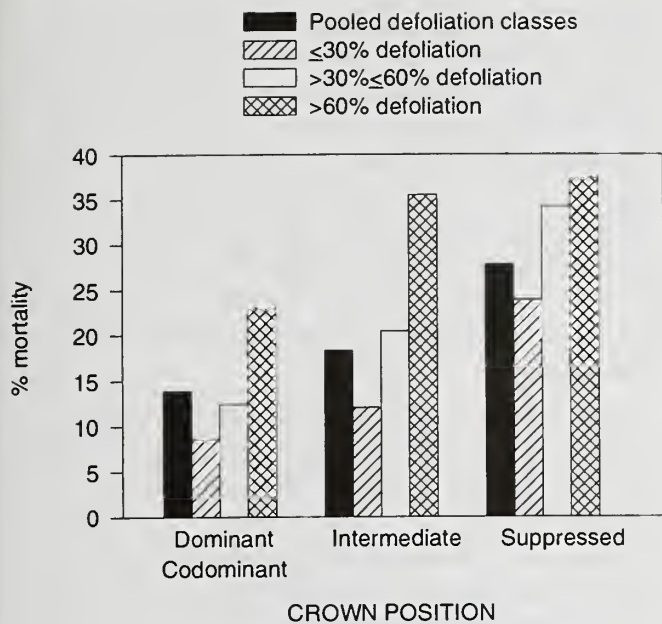
Figure 2.—Percent mortality of trees classified by crown position and defoliation class.

Figure 3.—Percent regeneration of major species in post gypsy moth defoliated stands. Data represent regeneration in areas surveyed 3 to 4 years subsequent to defoliation and includes all individual stems >0.1 ft in height, but ≤ 2.49" dbh.

by the gypsy moth are likely to undergo dramatic changes in species composition and structure. Early successional species replace a largely oak overstory in the East. Studies by Allen and Bowersox (1989), Ehrenfeld (1980), Feicht and others (1993), and Hix and others (1991) have examined regeneration following gypsy moth defoliation and indicate a reduced regeneration of previously dominant overstory species. Even in moderately defoliated areas, most of the regeneration consists of exploitive species, particularly red maple; and there is little evidence to suggest that shade tolerant trees replace the overstory in low to moderately defoliated areas.

Studies in the Ridge and Valley of PA, and the Appalachian Plateau of WV have yielded comparable results in terms of woody species regeneration following defoliation. Figure 3 demonstrates the overwhelming dominance of red maple in the regeneration as well as the variation among species between the two physiographic provinces. Black cherry assumes a more significant role in the Appalachian Plateau than in the Ridge and Valley, and Muzika and Twery (1995) have shown that this species dominates in size, although not numerically, in post-defoliated stands. The size advantage may be sufficient to dominate red maple in Appa-

lachian Plateau forests. For example defoliated stands had an average of 512 trees/acre > 5 ft tall. Oak constitutes a small portion of the regeneration in the Ridge and Valley and Appalachian Plateau forests, and probably will account for a minimal component in the future forest overstory.

EFFECTS ON FOREST ARTHROPODS

Arthropods are among the more poorly understood components of most ecosystems, and forests are not an exception. These organisms play critical ecological roles and in forests infested with gypsy moth, can account for substantial predation. Thus, maintaining healthy populations of soil, ground-dwelling, and arboreal arthropods is critical not only from the standpoint of biological diversity, but also as a means to control populations of forest pests (Smith and Lautenschlager 1978).

No previous information is available to describe potential effects of gypsy moth defoliation and mortality on forest arthropod communities. Over a 4-year period we examined the changes in populations of carabid beetles, spiders, phalangids, and ants to determine the extent to which gypsy moth defoliation affects these invertebrates. These four groups are important predators of the gypsy moth. The study took place on the West Virginia University Experimental Forest, located in Preston and Monongalia Counties, in north-central WV. In 1989, sixteen stands (20–30 ac) were located, baseline information was gathered, and eight of these were thinned in the winter of 1989. During 1990 and 1991, six stands were defoliated by gypsy moth. Large-capacity pitfall traps were used to trap, kill, and preserve invertebrates during an 11-week peiod beginning in late May to early July, from 1989–1992.

The average number of individuals captured, each year by group in defoliated stands is shown in Table 1. Analysis of covariance (1989 data as the covariate), showed that the total number of ants, spiders and beetles changed significantly from the pre-defoliation year. However, ant and beetle populations decreased, but spiders increased. Although these populations probably were influenced by the effects of gypsy moth defoliation, it is difficult to discern whether such effects alter patterns of natural variation in populations.

THE ROLE OF SILVICULTURE

Overstory

The use of silviculture to deal with forest pests has been expressed and explored for most of the century (see Gottschalk 1993 for complete references on this topic). An obvious role for silviculture is stand manipulation to change stand susceptibility, hence, reduce the likelihood that gypsy moth will cause substantial damage. Information is not available to verify the effectiveness of silvicultural treatments for gypsy moth. The West Virginia University Forest study described earlier has begun to yield some information about the potential benefits of thinning in advance of gypsy moth defoliation.

Initial results suggest that thinning may be an effective way to prevent excess loss of overstory basal area and particularly oak basal area. In stands with comparable defoliation, 5 years after thinning, the thinned stand lost 46% of the total basal area and 54% of the oak basal area, whereas the unthinned stand lost 63% total basal area and 85% of the oak basal area (fig. 4).

Table 1.—Average number of individuals per trap collected in pitfall traps in defoliated stands by year and group. Defoliation occurred in 1990 and 1991. Analysis of the spider data for 1992 has not been completed.

	Year			
	1989	1990	1991	1992
Ants	104	86	68	53
Phalangids	10	11	13	5
Spiders	73	93	120	NA
Carabid beetles	63	28	33	40
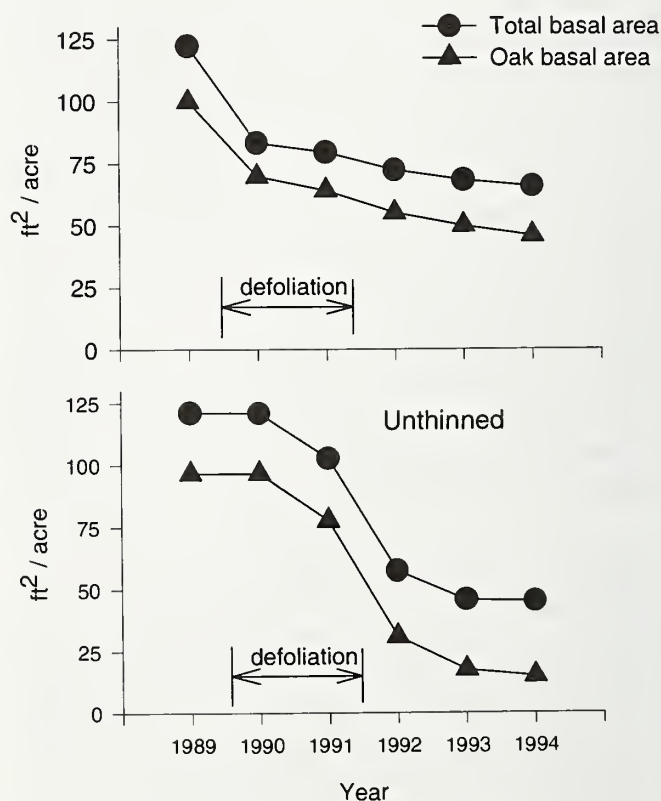
Figure 4.—Reduction in basal area (total and oaks only) over time in thinned and unthinned stands defoliated by gypsy moth. Stands were thinned in winter 1989–90 and defoliation occurred in 1990 and 1991. Basal area values were derived from stems >2.49" dbh.

Table 2.—Number of stems per acre > 5 ft tall, but less than 2.49" dbh, in defoliated stands and defoliated and thinned stands at the West Virginia University Experimental Forest 1989 and 1994.

Species	Defoliated		Defoliated and Thinned	
	1989	1994	1989	1994
Red Maple	34	19	160	79
Sweet Birch	9	11	6	4
Yellow-Poplar	0	0	0	4
Black Gum	30	24	11	0
Black Cherry	62	512	109	715
White Oak	4	4	2	0
Chestnut Oak	9	6	2	6
Northern Red Oak	13	4	2	0

Table 3.—Average number of anthropods per trap collected in pit-fall traps in defoliated and thinned stands, by year and group.

Anthropod	Year			
	1989	1990	1991	1992
Ants	83	74	64	51
Phalangids	8	10	18	8
Spiders	65	74	115	NA
Carabid beetles	64	26	48	38

Regeneration

When regenerating species, thinning does not seem to significantly change composition or dominance. In our study, regeneration has been followed since 1989 (pre-treatment) and will continue until 1999. Recent data (Table 2) demonstrate the changing pattern of dominance in the understory and indicate which species are likely to dominate the overstory. Black cherry is the only species with an increasing number in the large regeneration (>5 feet tall; 2.49" dbh) cohort over time since the thinning and defoliation. Thinning somewhat enhances the dominance of black cherry but has little effect otherwise. With the exception of chestnut oak in the defoliated and thinned stands, oaks in general have responded negatively to defoliation and thinning has not moderated that effect. Before defoliation, these stands had as much as 85% of the basal area in oak species, but it is obvious that the future forest will bear little evidence of that oak dominance.

Forest Arthropods

For populations of ants, phalangids, spiders, and carabid beetles, trends in stands that have been thinned and defoliated (Table 3) roughly parallel those of stands that had been defoliated only (Table 1). Thinning slightly elevated phalangid levels in 1990 and 1991 and also increased carabid populations in 1991. An increase in carabid abundance could be particularly significant because members

of this group are known, active predators of the gypsy moth. The abundance of all groups except spiders decreased over time, and spider abundance increased dramatically with each year.

Species-level analyses are needed to understand the complete effects of defoliation and thinning. Ameliorating potentially detrimental effects may present a more critical problem. In this same study area, for example, in stands that have not been defoliated but only thinned, there are notable changes in species and abundance. Moreover, the effects of defoliation and thinning alter forested ecosystems in a more dramatic way than either effect alone.

SUMMARY

The persistence of gypsy moth effects may go undetected or mistaken for natural processes, especially with the realization that ecosystems rarely attain a steady state. At a certain level, changes caused by gypsy moth may have nominal influence in natural processes. But, the effects of extensive and severe gypsy moth defoliation do not resemble processes of stand dynamics, but rather represent post-disturbance trends. Many such trends are predictable, such as the replacement of the overstory with shade intolerant species. The most dramatic changes in eastern forests reflect the loss in dominance of oak in the forests. In places like the Ridge and Valley Province of Pennsylvania, the full ramifications of changing forest composition may not be realized for decades. As the gypsy moth moves into other regions, e.g. the mixed mesophytic forests, the effects are likely to differ.

Preliminary information on other organisms, such as forest arthropods, indicates that gypsy

moth may influence biological diversity as well as food web dynamics. A more complete understanding of the interaction of other forest arthropods with gypsy moth populations is needed. Furthermore, the effects of defoliation appear to be site specific and have a great deal to do with pre-disturbance conditions, both in terms of vegetation and faunal communities.

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Exotic Pests: Major Threats to Forest Health

J. Robert Bridges[1]

Abstract.—Over 360 exotic forest insects and about 20 exotic diseases have become established in the U.S. Many of these organisms have become serious pests, causing great economic impacts and irreversible ecological harm. Despite efforts to exclude exotic species, forest insects and disease organisms continue to be introduced at a rather rapid rate. In the last few years, one disease organism and six forest insects have been introduced or discovered in the U.S. Some of these organisms have the potential to become serious pests. Preventing introductions of exotic organisms is a global problem that requires international cooperation. Rigorous quarantine protocols should be developed for all types of forest products, and monitoring progams are needed to detect new introductions. Lists of exotic species of quarantine significance should be developed to assist in assessing the risks of future introductions and in developing ways to prevent or eradicate exotic pests.

INTRODUCTION

Non-indigenous species seriously threaten the health of forest ecosystems. Many of the thousands of species of plants and animals introduced into the U.S. have become pests, and many are pests of forests. The threat of inadvertently introducing additional pests is increasing as the world's population increases and as world travel and commerce continue to expand. As more pests become established, their cumulative effects significantly degrade the health of our Nation's forests.

In this paper I will review the history of pest introductions and describe some of these organisms' impacts on forests. I will also discuss the potential of additional introductions and describe several forest pests that have been introduced in the past few years to illustrate the magnitude of the problem. Finally, I will suggest some ways to address the problem.

EXOTIC PEST INTRODUCTIONS

Over 4500 species of exotic organisms are established in the U.S. (U.S. Office of Technology Assess-

ment 1993). By far the most numerous introduced species are plants and insects (Table 1). Over 2000 species of plants and arthropods have been introduced. This reflects, in part, the fact that more species of plants and insects have been described than species in other categories. These are probably conservative estimates, especially for insects, because only about 50% of insects have been identified (U.S. Office of Technology Assessment 1993). Undoubtedly some exotic insects have not yet been identified.

Non-indigenous species continue to be introduced into the U.S. A recently published study of non-indigenous species in the U.S. concluded that there was no evidence that the number of introductions has decreased in recent years (U.S. Office of Technology Assessment 1993). In fact, the threat of introductions is probably increasing as world commerce expands. Increased movement of people and their goods around the world increases the potential for additional introductions.

Because the majority of forest pests have been introduced on plants or plant materials (Campbell and Schlarbaum 1994), it is important to examine the pathways of introduction of logs or trees. In the past few years there has been increasing interest in importing logs from countries such as Russia, New Zealand, and Chile. This interest has prompted

Table 1.—Estimated numbers of exotic species in the United States.[a]

Category	Number
Plant	>2000
Terrestrial vertebrates	142
Insects and arachnids	>2000
Fish	70
Mollusks (non-marine)	91
Plant pathogens	239
Total	>4,542

[a] Data from U.S. Office of Technology Assessment (1993)

Figure 1.—Cumulative number of exotic insects introduced into the United States.

studies to assess the risk of pest introductions on imported logs. These assessments demonstrated that importing logs poses tremendous risks of introducing pest organisms (USDA 1991, USDA 1992, USDA 1993). For example, the Siberian log assessment identified over 170 pests on larch (USDA 1991). Many of these pests were considered to pose a high risk of being introduced and becoming established.

Exotic Insects

Because the rate of introductions is not declining, the cumulative number of exotic pests continue to grow as illustrated by the introduction of insects into the U.S. (fig. 1). During the late 1800's and early 1900's, introductions increased almost exponentially. After 1920 the rate of introduction leveled off due in part to the passage of the Plant Quarantine Act in 1912 (Sailer 1983). Since the 1920's, approximately equal numbers were introduced each decade. The rate is not decreasing, and the cumulative number of introductions continues to rise extremely rapidly.

Many of the species of insects that have become established in the U.S. are forest dwelling. Mattson and others (1994) list 368 species of phytophagous insects on woody plants in the U.S. and Canada. About half of these insects are pests, some of which seriously threaten forest ecosystems and cause economical or ecological harm. Pimentel (1986) estimated that 19 of 70 major insects pests of U.S. forests were exotic species. Patterns of species introductions have paralleled intercontinental commerce patterns. Most came from Europe (73%) or Asia (18%) (Mattson and others 1994).

Exotic Diseases

Although only about 20 diseases have been introduced into the U.S. (Table 2), some of these pests have been devastating to native forests. Most are from Europe and were probably introduced by humans, often on infected plants. A characteristic of plant pathogen introductions has been their association with humans and the transport of nursery material or timber. The most serious forest pests arrived this way before strict implementation of quarantines (von Broembsen 1989).

Chestnut Blight

Perhaps the most striking example of an exotic forest disease is chestnut blight. The impact of chestnut blight impact has been called the largest single change in any natural plant population in history (Harper 1977). The fungus was discovered in the early 1900's in New York City (Liebhold and others 1995), but was probably introduced from Asia on ornamental nursery material in the late 1890's (von Broembsen 1989). The disease spread rapidly throughout the eastern U.S. and in less than 50 years had spread throughout the range of chestnuts, virtually eliminating chestnut, which was the dominant tree species in the hardwood forests of the East.

Table 2.—Exotic diseases of woody plants established in the United States.[a]

Disease organism	Common Name	Origin	Reference
Ascocalyx abietina	Scleroderris canker	Europe	Manion 1984
Cercospora nandinae	Heavenly bamboo blight	Japan	Sinclair et al. 1987
Coleosporium sonchi	Scotch pine needle rust	Europe	Boyce 1961
Cronartium ribicola	White pine blister rust	Europe	Walker 1950
Crypphonectria parasitica	Chestnut blight	Asia	Walker 1950
Discosporium populeum	Dothichiza canker	Europe	Hubbes 1967
Discula destructive	Dogwood anthracnose	Japan	Redlin 1991
Elsinoe euonymi-japonica	Euonymus scab	Japan	Sinclair et al. 1987
Fusarium oxysporium f.sp. perniciosum	Mimosa wilt	Asia	Boyce 1961
Fusicladium saliciperdum	Willow scab	Europe	Boyce 1961
Gymnosporangium confusum	Medlar rust	Eurasia	Sinclair 1987
Lachnellula willkommii	Larch canker	Europe	Boyce 1961
Melampsora larici-populina	Poplar leaf rust	Asia	Newcombe & Chastagner 1993
Nectria coccinea var. faginata	Beech bark disease	Europe	Houston & O'Brien 1983
Ophiostoma ulmi	Dutch elm disease	Europe	Walker 1950
Phomopsis arnoldiae	Phomopsis canker	Europe	Sinclair et al. 1987
Physalospora miyabeana	Black canker of willow	Europe	Boyce 1961
Phytophthora cinnamomi	Phytophthora root rot	Asia	Sinclair et al. 1987
Phytophthora lateralis	Phytophthora root rot	Asia	Roth et al. 1972
Sirococcus clavigignenti-juglandacerarum	Butternut Canker	?	Ostry et al. 1994
Viscum album	Mistletoe	Europe	Sharpf & Hawksworth 1974

[a]*List compiled by Imants Millers, USDA Forest Service*

White Pine Blister Rust

White pine blister rust (WPBR) is the most important disease of five-needle pines. The disease is native to Asia but was introduced to Europe in the 1800's where it was then exported to the U.S. on diseased nursery stock in the late 1900's (Liebhold and others 1995). WPBR has spread throughout the range of the white pines (Schmidt 1992) and was recently discovered as far south as New Mexico, where it infects southwestern white pine *Pinus storbiformis*. WPBR has had a major impact on the timber industry (Ketcham and others 1968) and has caused ecological impacts by killing whitebark pines throughout their distribution. Seeds from this tree are an extremely important food source for the endangered grizzly bear and associated birds and mammals (Schmidt 1992).

Dutch Elm Disease

Dutch elm disease is the most important pest of shade trees in the U.S. It is caused by the fungus *Ophiostoma ulmi*, which is vectored by bark beetles. The primary vector is the European elm bark beetle, *Scolytus multistriatus*. Both the fungus and its vector were introduced from Europe on diseased timber in the early 1900's. By 1977 the disease had spread to most of the contiguous 48 states and by 1979 had killed three quarters of the elms in the Northeast (Campbell and Schlarbaum 1994).

Butternut Canker

Butternut canker is caused by the fungus, *Sirococcus clavigignenti-juglandacerarum*, of unknown origin. It was discovered in the U.S. in 1967 in Wisconsin but is thought to have been introduced several years before (Ostry and others 1994). The fungus was described as a new species in 1979, and butternut is the only known natural host. The disease is thought to be exotic, although there are no records of its occurrence anywhere else in the world (Ostry, personal communication). Since its discovery, the disease has spread very quickly throughout much of the range of butternut (Campbell and Schlarbaum 1994). It is very destructive with only a few "resistant" trees surviving. The loss of butternut from this disease has been so rapid and extensive that butternut is a Category 2 candidate for listing under the Endangered Species Act. (Ostry and others 1994).

RECENT INTRODUCTIONS

Animal and Plant Health Inspection Service (APHIS) port inspectors often find insects on cargo entering the U.S. APHIS maintains a database of these interceptions. Most of the intercepted forest insects are associated with wood (mostly crating, pallets, dunnage). Some of the most frequently intercepted pests on wood include several bark beetles that have the potential to be serious pests. Table 3 shows a list of the most frequently intercepted species during 1985–1994. In addition to these insects, unidentified species in the family Scolytidae (bark beetles) were intercepted over 1000 times during the same period. Most interceptions are bark beetles in the family Scolytidae, mainly from Europe (Table 3). *Pisodes* and *Hylobius* are weevils. Three species on this list, *Hylurgus ligniperda*, *Ips typographus*, and *Tomicus piniperda*, have been introduced or discovered in the last few years.

Within the last few years, at least one disease organism and six insects have been introduced or discovered in the U.S. Most species are established here and some were probably here for some time before being discovered. Of the insects, most are bark beetles that have been intercepted at ports many times through the years.

Table 3.—Most frequently intercepted insects found on wood at U.S. ports (1985–1994).[a]

Species	Most common countries of origin	Number
Pityogenes chalcographus	West Germany, Italy, Belgium	318
Ips erosus	Spain, Italy	305
Pissodes sp.	United Kingdom, Italy	215
Hylurgops palliatus	West Germany, Belgium, United Kingdom	187
Hylurgus ligniperda	Italy, Spain, Portugal	135
Ips typographus	Italy, West Germany	133
Hylobius sp.	West Germany, United Kingdom, Belgium	127
Ips sexdentatus	Italy, Spain	111
Hypothenemus sp.	India, Brazil	96
Tomicus piniperda	France, United Kingdom, Italy	94

[a]Data from USDA, Animal and Plant Health Inspection Service, Room 312E, Administration Building, Washington, DC 20250–3401.

Asian Gypsy Moth, *Lymantria dispar*

In the past few years the Asian strain of the gypsy moth has been introduced several times in the U.S. and Canada, both on the east and west coasts. Although it is similar to the gypsy moth that has been in the North America for over 100 years, the Asian strain has certain characteristics that could increase its potential to be a serious pest. Unlike the North American strain, females of the Asian strain are capable of sustained flight. The Asian strain is also thought to have a wider host range, which includes larch as a preferred host.

In 1991 a large number of egg masses were found on Russian grain ships docked at Vancouver, BC and Portland, OR. That summer male moths were caught in pheromone traps in areas around Portland, Vancouver, and Tacoma, WA. The source of these moths were thought to be larvae blown ashore from the Russian ships. A large eradication program using sprays of Bt was initiated in 1992 in Washington, Oregon, and British Columbia. The eradication program was apparently successful because no Asian gypsy moths were trapped in the sprayed areas in subsequent years.

The Asian gypsy moth (AGM) was introduced into North Carolina in July, 1993 by a military cargo ship from Nordenham, Germany, docked at Sunny Point Military Ocean Terminal near Wilmington, NC (Hofacker and others 1993). When inspectors examined the ship, they found that it was contaminated with gypsy moth pupae, larvae, and egg masses. Thousands of moths, including females, were seen flying from the ship. DNA testing of samples of moths from the ship demonstrated that the Asian strain, the European strain, and Asian × European hybrids were present. Apparently, the Asian strain had been introduced into western Europe and had hybridized with the native European strain. During an outbreak in Germany individuals of both strains and hybrids were accidentally transported on cargo containers (Hofacker and others 1993).

Areas around Wilmington, NC were sprayed in 1994 in an attempt to eradicate AGM populations. In 1995 additional areas were sprayed in nearby South Carolina. In 1994, a gypsy moth specimen trapped near Puyallup, WA was determined by

DNA testing to be an AGM strain from central Siberia. An area of one-half mile radius around the trap was sprayed with Bt to eradicate AGM populations. Results of ongoing trapping surveys will determine whether these eradication efforts were successful.

In addition to these introductions, moths with AGM characteristics as determined by DNA testing have been trapped in several states. Although there is no definitive evidence that AGM has become firmly established in the U.S., the risk that it will become established in the U.S. remains high.

Larger Pine Shoot Beetle, *Tomicus piniperda*

Tomicus piniperda was first detected in the U.S. in July 1992 in a Christmas tree plantation near Cleveland, Ohio. Since that time it has been found in nine states in the U.S. and in Ontario, Canada. The current distribution indicates that it was probably introduced in the 1980's, but it was not detected until 1992 (Haack and Lawrence 1994). Recent genetic analyses suggest that populations in the U.S. may have arisen from two introductions—one in Illinois near Lake Michigan, and one in Ohio near Lake Erie (Carter and others 1995).

Most *T. piniperda* infestations in the U.S. have occurred in Scotch pine, primarily in Christmas tree plantations. However, adults have been recovered from shoots of native jack pine, red pine, and white pine (Haack and others 1993). Studies in this country have shown that *T. piniperda* shoot-feed and reproduce in many North American pines, including southern pines (Lawrence and Haack 1995). The extent to which this beetle will become a serious pest has not been determined, but it is likely to be very successful in North America. *T. piniperda* is the first beetle to fly in the spring, which may give it a competitive advantage over native bark beetles (Haack and Lawrence 1995). Many, if not all, native pines will be suitable hosts, and *T. piniperda* will probably spread through the pine-growing regions of North America (Lawrence and Haack 1995).

T. piniperda is a significant pest in its native range of Europe, Asia, and North Africa (Haack and Lawrence 1994). It breeds in downed pines and stumps. Newly developed adults fly to crowns of living pines and feed inside the shoots during the summer, killing the attacked shoots and causing growth loss. It is this shoot-feeding behavior that causes this insect to be a major pest of pines.

Following the discovery of *T. piniperda* in 1992, APHIS and cooperating states in the Northeast initiated a trapping program in 1993 to survey for exotic bark beetles. The program consisted of deployment of pheromone-baited traps in areas around ports, near importer warehouses, and in areas near logging operations, lumberyards, etc. The targeted species were ones determined to have the highest potential for introduction. Most of the targeted species are on the list of most frequently intercepted insects on wood (Table 3). *Ips typographus* and *Hulurgus ligniperda* were considered to have the highest risk of introduction (Knodel 1995). Both were found in the first year of the trapping program. Other targeted species were *Pityogenes chalcographus*, *Ips sexdentatus*, *Ips erosus*, *Hylurgus palliatus*, and *T. piniperda*. In 1994, for example, 4 exotic species of bark beetles were found in New York (Knodel 1995).

In addition to the pheromone trapping efforts, APHIS and cooperating states in the Northeast implemented a trapping program to monitor for the pine shoot beetle, *T. piniperda* (Hoebeke 1994). This program consisted of deployment of pine logs baited with ethanol. In addition to trapping *T. piniperda* and several species of native bark beetles, exotic species were also discovered (see below).

European Spruce Beetle, *Ips typographus*

Thirteen specimens of *Ips typographus* were trapped at the port of Erie, PA in May 1993 in pheromone-baited traps deployed as part of the exotic bark beetle monitoring program described above. The captures were in the vicinity of a waste dunnage pile, which could have been the source of the beetles. In June 1993, several hundred additional pheromone-baited traps were placed in and around the port area. Trapping results for 1993 and 1994 have been negative for *Ips typographus*. In 1995 another European spruce beetle specimen was captured in a pheromone trap near Porter, IN. An intensive trapping program has been initiated in

the area of the capture to determine whether an infestation exists.

Ips typographus is native to Eurasia where it is a serious pest of spruce (USDA 1991). It occasionally attacks other species such as pines and larches. The beetle is associated with several species of fungi, some of which are extremely pathogenic. Spruce beetles most often attack downed trees but can attack and kill healthy trees during outbreaks. The beetle has 1–3 generations per year in Europe depending on temperature. Spruce beetles are strong fliers and if established in North America would be expected to spread rapidly; it could become a serious pest of spruce forests. The pathogenic fungus, *Ophiostoma polonica*, would probably also be introduced with *I. typographus* and might then be transmitted by native bark beetles (USDA 1991).

European Black Pine Beetle, *Hylastes opacus*

Hylastes opacus was first collected in North America in Suffolk Country, NY in 1989 (Wood, 1992). In 1993 and 1994 it was collected several times as part of the exotic bark beetle monitoring program in Maine, Vermont, New Hampshire, and West Virginia (Rabaglia and Cavey 1994). In 1993, 117 specimens of *H. opacus* were collected from 32 sites in 22 counties across New York (Hoebeke 1994). These collections were made during the trap-log survey program for *T. piniperda*.

H. opacus is widely distributed in the Palearctic region (Hoebeke 1994). Its hosts are *Pinus* spp., but it will occasionally infest other conifers. Its primary host is Scotch pine, *P. sylvestris*. It breeds in stumps or at the base of weakened trees. Adults feed on the tender bark near the root collar or seedlings, often girdling them. This species is frequently a pest in nurseries and pine plantations where it kills young trees and wounds older trees exposing them to infection by disease organisms (Hoebeke 1994).

Two-Toothed Bark Beetle, *Pityogenes bidentates*

The two-toothed bark beetle, *Pityogenes bidentates*, was first reported in nursery stock in

Lima, NY in 1988 (Hoebeke 1989). This initial detection was thought to be only an interception, because the infested stock was destroyed and infestations were not found in subsequent years. It was collected again in 1993 from two sites in Monroe County, NY during a survey for *T. piniperda* using trap logs (Hoebeke 1994). In 1994 a single specimen was captured in a pheromone-baited trap near Rensselaer, NY as part of the exotic bark beetle survey (Knodel 1995). These collections suggest that this bark beetle is established and breeding in New York.

Pityogenes bidentates is widely distributed in Europe and attacks several species of conifers, including fir, larch, spruce, and pine (Brown and Laurie 1968). It usually breeds in slash and is considered to be a secondary pest. It has been reported occasionally as a pest in young plantations, especially following frost damage.

Red-Haired Bark Beetle, *Hylurgus ligniperda*

The red-haired bark beetle, *Hylurgus ligniperda*, was found for the first time in North America in May, 1994 during the exotic bark beetle survey (Knodel 1995). A single female beetle was collected in a pheromone trap near Rochester, NY in the vicinity of a stand of mixed conifers that had been damaged during a winter storm in 1991. Follow-up trapping and surveys are planned for this year.

Hylurgus ligniperda is distributed throughout Europe, into the Caucasus Mountains and Western Siberia (USDA 1991). It has also been introduced into several other countries, including Japan, Chile, and New Zealand. This insect feeds and breeds in phloem of logging slash, stumps, stump roots, and at the root crown of pine seedlings. Damage occurs when newly emerged adults feed on roots of young pine seedlings until beetles reach sexual maturity (USDA 1991). It has the potential to vector diseases associated with intensive management, such as that caused by the fungus, *Leptographium wageneri*. Its potential to be a significant pest is related to its potential to vector black stain root disease. *Leptographium* species have been isolated from more than 70% of beetles examined in New Zealand (USDA 1995).

Popular-Larch Leaf Rust, *Melampsora larici-populina*

Popular-larch leaf rust caused by *Melampsora larici-populina* was first found in North America in 1991 in hybrid poplar plantations along the Columbia river in Washington and Oregon (Newcombe and Chastagner 1993). Although the fungus is native to Eurasia, little is know of its distribution in North America (Haack 1993), but it has been reported from California (Liebhold and others 1995). It is not known how it was introduced or when it arrived (Haack 1993).

Melampsora larici-populina alternates between species of larch and poplar. Spores of the fungus are disseminated by wind and can be spread over great distances (Liebhold and others 1995). The rust is thought to have great potential for spreading given the widespread distribution of larch and poplar and could potentially be a serious pest in plantations. Little is known about its pathogenic variability or host resistance (Liebhold and others 1995).

IMPACTS OF EXOTIC PESTS

Exotic pests have had huge, irreversible impacts on forest resources. Timber losses alone have exceeded $2 billion (Pimentel 1986). Species such as chestnut, butternut, American elm, and Port-Orford-cedar are no longer used for timber due to the impacts of exotic pests (Campbell, 1994). White pine in the West is not being planted as it once was for fear of loss to WPBR (Ketchum and other 1968). Pest control activities, tree improvement breeding, silvicultural controls and other programs are expensive but necessary to mitigate the effects of exotic pests (Campbell 1994). For example, the amount of money spent annually for research, eradication, and control of the gypsy moth averaged more than $20 million during the last decade.

Ecological impacts are immeasurable. According to Campbell (1994) the impacts of exotic pests have been greater than that of other, more widely recognized, human-caused factors, such forest fragmentation, pollution, and altered habitat. Liebhold and others (1995) consider the impacts of exotic pests to be comparable to that caused by global warming.

Ledig (1992) considers exotic species to be the most serious threat to biological diversity of forest ecosystems. There are many examples, especially in the East, where forest ecosystems have been or are being changed by exotic pests. Chestnut has been virtually eliminated by chestnut blight; butternut is threatened by butternut canker; oak-hickory forests of the East have been changed by the gypsy moth; wildlife has no doubt been negatively affected by the loss of mast production by these species. The hemlock woolly adelgid (*Adelges tsugae*) threatens unique stands of eastern hemlock, and the balsam woolly adelgid (*Adelges picea*) threatens to eliminate high elevation stands of Fraser fir.

WHAT CAN BE DONE?

First we must recognize that exotic pests are a global problem. As the movement of people and their materials increases around the world, the risk of introducing foreign organisms increases. As more species are introduced around the world, the chances of further introductions also increase. We need to cooperate with foreign colleagues to assess the risk of introductions and develop ways to prevent introductions. We need to conduct studies in foreign countries on pest organisms before they are introduced. A starting point would be to prepare a list of insects and pathogens by host and country of origin, especially for areas of high risk, such as that complied several years ago for diseases of commercial tree species (Anonymous 1963). Compilations of information on exotic species of quarantine significance would be invaluable for developing prevention and eradication programs.

The most efficient way to address the problem of exotic pests is to prevent their entry. Quarantine procedures should be developed for all types of forest products. The reports by the three assessment teams (USDA 1991; USDA 1992; USDA 1993) provide a model of interdisciplinary approach to analyzing the risks of exotic introductions from which prevention protocols can be developed. In addition to aggressive prevention programs, we also need monitoring efforts to detect new introductions. This would increase our ability to eradicate incipient populations before they have a chance to expand or spread.

Liebhold and others (1995) recommended against widespread planting of exotic tree species, which can be at higher risk of being hosts for exotic pests. Some exotic trees have the potential to become pests. They also recommend not planting a limited number of species over large areas.

Finally, we need to continue to develop ways to reduce the damaging effects of exotic forest pests already present. Research needs to respond quickly to introductions and threats of introductions with information about the pest to support eradication and control.

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Assessment and Monitoring

Assessing Pathogen and Insect Succession Functions in Forest Ecosystems

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Abstract.—The pilot test of a method to assess the ecological function of pathogens and insects in forests is reported. The analysis is a practical application of current ecosystem management theory. The influences of pathogens and insects on forest succession are measured by relating successional transition rates and types to conditions for pathogen and insect activities which are expected to lead to transitions. Results of this analysis provide means to better understand historic and current functions of pathogens and insects. They also provide a basis for predictions of future trends of pathogen and insect activities with respect to specific ecological functions. Like controlled burning, the predictable actions of pathogens and insects may, in the future, be used as tools for ecosystem management.

INTRODUCTION

Understanding the ways in which forest pathogens and insects influence the ecological health of forests is a key to ecosystem management. Pathogens and insects are the primary disturbance agents in most natural forests. These agents recycle far more biomass over the course of stand development than is typically consumed in fires in even the most fire-intensive ecosystems. Epidemics of diseases and insect herbivory have occurred throughout history. Veblen and others (1991) described a series of spruce beetle outbreaks in subalpine forests in Colorado which altered the species composition of forests as far back as 1810. Similar history has been described for western spruce budworm outbreaks (Swetnam and Lynch 1989). Root disease epidemics have been common and enduring in large areas of the western United States (Filip and Goheen 1984, Hagle and Byler 1993, Hagle and others 1994).

Less extensive and intensive activity by pathogens and insects occur on every hectare of forest, every year and form much of the character of forests (Williams and others 1992). Both epidemic and endemic types of activities are characteristic of the forests in which most of our native species evolved or to which they have adapted (Amman 1977). In this context, it is not appropriate to view them as stresses (O'Laughlin and others 1993). In fact, they may be important mechanisms by which native biodiversity is maintained.

The ways in which pathogens and insects influence succession are among their most important functions in forests ecosystems. The succession functions of pathogens and insects also may be among the most predictable of the disturbances in forests (Amman 1977, Veblen and others 1991, Goheen and Hansen 1993).

Future forest plans will almost certainly be based in part on landscape-level analyses which use successional modelling as their primary prediction tools (Salwasser and Pfister 1994). To assure full consideration of the important successional functions of pathogens and insects in future plans, predictable effects of pathogens and insects must be integrated into developing succession models. Types of successional transition, and time required for transitions to take place, are the primary driv-

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ers of the dominant successional models under development in the Northwest (Kurz and others 1994).

In 1991 we undertook an analysis to identify and characterize important successional functions of forest pathogens and insects in Montana and northern Idaho (USDA—Forest Service Northern Region) (Hagle 1992, Hagle and Williams 1995). These efforts are aimed at describing how pathogens and insects affect spatial and temporal patterns of succession, describing current and historic pathogen and insect regimes (the spatial and temporal patterns of pathogen and insect actions), and predicting future successional trends that reflect the role of pathogens and insects.

Only those pathogens and insects which have significant successional functions at a Regional scale were analyzed (Table 1). For each of these agents the actions and the functions have been defined. The "actions" on the part of the pathogen or insect, in conjunction with the physical conditions of the polygons, determine the most likely functions of the pathogen or insect. These include, the potential vegetation type, cover type, structural stage, elevation, and so on. By focusing only on functions which are expected to be significant at this broad scale, many of the actions of pathogens and insects were eliminated from consideration. When applying this analysis system to other spatial scales, it may be necessary to add other pathogen or insect functions of the analysis and leave out others to better reflect local conditions or influences.

ANALYSIS STRUCTURE

The analysis consists of three general phases. In the first phase we:

1) selected a stratified random sample to represent a broad range of conditions on each Forest,
2) identified significant pathogen and insect succession functions associated with the represented forest types,
3) identified actions which lead to the significant functions and the conditions under which they occur,
4) analyzed the data from 1975 surveys to assign

Table 1.—Pathogens and insects included in the analysis.

Category	Primary causes
Root diseases	*Armillaria ostoyae*
	Inonotus sulphurascens (*Phellinus weirii*, Douglas-fir form)
	Heterobasidion annosum (s-type)
Bark beetles	*Dendroctonus ponderosae*
	Dendroctonus pseudotsugae
Dwarf mistletoe	*Arceuthobium douglasii*
	A. laricis
	A. americanum
Stem rust	*Cronartium ribicola*
Stem decay	*Echinodontium tinctorium*
	Phellinus pini
	Phaeolus schweinitzii and ecologically similar spp.
Defoliator	*Choristoneura occidentalis*

probability index values for each identified action,
5) characterized polygon classes according to their average, range and frequency distributions of pathogen and insect action indices.

In the second phase we:

1) analyzed successional changes from 1935 to 1975 in polygons covered in surveys from both years.
2) assign pathogen and insect action probability indices to polygons based on their 1935 classes,
3) compared 1935 and 1975 pathogen and insect action probability indices,
4) analyzed successional stage changes from 1935 to 1975,
5) calibrated FVS and pest models to reflect actual successional transitions according to polygon classes and pathogen and insect action probability indices.

In the third phase we will:

1) use actual transitions for well-represented classes and calibrated FVS simulations for poorly-represented classes to produce factors for types and rates of successional transitions,
2) enter the factors into transition matrices as appropriate for two landscape successional models which are currently under development.

In this paper we present an overview of the process in the context of the pilot test on the Nez Perce National Forest, Idaho. This set of sample areas was chosen because there were relatively few polygons in the sample and few with both 1975 and 1935 surveys. The small dataset was efficient for developing and testing the process for analysis of the large sample that represents the Northern Region. The methods were discussed in greater detail in a recent paper (Hagle and Williams 1995) so we will concentrate on greater discussion of results of the test on the Nez Perce.

ASSIGNING THE ACTION PROBABILITY INDEX (API):

The primary action of root pathogens is killing Douglas-fir (*Pseudotsuga menziesii*) and true firs of all ages. Root disease in stands was evaluated using aerial photography. The photographs were interpreted to assign a severity index value on a scale of 0–9 to reflect the relative degree of effect observable in the stand. A rating of "0" implies no visible effect from root diseases and "9" indicates root diseases have so severely affected the polygon that there are no remaining live overstory trees. All other values are relative to these minimum and maximum effects. Color aerial photographs at 1:24,500 were interpreted stereoscopically using the methods of Hagle (1992).

Actions generally have patterns such as the "weeding" action of Douglas-fir beetle (*Dendroctonus pseudotsugae*) in which single Douglas-fir trees or small groups are killed. Douglas-fir beetles also have a "outbreak" action in which large parts of a stand or multiple stands can be greatly altered in composition by the death of mature Douglas-fir trees. The two types of action on the part of Douglas-fir beetle are likely to have very different successional functions. The queries designed to detect the conditions under which the two types of Douglas-fir beetle actions may occur are distinct and independent.

The results of the action queries contribute both to the determination of probable function and to the initial assignment of probability of transition from one successional state to another. The function queries utilize the information produced by the action queries along with site and stand composition information contained in the Regional database to determine the most probable types of functions. These function queries designate the successional transition associated with a particular insect or pathogen action.

Douglas Fir Beetle Action Indices for Outbreak Probability

The outbreak query was based on a hazard rating system developed by Weatherby and Their for southern Idaho (Weatherby and Their 1992). This system was based on a report by Furniss (1981). That hazard rating system is based on stand basal area, proportion of the stand basal area which is Douglas-fir, the average stand age, and average diameter of Douglas-fir sawtimber. The query sorts stands by age class, diameter, percent basal area in Douglas-fir and total basal area of the stand. Low hazard attributes were not included because the probability of group mortality was low. Under these conditions the actions of Douglas-fir beetle are better captured by the "weeding" action index. The outbreak probability index values were assigned as in Table 2.

Table 2.—Structure of query for Douglas-fir beetle outbreak probability index.

Average DBH of Douglas-fir which are >5"DBH	% of stand BA =DF	Stand BA	Age	Code
10–13.9	25–49	80–119	80–119	M
			120+	M
		120–249	80–119	M
			120+	H
		250+	80–119	M
			120+	H
50+		80–119	80–119	M
			120+	H
		120–249	80–119	H
			120+	H
		250+	80–119	H
			120+	H
14+	25–49	80–119	80–119	M
			120+	H
			120+	H
50+		80+	80+	H

Table 3.—Structure of query for the Mountain Pine Beetle probability index.

Age class of Lodgepole pine component	Mean DBH of Lodgepole pine component	Code
<60		L(low)
60–79	<7"	L
	>=7"	M(moderate)
>=80	7–8	M
>=80	>8"	H(high)

Mountain Pine Beetle

Mountain pine beetle (*Dendroctonus ponderosae*) can have three relevant actions depending on the composition of the forest in which it is active. They are: killing mature lodgepole pine (*Pinus contorta*), killing large-diameter western white pine (*Pinus monticola*), or killing immature ponderosa pine (*Pinus ponderosa*). Logic to assess the possible extent and probability of mountain pine beetle killing lodgepole pine in a stand was derived from a hazard rating system developed by Amman and others (1977) and, like the Douglas-fir beetle query, condensed to represent the significant classes with respect successional functions (Table 3). Stands with less than 10% lodgepole pine are assigned the value "0" since they are unlikely to experience successional transitions caused by mountain pine beetle even if all of the lodgepole pine is killed. All of the sample polygons on the Nez Perce National Forest received the "high" elevation/latitude factor (Amman and others 1977).

SAMPLE POLYGON CLASSES IN 1935 AND 1975

There had been very little tree harvest activity in the sample polygons before 1975, probably less than about 7% of hectares overall (Hagle and Byler 1993). Fire exclusion probably did affect some of the area, however; particularly on the drier, more fire-prone sites. For the most part, however, the changes seen on sites can be attributed to natural succession, including the actions of pathogens and insects. Polygons with evidence of harvest activity were excluded from this phase of the analysis because there were too few to provide a viable sample. As greater numbers of harvested polygons are encountered in the analyses of the rest of Idaho and Montana, we will look for opportunities to examine the successional influences of management as well.

Habitat Type Groups

Habitat type groups, in descending order of importance in the sample, were; grand fir (*Abies grandis*), subalpine fir (*Abies lasiocarpa*), Douglas-fir, and western redcedar (*Thuja plicata*). Grand fir habitat types comprised 39 percent of the sample area. These are productive site types on which ponderosa pine, Douglas-fir and lodgepole pine are the primary seral species. Both mixed severity and stand replacement fire regimes are common on these habitat types. Grand fir cover type was found on 40 percent of these habitat types. Ponderosa pine, Douglas-fir and lodgepole pine cover types were about evenly split on these habitat types and, combined, made up another 40 percent of the area.

Subalpine fir habitats were divided into three groups. The most common of the three was the moderately dry type group, typified by the subalpine fir/beargrass (*Xerophyllum tenax*) habitat type. Second in importance was the moist group typified by subalpine fir/Menziesia (*Menziesia ferruginia*) habitat type. Lodgepole pine is the most important seral species found in either of these habitat type groups. The high elevation types which are potentially important habitat for whitebark pine (*Pinus albicaulis*) were found in 175 hectares of the sample area (5%). Here, both lodgepole pine and whitebark pine have the potential to be important seral species. Seral cover types dominated the subalpine fir habitat type sites, comprising 64% of the areas.

Douglas-fir and western redcedar habitat types covered (17%) and (14%) of the sample area respectively.

Cover Types

Douglas-fir cover type covered 29% of the overall sample area in 1975. Grand fir and lodgepole pine cover types comprised 19% and 17%, respectively, of the area. A mixture composed of at
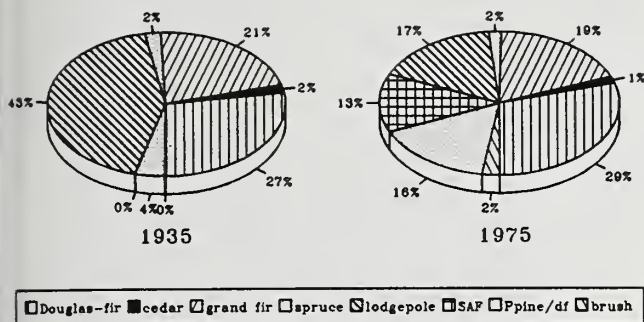
Figure 1.—Cover types of sample polygons.

Structural stages: brush = <25 trees per acre. Seedl/sapl = seedling/sapling. Pole = pole size/ submature, Mtr/full = mature/well stocked (>2 MBf/A) Mtr/broken = mature/ poorly stocked (2 MBf/A).

Figure 2.—Structural stages of sample polygons.

least 25% ponderosa pine, called the pine/fir type covered 16% of the area. Subalpine fir and Douglas-fir was the only other common cover type (13%), although there were small amounts of Engelmann spruce (*Picea engelmannii*), western redcedar and brush types (fig. 1).

Structural stages were based on the combination of the size and density of trees on the site. The 1935 survey data contained information about the cover type, size class, stocking density, age class and, generally, the percent composition of stands by tree species. These data are sufficient to assign the cover type and structural stage of stands, the combination of which represent the successional stage. Cover types and structural stages for the 1975 survey data were assigned using the criteria used in the 1935 survey to provide the greatest comparability. Although the query designed to assign these attributes is quite lengthy, the general criteria for assigning structural stages are provided in Table 4.

Structural Stages

Mature structural stages (3 and 4) dominated the area, covering 67 percent of the grand fir habitat type. About half of the area covered by mature structural stages was closed canopied and well stocked as indicated by structural stage 3. The other half of the area with mature structural stages had open canopy, multi-storied structures (structural stage 4) often associated with the outcome of root disease and bark beetle activities.

Table 4.—General criteria used to class polygons for structural stage from both 1935 and 1995 survey data.

Criteria	Structural Stage
>=4000* bdft/acre total	
AND >50% of CFV in trees >= 13"** dbh	
>=20,000 bdft/A total stand volume	4
4–20,000 bdft/A total stand volume	3
<4000* bdft/A total	
AND <50% of CFV in trees >13"** dbh	
AND >25 tpa of trees >= 6"dbh	2
<4000* bdft/A	
AND >50% of CFV in trees >13"** dbh	
AND <25 tpa of trees >= 6" dbh	
AND >25 tpa total	1
<25 tpa total and <4000 bdft/A total	0

3000 bdft/A for ponderosa pine, lodgepole pine, subalpine fir, mountain hemlock or whitebark pine cover types.
**11" dbh for western redcedar and western white pine*

The area was dominated by mature structural stages. Stages 3 and 4 combined comprised 56% of the area (fig. 2). Young, regenerating stands were only 11 percent of the sample area, the vast majority occurring in the highest elevation subalpine fir/whitebark pine types.

Results from queries designed to assign the polygon class (habitat type, cover type, structural stage) and pathogen and insect action probability

Table 5.—Action array table for selected polygon classes.

CT SS	RRSV 0–9*	dfb 0–H	mpblp 0–H	mpbpp 0–H	dmdf 0–6	dmwl 0–6	dmlp 0–6	et 0–11	pini 0–3	oth 0–3	wsbw 0–9
Habitat type group = western redcedar											
DF 1	8	0	0	0	4	0	0	0	0	1	0
	8	0	0	0	4	0	0	0	0	1	3
	6	0	0	0	4	0	1	0	0	1	0
2	8	0	0	L	4	0	0	0	0	1	0
	4	0	0	0	4	0	0	0	0	1	3
3	4	H	0	H	4	0	0	0	0	1	3
4	8	0	0	L	4	0	0	0	0	1	0
	4	0	0	0	4	0	0	0	0	1	0
	3	0	0	0	4	0	0	0	0	1	3
Habitat type group = Douglas-fir											
DF 4	6	0	0	0	5	0	0	0	0	3	0
	5	H	0	0	5	0	0	0	0	1	0
	5	0	0	M	4	0	0	0	0	1	7
	5	0	0	0	5	0	0	0	0	1	0
	5	0	0	H	4	0	0	0	0	1	0
	2	H	0	0	6	0	0	0	0	2	0
	1	0	0	0	5	0	0	0	0	2	0
Habitat type group = moderately dry subalpine fir											
LP 2	3	0	L	0	1	0	4	0	1	0	0
	8	0	0	L	4	0	0	0	0	1	0
	4	0	0	0	4	0	0	0	0	1	0
	3	0	0	0	4	0	0	0	0	1	0

CT = cover type, SS = structural stage, RRSV = root disease severity, DFB = Douglas-fir beetle outbreak, MPBlp = mountain pine beetle in lodgepole pine, MPBpp = mountain pine beetle in ponderosa pine, DMDF = Dwarf mistletoe in Douglas-fir, DMWL = dwarf mistletoe in western larch, DMLP = dwarf mistletoe in lodgepole pine, ET = stem decay caused by Echinodontium tinctorium, PINI = stem decay caused by Phellinus pini, OTH = stem decay caused by Phaeolus schweinitzii and ecologically similar fungi, WSBW = western spruce budworm, DF = Douglas=fir, LP = Lodgepole pine.

*Ranges of possible action probability index values. 0 = no probability; higher values imply higher probability of the action occurring.

indices (API), are stored in an Oracle data table called the "Action array table" (Table 5). From this table, further analyses were designed to discover relationships between polygon classes and the API's.

DISEASE AND INSECT ACTION INDICES IN THE SAMPLE AREA

The action indices indicate the relative probability of a particular type of action occurring in a polygon. The average root disease severity for polygons in 1975 ranged 0–8. The overall average for the samples was 4.2. Cedar habitat type group had the highest average root severity (5.7), moderately dry subalpine fir group was second with the average 4.5, and grand fir was a close third with 4.3 (fig. 3). The average root disease severity in seedling and sapling stands with Douglas-fir and grand

fir cover types was particularly high on cedar habitat types (7.5) and considerably lower on grand fir habitat types (4.4). Byler and others (1982) reported a similar relationship with habitat type on the Lolo National Forest in Montana. The probably of mortality from root disease was significantly higher on cedar and hemlock habitat types with Douglas-fir or grand fir forest types than on other habitat types or cover types.

Douglas-fir beetle outbreak probability tended to be either high (14.2 percent of hectares) or none (85.8 percent of hectares). Both Douglas-fir beetle and the major root pathogens on the Nez Perce have a strong host preference for Douglas-fir. The relationship of root disease severity and Douglas-fir beetle outbreak probability index is indicative of their relative effects on the forest composition. At the high end of root disease severity, there are few large trees remaining alive so there is little prob-

Root disease severity

WRC = western redcedar, GF = grand fir, DF = Douglas-fir, SAF-m = subalpine fir- moderately dry, SAF-w = subalpine fir warm and moist, ALL = Overall average for classes (*habitat type group/ cover type/structural stage) containing at least 50 hectares in 1935 sample.
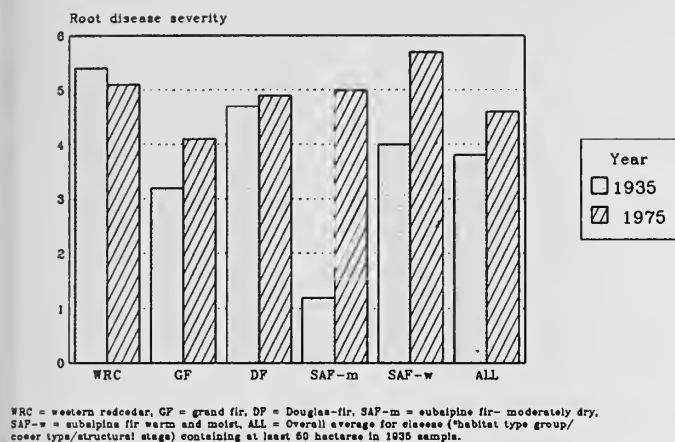
Figure 3.—Average root disease severity comparison 1935–1975 for polygon classes* with at least 50 hectares.

Thousands

noRR = FVS projection without root disease/bark beetle model, RRnocalib = root disease/bark beetle model used without calibration, RRcalib = root disease/bark beetle model calibrated to match actual transitions/decade

Figure 4.—FVS and root disease/bark beetle model projections calibrated and uncalibrated root disease/bark beetle models.

ability of a Douglas-fir beetle outbreak. In the mid-range of disease severity, the probability of Douglas-fir beetle outbreak reaches it's maximum (fig. 4).

High and moderate probability indices for mountain pine beetle in lodgepole pine were obtained for 2% and 10%, respectively, of the sample area. Low probability index was assigned to 16 percent of the hectares. Although the frequency is low, as we'll show later, polygons with high probability indices did undergo dramatic changes between 1935 and 1975.

Comparison of Historic and Current Probability Indices

Coverage in the 1935 survey was inconsistent on the Nez Perce National Forest. We were able to locate 1935 photo coverage for only 7 of the 22 sample subcompartments. This is far less than the 73–100% coverage we obtained for the sample subcompartments for the other National Forests of northern Idaho and western Montana. They did, however, provide useful insight and experience in the operational aspects of the GIS analysis. They also demonstrated the usefulness of the comparing the 1975 and 1935 surveys even though it represents only a 40-yr interval. In that 40 years, 76% of 97 polygons surveyed in both years, transitioned from one successional stage to another. Cover type

changed in 59% of those which transitioned (44% of all sample polygons represented in the 1935 survey). In the remaining 41% the cover type was the same in both 1935 and 1975, but the structural stage had changed. Typically, the structural stages had changed to later successional structures.

As polygons changed from one cover type or structural stage to another, their associated API's changed as well. Some habitat type groups were more prone to dramatic changes in cover or structure than others. For example, the moderately dry subalpine fir habitat type group which mostly had lodgepole pine cover types in 1935 (98%) converted to a significant proportion of subalpine fir cover type by 1975 (31%). Although the 1975 root disease severity rating (RRSV) was fairly high (5), the cover types and structural stages in 1935 suggest an expected average RRSV of only 1.2 (fig. 3). The opposite changes were seen in mountain pine beetle API's. The frequency of moderate to high MPB API's dropped from the expected 48% in 1935 to 31% in 1975. Mountain pine beetle was probably largely responsible for the changes in cover type within this class.

Tracking Transitions

A single polygon class often transitioned to a number of other successional stages (Table 6). For

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Table 6.—Transitions in selected cover types and structural stages occurring in western redcedar, Douglas-fir and moderately dry subalpine fir habitat type groups in the Nez Perce pilot test.

| Habitat type group | 1935 Survey | | 1975 Survey | | |
	Cover type	Str.* stage	Cover type	Str. stage	Frequency
Cedar	Douglas-fir	1	Douglas-fir	1	.15
			Douglas-fir	2	.07
			Douglas-fir	4	.63
			Grand fir	1	.15
Douglas-fir	Douglas-fir	4	Ponderosa	3	.44
			Ponderosa	4	.08
			Douglas-fir	4	.48
Subalpine fir, moderately dry	Lodgepole	1	Lodgepole	1	.06
			Lodgepole	2	.65
			Subalpine fir	2	.29
		2	Lodgepole	2	.69
			subalpine fir	2	.31

*Structural stage

example, on sites in the cedar habitat type group (C HT), with Douglas-fir cover type (DF CT), and seedling/sapling structural stage (SS 1), there were 5 types of transitions which occurred, all of which appeared to be heavily influenced by root diseases. In one transition type the tree density had dropped below 25 trees per acre. This placed the polygon cover type in class 19 which designates a non-tree cover class on a stockable site (referred to as "brush").

Another transition type was to "pole" size trees (structural stage 2) with Douglas-fir cover type the stocking was only moderately dense in stands which had made this transition, less than 200 trees per acre. A third transition type was to structural stage 4 with Douglas-fir cover type. This indicates that some trees did grow large but the stocking density was moderate to poor (less than 20,000 bdft/A at maturity). The fourth transition type was to structural stage 4 as well but with a ponderosa pine/Douglas-fir cover type. The final transition found was from seedling/sapling Douglas-fir to seedling/sapling grand fir and western redcedar. The remaining polygons indicated no transition occurred. It would seem unreasonable to find seedling/sapling Douglas-fir stands that remained so 40 years later. In fact the average root disease severity assigned to these polygons in the aerial photography interpretation was "eight" out of a possible nine. This was the most severe root disease rating assigned in the pilot study area.

SUCCESSIONAL FUNCTIONS

The influence of pathogens and insects was evident in most of the transitions observed in the polygons from 1935 to 1975. For example, in the polygon class with western redcedar habitat type (C HT), Douglas-fir cover type (DF CT) and seedling/sapling structural stage (SS1) 25% of the hectares were still in the seedling/sapling stage 40 years later. Root disease severity on those sites averaged 7.6 in 1975. This is an indication that the root pathogens have functioned on these sites to "stall" succession. The root pathogens on these sites will chronically kill trees, effectively preventing most of the trees from growing into pole size classes. The result is that the stands have not transitioned to pole or mature structural stages. Regeneration in openings created by mortality is dominated by Douglas-fir or grand fir as evidence by the sites remaining in Douglas-fir and grand fir cover types. The frequency with which this function should be applied to successional models for the class CHT, DF CT, SS1 on the Nez Perce National Forest is estimated to be .25/ 40 yrs, according to these data. One third of polygons beginning in this class should remain in the class over a 40-yr projection.

Interaction of root diseases and Douglas-fir beetle is evident in polygons in class; Douglas-fir habitat type group (DF HT), Douglas-fir cover type (DF CT), structural stage mature, low density (SS4) in 1935. The root disease severity average expected

for the polygons in 1935 is 4.7 and the disease severity assigned to the same sites in 1975 averaged 4.9. According to the Douglas-fir beetle API's for this class, 17% of the stands in this class are dense enough to support a Douglas-fir beetle outbreak and all of the stands in the class are prone to Douglas-fir beetle single or small-group killing action. One half of the hectares had converted to ponderosa pine cover type over the 40 year period. Without the influence of root diseases and Douglas-fir beetle, these sites would have been expected to remain Douglas-fir cover types and in the absence of ground fire, they would be expected to increase in Douglas-fir density. Ponderosa pine is a shade-intolerant seral species in this habitat type group. Root diseases and Douglas-fir beetle are both expected to function to maintain seral species such as ponderosa pine, where they are present in the stands. Root diseases will selectively kill Douglas-fir of any age from such a species mix and Douglas-fir beetle will selectively kill mature Douglas-fir. Together they can be expected to enhance the survival of the pines by reducing the lateral competition. This function appears to have been strongly expressed in these polygons.

The other half of the hectares in the DF HT/ DF CT/ SS4 polygon class, remained in the same class after 40 years. The density did not increase, as may have been expected in the absence of ground fire. The 1975 root disease severity average of 4.9 and indicates that some mortality of Douglas-fir has probably occurred which may be the reason the stand has not increased stocking to more than 20,000 bdft/A, poor mature-stand stocking for this site quality.

Mountain pine beetle API's for lodgepole pine cover types, structural stages 2 and 3 (regardless of habitat type), were 13% = high, 41% = moderate, 39% = low and 0% = 0. This distribution of expected API's is associated with 38% of the hectares in these classes converting to other cover types (primarily grand fir or subalpine fir) or to structural stages indicating that the largest trees had been killed (such as from SS4 to SS2).

Forest Vegetation Simulator Calibration

To account for transitions not well represented in the sample polygons with both 1935 and 1975 surveys, Forest Vegetation Simulator (FVS) (Wykoff and others 1982) was calibrated to reflect the pathogen and insect functions appropriate for each polygon class. This was accomplished using a model produced by combining the annosum root disease model and western root disease model (Stage and others 1990). This model is an update which combines the capabilities of both models in a single model. This was used with the dwarf mistletoe damage model both of which operate in conjunction with FVS. The combined root disease model allows simulation of various types of bark beetle actions as well.

The root disease/bark beetle and dwarf mistletoe model parameters were adjusted according to both the probable action of the pathogens and insects, bases on the API values and the actual transitions which occurred in sample polygons over a 40-yr period. The calibrated models match closely the actual transitions in species composition and structural class of each polygon class for which they were calibrated. Transitions for the remaining polygon classes were derived from making FVS, root disease/barkbeetle, dwarf mistletoe model runs (based again on API and most similar polygon classes).

The calibrated models produced greatly different projections compared to the uncalibrated models runs or the FVS without root disease/barkbeetle models. For example, figure 4 illustrates an FVS simulation, an FVS with uncalibrated pest extensions simulation, and a calibrated simulation. In this simulation we were interested in representing the 25% of stands on cedar habitat types with Douglas-fir cover types and beginning in successional stage 1 (seedling/sapling) which remain in that structural class for at least the 40 years covered by this study. Without calibration the FVS and root disease model extension projected a transition to a well-stocked mature structural stage within 40 years. By calibrating the root disease model, we produced projections in which the stands remained in the Douglas-fir cover type and seedling/sapling structural stage through root disease-caused mortality and predominantly Douglas-fir regeneration. Using these calibration factors and slightly lowering the initial root disease inoculum at model initialization produced projections in which the stands changed to structural stage 4, mature with

poor relative stocking. This transition was represented in 63% of the sample area which was in the C HT, DF CT, SS1 in 1935.

Since FVS and pest extensions are sensitive to tree species composition, it is not necessary to calibrate for each forest type except as bark beetle parameters need to be adjusted to respond to relative purity of host. This significantly lessens the task of calibration, making the use of FVS simulations a useful link between stand-level assessments such as producing the API values, the landscape level projections.

Tables of transitions and 40-year probabilities of transition are being constructed through this analysis. These transition matrices will be the basis for landscape model calibration in the final phase of this project.

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Describing the Conditions of Forest Ecosystems Using Disturbance Profiles

J.E. Lundquist and J.P. Ward, Jr.[1]

Abstract.—Data from a study on the effect of small-scale disturbances on small mammal prey of the Mexican spotted owl illustrates how spatial models of canopy cover and disturbance profiles of forest stands might be used to define forest stand condition and develop silvicultural prescriptions.

INTRODUCTION

Many facets of forest health have been addressed in several excellent papers at this workshop. These papers suggest that good health is a consistent characteristic of productive forest stands. These papers also show that forest health is difficult to describe because it is composed of so many interacting components. Characterizing and quantifying this complexity has been a difficult puzzle to solve (Kolb and others 1994).

Despite its complexity, managers still must make day-to-day, stand-level decisions that affect forest health. The quality of these decisions will depend on the managers' judgement of what a 'healthy forest stand' looks like, and on what silvicultural tools they have to measure and manipulate stands.

Silviculturists are applied ecologists who manipulate stands to achieve specific goals (Smith 1962). In addition to timber production, these goals include providing habitat for wildlife, maintaining or enhancing biodiversity, old growth maintenance, and other non-timber objectives. Silviculturists intervene by mimicking or redirecting small-scale disturbances (Oliver and Larson 1990). These interventions should be based on a keen understanding of the disturbance and recruitment processes underlying forest stand structure.

This paper builds upon two others presented earlier at this workshop. In the first paper (Geils and others, *these proceedings*), Brian Geils argued that silviculturists may need new ways of measuring and assessing stands to deal with the increasing diversity of management objectives. In the second paper (Beatty and others, *these proceedings*), Jerry Beatty described two potentially useful tools that are currently being assessed in a joint project between the USDA Forest Service's Rocky Mountain Forest and Range Experiment Station and Region 6 - Forest Pest Management; these tools included a spatial model called a patterned isopleth (which he referred to as a "gapogram"), and a multivariate metric called "disturbance profile". The purpose of this paper is to weave together the thoughts presented by Geils and Beatty by showing how spatial models and disturbance profiles might eventually be used to make silvicultural decisions involving small-scale disturbances. The discussion was developed from on-going studies in the Sacramento Mountains, New Mexico (Lundquist, Geils and Ward 1994). Since this is a discussion of early developmental efforts, much of this is still hypothetical; some of the assumptions are tenuous. It should, however, provide insight into a potential tool for silviculturists.

In 1992, a study was initiated to examine the effect of small-scale disturbances on small mammalian prey of the Mexican spotted owl (*Strix occidentalis lucida*) in stands representative of the major forest types in the Sacramento Mountains (Lundquist, Geils and Ward 1994). The Mexican

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spotted owl dwells in montane forests and canyons in Southwestern United States and Mexico. In 1993, this owl was listed by the United States Department of the Interior (USDI) Fish and Wildlife Service as a federally threatened species in the United States (USDI Fish and Wildlife Service 1993). At that time, little was known about how specific silvicultural practices or natural small-scale disturbances influence the quality of owl habitat (MacDonald and others 1991).

METHODS

The discussion here is based on data collected in a mixed-conifer stand named Delworth, which was composed primarily of Douglas-fir (*Pseudotsuga menziesii* (Mirb.)Franco), southwestern white pine (*Pinus strobiformis* Engelm.), and white fir (*Abies concolor* (Gordon & Glend.) Lindl.). This stand had been selectively harvested at various times since the turn of the century.

Methods described earlier in these proceedings (Beatty and others 1995) were used to generate the patterned isopleth shown at the top of figure 1. This isopleth is composed of 1681 cells, each representing 25 m^2 for a total combined area of 4-ha. A value of 0 to 100% canopy density is attributed to each cell, which is classified into 3 groups: full canopy (dark cells, 75–100%), intermediate canopy (hatched, 60–74%), and open canopy (white cells, <60%).

In a concurrent study, wildlife biologists live-trapped small mammals on a grid with 20 m intervals between trap station. Additional details on methods used to sample these small mammal populations can be found in Ward and Block (1994). Traps were positioned at coordinates in the same plot used to develop the patterned isopleth. Trapping data represent presence/absence of individuals. Only first-time captures of individuals were used in the analysis. Repeat visits to the same traps or subsequent visits to other traps by previously captured individuals were not included in presented analyses. For this presentation, only data during August 1992 were used.

Ward and Block (1994) showed that the diet of the Mexican spotted owl in the Sacramento Mountains is primarily deer mice (*Peromyscus*

Figure 1.—Patterned isopleths representing canopy-structure of the 4-ha Delworth plot. These diagrams were derived from ground observations of canopy density at 1681 points and classified into gaps (white), edges (hatched), and interior (solid). Each side is 200 m long and each cell represents a 25 m^2 block of forest. The upper diagram represents the plot before treatment. The lower diagram represents plot after existing gaps were enlarged and cut trees were left on the ground, as described in text.

maniculatus), brush mice (*P. boylii*), long-tailed voles (*Microtus longicaudus*), Mexican voles (*M. mexicanus*), and Mexican woodrats (*Neotoma mexicana*). We compared the distribution of each of these mammal species to the distribution of canopy density by overlaying the two images in a Geographic Information System (IDRISI, J.R. Eastman, Clark University; fig. 2).

USING PATTERNED ISOPLETHS AND GIS TO DESCRIBE HABITAT

The image overlays shown in figure 2 suggest that the distribution of some of the owl's prey may be related to canopy structure. For instance, during the August 1992 period, Mexican voles were associated with the interiors of relatively large gaps; long-tailed voles were associated with fragmented parts of the stand where gap edges were numerous; Mexican woodrats avoided gaps; and deer mice did not discriminate between gaped and non-gaped areas of the stand.[2] Observations like

Mexican woodrat   Deer mouse

Mexican vole   Long-tailed vole
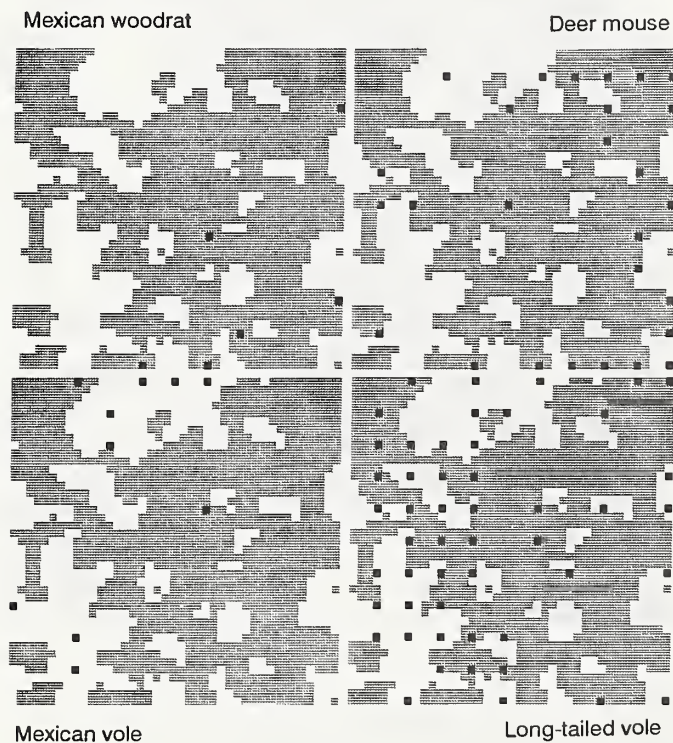
Figure 2.—Composite maps of canopy-structure Delworth plot overlayed with distribution of four small mammal species. Unshaded areas are identified as canopy gaps; shaded areas include both edge and interior; solid squares indicate trap sites where at least one individual was recovered.

these would be difficult or impossible to make without spatially referenced data. Non-spatial metrics like basal area, stems per hectare, and average dbh can not describe gap shape, gap placement, canopy fragmentation or other spatially-dependent features that can influence wildlife.

More importantly, the data suggest that managers might be able to control the abundance and distribution of mammals by manipulating canopy structure. For instance, long-tailed vole populations might increase and their spatial distribution be spread more widely if small gaps were enlarged or introduced to non-gaped portions of the stand, as portrayed in the bottom isopleth of figure 1. Mexican vole populations might increase if existing gaps were enlarged. Mexican woodrat populations might increase if edge trees were encouraged to fill gap openings. This is a relatively simple example of the potential use of patterned isopleths and spatially-referenced data to make stand-scale silvicultural decisions.

The isopleths shown in figure 1 represent only a small portion of the Delworth stand. To meet the purpose of our research study, (i.e., to establish the wildlife/canopy-structure associations), the intensity of sampling was necessarily intense, and the study area limited. If similar maps of the canopy distribution could be economically generated for the entire stand, decisions about where to conduct specific silvicultural manipulations would be enhanced and these kinds of spatial models would be much more useful to management. Remote sensing coupled with image processing procedures may soon offer an alternative to the need for such intense field surveys, and make stand-scale images practical (Lundquist and Sommerfeld unpublished).

INTERPRETING DISTURBANCE PROFILES

Manipulating animal abundance and distribution may require more than simply cutting holes in

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[2]It should be noted that these isopleths summarize only one year's data; small mammal populations can vary considerably from year to year. Conclusive statements would have to be based on several years' data.

Table 1.—Current disturbance profile for one 4-ha plot in one mixed-conifer stand (Delworth) in the Sacramento Mts, New Mexico, and a set of hypothetical desired condition for maintaining adequate diversity and abundance of small mammal prey for the Mexican spotted owl. Letter in parentheses indicate that current stand conditions are high (H) or low (L), and may need to be adjusted.

Index	Units	Current	Desired condition
Ave. stem diameter	cm	29.8	30–40
Stem density	stems/ha	437(H)	150–250
Basal area	m²/ha	30	25–35
Gap frequency	gaps/ha	26	20–30
Mean gap diameter	m	13.6	10–20
Skewness (gap dia distr)	g_1	0.6	0.5–2.0
Kurtosis (gap dia distr)	g_2	−0.7	−0.8–0.5
No. cause pathways	Number	68	40–70
Shannon-Weaver (causes)	H'	8.8	4.0–9.0
Snag frequency	snags/ha	211(H)	50–200
Log frequency	logs/ha	214(L)	300–400
Ave. densiometer	%	84(H)	40–70
Skewness (densio distr)	g_1	−1.4	−2.0–2.0
Kurtosis (densio distr)	g_2	5.9	3.0–7.0
Shannon-Weaver (densio)	H'	0.7	0.5–2.0
Dominance	c	0.7	0.1–0.9
Contagion	C	2.0(H)	.5-1.5
Number of edges	Number	218(L)	300–500
Ave gap area	No 100 m² cells	3.2	3-7
Fractal dimension	D	1.3	1.2-1.4
Variogram sill	semivariance	133	120–200
Variogram range	lag distance	26	20–30

the canopy. Gaps at Delworth, for example, are composed of downed logs and other coarse woody debris, snags, recolonizing vegetation, and other elements that together make individual gaps differ from one another. Unique combinations of these components give each gap a unique signature. Furthermore, stands are composed of multiple gaps, each contributing a different signature to the composition of the stand. The number of ways a stand can be characterized is vast.

Disturbance profiles are multivariate metrics composed of various spatial and non-spatial statistics based on crown cover, coarse woody debris, live vegetation and composition of disturbance agents (Lundquist 1995b). A disturbance profile of the Delworth plot is presented in Table 1. This profile is composed of 22 variables. Fractal dimension—a measure of gap complexity (Stewart 1989) , variogram range—a measure of spatial dependency (Isaaks and Srivastava 1989) , contagion—a measure of gap clustering (Gustafson and Parker 1988) , and other spatial statistics (O'Neill

and others 1988) in the profile may be unfamiliar to many managers. Spatial statistics like these, however, describe patterns of the stand that cannot be illustrated using non-spatial statistics. Undoubtedly, these kinds of metrics will become more important as the use of GIS becomes more prevalent.

We envision using disturbance profile information like that in Table 1 for guiding stand assessment or prescriptions. For example, let us assume for illustrative purposes that the management objective of the Delworth stand is to maintain Mexican spotted owl habitat, but that the diversity and abundance of small mammal prey is low. The manager wants to determine why and how to correct the situation. Let us also assume that the target profile for this objective has been established. For this exercise, 'healthy' is defined as a state of the stand in which the populations of small mammal prey for the Mexican spotted owl are adequately diverse. In this context, diverse includes species richness and abundance of each target species. "Adequate" means enough diversity to increase the availability of the owl's prey. Thus, an adequate condition should not eliminate the potential for owls to forage in the stand while incresing prey diversity. Keeping canopy gap sizes below a critical threshold would help to insure the adequate condition is met. In addition, "health" is a relative term that depends on the stand's current state relative to the desired or target state. Threshold values of health depend on and vary with management objectives.

When compared to the hypothetical profile for enhancing habitat of the owl and its prey (presented as desired condition in Table 1), the current Delworth profile shows a few out-of-range variables. Specifically, stem density of all tree species, canopy density of overstory, and contagion are high; log (downed woody debris >1 m long and > 10 cm diameter at widest end) frequency is low; and snag frequency and average gap area are slightly low. A silviculturist would have to determine whether these values indicate the need for silvicultural intervention.

Interpreting disturbance profiles might present a formidable task. A silviculturist might ask a plant pathologist, entomologist, wildlife biologist, or other specialist for help in interpreting the profile,

much as a general practitioner asks help of various specialists to interpret results of a blood profile. The manager might consider disturbance profiles of adjacent stands and the spatial/temporal distribution of proposed treatments among these stands. Different stands may have various objectives, and individual stands themselves may have multiple objectives. Methods of dealing with multiple stand-multiple profiles need to be developed. Until we have more diagnostic experience using disturbance profiles, interpretations will depend on logic, good judgement, and field experience.

A silviculturist might derive the following from the data presented in Table 1:

> *Interpretation*—Delworth has too many trees, too strongly clustered canopy gaps, and not enough logs on the ground.

> *Prescription*—enlarge small gaps in less-gaped parts of the stand (use the gapograms to guide placement of gaps) to diameters ranging between 5 m and 15 m and leave the cut trees (> 10 cm diameter and > 1 m length) on the ground within gaps.

By indicating specific abnormal stand-level functions, disturbance profiles would offer a mechanistic basis for making silvicultural decisions. Eventually, root diseases, bark beetles, spot fires and other disturbance agents themselves might be used as silvicultural tools to adjust stands. However, until a much better understanding of their biology and dynamics is developed through research and field observations, the chainsaw will probably remain the major disturbance agent used by the silviculturist. Silvicultural prescriptions could be based on styling gaps to mimic natural disturbances. Gap size could be increased or specific gap shapes fashioned. Dead wood could be imported. Individual trees could be killed and left standing to create snags. Grasses could be planted. These would be very aggressive management actions, and cost effectiveness would certainly be questioned. These actions, however, do illustrate tools available to silviculturists. As the value of non-timber resources becomes better understood, an examination of the cost effectiveness of these actions may yield unexpected results.

The range of values for target condition in this example are only hypothetical and undoubtedly simplistic. Indeed, current on-going studies have shown that the habitat requirements of the Mexican spotted owl are probably much more complex than the above statements indicate. For instance, site potential would also need to be considered in developing prescription. Enlarging tree canopy gaps at xeric locations of a stand, for example, may not enhance habitat of long-tailed voles over Mexican voles because grasses, forbs and herbs may not have the potential to produce thick cover needed by voles. Furthermore, there may be inter-specific competition among the targeted mammals. Long-tailed voles and Mexican voles tend to exclude deer mice from open areas. Thus, when vole populations are high, deer mice are not found in gaps; when voles are low, deer mice populations are relatively high within the gaps.

One aspect of our current research at the Rocky Mountain Experiment Station is to identify associative patterns and establish target conditions. For some objectives, however, initial operational target values could be derived from best guesses (or informed decisions) by combined research/management teams that periodically monitor, evaluate and revise their decisions. Additional iterations would yield better and better values for target ranges. Ultimately, however, target profiles will need to be based on a solid understanding of how disturbance and recovery processes integrate with managed forest resources.

SIMPLIFYING INTERPRETATION OF DISTURBANCE PROFILES

An array of statistical analyses can be used to analyze multivariates like disturbance profiles (Dillon and Goldstein 1984). Statistical analyses may be useful in simplifying the interpretation of this metric. In a study conducted in the Black Hills, for example, several ponderosa pine stands were grouped using cluster analysis based on disturbance profiles (Lundquist 1995c).

Other ordination techniques are currently being examined for determining target values and quantifying health (Lundquist and King unpublished). For example, multidimensional scaling (Dillon and Goldstein 1984) has been used to represent similarity among stands as the distance between points in
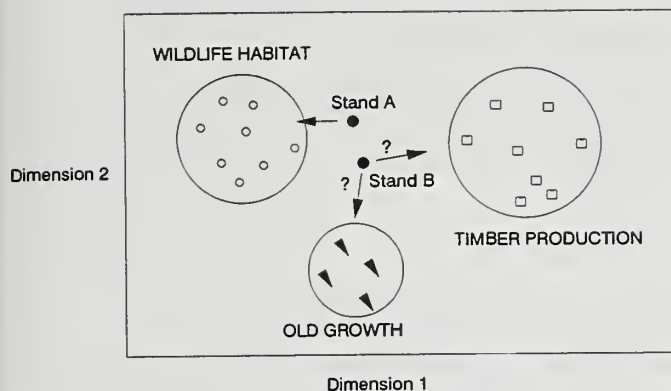
Figure 3.—Hypothetical two-dimensional clustering of the disturbance profiles associated with stands used for three different management objectives. Each box, triangle, or circle represents a single stand. Objectives include: timber production (boxes), old growth landscape (triangles), and enhancement of Mexican spotted owl habitat (empty circles). The three large circles each define target conditions for each objective. The arrow signifies the trajectory or direction and magnitude of change that must be induced by silvicultural manipulations to make stands A and B suitable for one of the objectives. Stand A (which represents Delworth) is closest to the wildlife habitat cluster, and management interventions would probably best be aimed at that objective. Stand B is equidistant from the clusters for timber production, old growth landscape, and wildlife habitat; more information would be needed before silvicultural prescriptions can be developed (Lundquist and King, unpublished).

2-dimensional space (fig. 3). With this procedure, desired stand conditions are quantitatively defined as a clustered space on the multidimensional model.

Operationally, a silviculturist would be presented with a computer image, as shown in figure 3. The current condition of a stand would be represented by a point in this space. If this point were outside the target cluster, then silvicultural manipulations or alternative objectives would be necessary. The objective of silvicultural manipulations would be to move this point to within the target space by selectively manipulating the values composing the disturbance profile. An adjusted profile would be calculated and displayed as a newly positioned point. The direction and length of point movement (its trajectory) would be a quantitative measure of the effectiveness of the silvicultural manipulation. The distance between the point and the target area would be a quantitative measure of the stand's health.

CONCLUSIONS

Small-scale disturbance processes help shape forest ecosystems. Using small-scale natural disturbances as tools of silviculture will require solid scientific knowledge about how disturbances affect the environment and the many resources of societal value within the environment. Managers need methods to quantify and predict ecological effects to make appropriate decisions on the use of natural disturbance. Inventory and data collection efforts must be able to adequately assess the positive impacts of forest disturbances, as well as the negative impacts. Researchers who try to understand the processes controlling the forest environment, and managers who try to manipulate these processes, will rely more and more on each other as they are forced to manage a greater and more complex mix of resources.

The spatial models and disturbance profiles discussed above are still mostly hypothetical. The odds are that no single or complex metric will ever be able to capture the true complexity and dynamicism of a forest stand. But, disturbance profiles may be able to capture enough of the complexity to make them useful tools to silviculturists. Much work remains to be done before they can become operational. Nonetheless, we believe that disturbance profiles (or some multivariate metric like them) will meet the five criteria required of a metric to relate disturbance and forest health (Geils and other 1995, these proceedings): 1) sensitive and responsive to disturbance and recovery; 2) relates to ecological patterns and processes at a scale that silvicultural decisions are made; 3) links to multiple scales; 4) corresponds to ecological functions that affect resource values; and 5) can portray the impact of management actions in quantitative models. We believe that eventually spatial models and disturbance profiles will be able to define the condition of a stand as well as to help guide silviculture.

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Forest Vegetation Simulation Tools and Forest Health Assessment

Richard Teck[1] and Melody Steele[2]

Abstract.—A Stand Hazard Rating System for Central Idaho forests has been incorporated into the Central Idaho Prognosis variant of the Forest Vegetation Simulator to evaluate how insects, disease and fire hazards within the Deadwood River Drainage change over time. A custom interface, BOISE.COMPUTE.PR, has been developed so hazard ratings can be electronically downloaded directly to the District's GIS. Spatial and temporal evaluation of hazards can now be made when comparing management alternatives. GIS maps depicting hazard ratings through time generated from the FVS simulations provide ID team members with information to determine if landscape conditions are moving towards desired future conditions.

INTRODUCTION

Forest health is a major concern throughout much of the interior west. No where is this more apparent than on the Boise National Forest. During the past five years, the Boise National Forest has been occupied with the salvage of dead and dying trees from bark beetles, defoliators, and catastrophic wildfires.

Recently, the Boise National Forest Supervisor and the Lowman District Ranger challenged the Lowman Ranger District staff to develop and validate ecosystem management concepts using a landscape approach to address the forest health issue. The Lowman Ranger District has taken on that challenge, specifically within the context of the Deadwood Landscape (USDA, 1994a, USDA, 1994b).

The objective of the Deadwood Landscape Analysis and subsequent management activities is to restore and maintain the health and long-term sustainability of the Deadwood Landscape.

No attempt will be made to define the term "ecosystem." Rather we will focus on how available tools and technology, including databases, vegetation simulation models, hazard rating systems, and geographic information systems can be used for understanding and characterizing ecosystem factors such as complexity, landscape attributes and viability, and resilience to stress.

DESCRIPTION OF PROJECT AREA

The Deadwood River Drainage is located in the west-central mountains of Idaho in Boise and Valley Counties. It encompasses approximately 153,000 acres and is roughly 32 miles long by 13 miles wide. Thirty percent of the Lowman Ranger District is contained within this drainage. The elevation ranges from 3680 feet, at the confluence of the Deadwood River with the South Fork of the Payette River, to 8696 feet at Rice Peak summit. The Deadwood river flows south, draining into the South Fork of the Payette River.

The Deadwood River Drainage has not recently had major disturbances from insect, disease, or wildfire. It is a diverse community containing both warm, dry sites of ponderosa pine, as well as cool, wet sites of subalpine fir. From pre-settlement times to the present, the warm, dry sites have

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changed from open stands of ponderosa pine to dense stands of douglas-fir. On the cooler sites, very dense stands of lodgepole pine are now dominated by subalpine fir. Considering recent events that have taken place in other parts of the forest, this existing combination of species composition and stand structure is a forest health concern. The Deadwood Landscape now appears to be susceptible to insect and disease epidemics and catastrophic wildfire.

MANAGEMENT OBJECTIVES

Within the general purpose of the Deadwood Landscape Analysis, specific objectives include: (1) restore and maintain the health and long-term sustainability of the Deadwood Ecosystem through silvicultural treatment of high risk/hazard stands, (2) maintain species diversity, (3) prioritize treatments where high risk from insects, disease, and wildfire are threatening neighboring low risk sites, (4) reduce the severity of potential fires, and (5) apply adaptive management techniques to ensure that treatments meet desired goals and objectives.

The project is an attempt to take full advantage of available tools and technology, allowing the District to analyze and evaluate silvicultural alternatives for restoring and maintaining the long-term health and integrity of the landscape.

The data manipulation and modeling procedures used in this analysis allows for both the assessment of current hazards and risks within individual stands and across the landscape, and more importantly, evaluation of how proposed management actions will affect those hazards and risks through time. Comparisons can then be made on how proposed actions will affect successional pathways due to the influences of disturbance agents and their associated changes to disturbance regimes.

It should be noted that the Boise National Forest in particular, and the National Forest Systems in general, are beginning to concentrate less on intensive forest management and more on "maintenance management" to utilize natural processes, whenever possible, to maintain desired future conditions. However, successful "maintenance management" must recognize when natural processes result in less than desirable conditions, and

must dictate appropriate management actions to prevent such conditions from occurring.

A hazard analysis will be done on the Deadwood Landscape to determine stands at high risk from wildfire, insects, and disease. Hazard ratings will be assigned to stands, and silvicultural prescriptions will be developed to alleviate these high hazards. A management schedule will be proposed to treat the high hazard stands over the next five years, and to treat stands with lower hazard ratings soon thereafter. All proposed treatments will be designed to maintain and/or restore structure, function, and diversity across the landscape.

SCOPE OF ANALYSIS

Over the past decade, more than 400,000 acres have burned in catastrophic wildfires on the Boise National Forest. Many of these acres were predisposed to intense wildfires due to prior insect and disease epidemics. These events killed trees on thousands of acres, and increased the hazard of catastrophic wildfire.

The vulnerability of individual forest stands (sites) to such events increases the hazard of converting diverse landscapes to homogeneous landscapes. Given the current paradigm that more diversity is better than less diversity, there exists a need to assess the health of forest stands and their associated hazards from agents of change. The juxtaposition of individual forest stands and their associated hazards will directly affect the hazard of the landscape as a whole.

The scope of this analysis considers about 153,000 acres in the Deadwood River Drainage and adjacent acreage of neighboring watersheds. This analysis will determine what management is needed over the next five to ten years, and where that management will occur.

To assess existing and future hazards due to management actions or lack thereof, the Lowman Ranger District is evaluating current and projected stand conditions using RMSTAND data (USDA, 1993), the Forest Vegetation Simulator (Wykoff, et al. 1982), a Stand Hazard Rating System for Central Idaho Forests (Steele, et al. 1994), and a geographic information system.

RMSTAND data is projected through time using the Forest Vegetation Simulator (FVS). FVS provides the ability to calculate hazard ratings on a stand by stand basis. Utilizing the FVS Event Monitor (Crookston, 1990), hazard ratings for individual stands along with other user-defined custom variables are calculated and then downloaded directly into the District's GIS database for further analysis and visual display.

Linking FVS output to the GIS, allows for landscape level analysis, using stand level simulation results. FVS output is downloaded into the GIS database as a unique layer, spatially linked to other existing GIS layers. GIS analysis models, such as wildlife habitat models and sedimentation models, use both vegetation data (FVS output) and other geographic information, such as roading and slope. These models are used to predict other ecosystem attributes, processes and functions for both existing and future conditions.

The National Forest Management Act (NFMA) portion of the Deadwood Landscape Analysis was completed in August 1994 (USDA, 1994a). Work is currently underway on the National Environmental Policy Act (NEPA) analysis to disclose the direct, indirect, and cumulative environmental impacts of the proposed action and other alternatives on the long-term sustainability of the Deadwood Landscape. The Deadwood Landscape Analysis will be the basis for future management activities. Hopefully, these activities will reduce the potential of catastrophic events taking place within the Deadwood River drainage.

SOURCES OF DATA

Vegetation data have been utilized from several sources to perform both a coarse filter analysis and a fine filter analysis.

The coarse filter utilized image processing and GIS analysis of Landsat Thematic Mapper Scenes along with USGS 1:24,000 scale DEM data. This coarse filter analysis is described in detail in the NFMA documentation (USDA, 1994a) and categorizes vegetation data by maturity class and density class.

The fine filter utilized RMSTAND/RMRIS (stand exam) data. Unfortunately, complete stand exam

coverage for the drainage is not available. For acreages not covered by stand exam data, the District is utilizing The Most-Similar Neighbor (Moeur, et. al. 1995) procedure to assign surrogate stand attributes to non-inventoried stands. This methodology utilizes stand location, stand elevation, stand slope, and stand aspect derived from DEM data, plus the average and standard deviations of each of the seven LandSat bands within each stand. This will allow the District to perform FVS simulations on the entire landscape.

TOOLS

Many tools were utilized in the fine filter phase of the Deadwood Landscape Analysis. The following computer programs, databases, simulation models, and hazard ratings, form the core set of tools for the forest health assessment component of the analysis.

- **RMSTAND** (Rocky Mountain Stand Exam Computer Program) generates reports of existing forest conditions. The program uses stand exam and/or forest inventory data as input. It is currently used by Regions 2, 3, and 4.
- **RMRIS** (Rocky Mountain Resource Information System) is an integrated data base. RMSTAND data is loaded into and extracted out of the RMRIS database. It is currently used by Regions 2, 3, and 4.
- **Forest Vegetation Simulator** (FVS) is an individual-tree, distance-independent forest growth model (see Appendix A). FVS projects forest stand exam and/or inventory data through time. Simulations can include management actions. FVS provides the capability for users to define, calculate, and output custom variables associated with forest structure, species composition, stand-level hazards, etc. . . . FVS output can be downloaded to a GIS database and to the Stand Visualization System (McGaughy, 1995), state-of-the-art forest visualization computer software.
- **Most Similar Neighbor Analysis** is used to find the "most similar" sampled parcel of land and use it as a surrogate for a parcel that does not have a detailed inventory available. The surrogate for an unsampled parcel is called its

Most Similar Neigbor (MSN), and the inventory attributes of the MSN parcel are subsituted for the unsampled parcel (Moeur, et al., 1995).

- **Stand Hazard Ratings for Central Idaho** "has been developed as a composite of eleven individual ratings in order to compare the combined and often different health hazards of different stands...(Steele, et al., 1994) . . . The composite rating includes Douglas-fir beetle, mountain pine beetle, western pine beetle, spruce beetle, Douglas-fir tussock moth, western spruce budworm, dwarf mistletoe, annosus root disease, armillaria root disease, Schweinitzii root and butt rot, and wildfire".

- **Landsat Thematic Mapper Scenes provided** estimates of forest cover type. Cover type consisted of maturity class (immature, mature, and undetermined) and density class (dense, medium, open, and undetermined). This data was utilized by the Most Similar Neighbor procedure.

- **U.S.G.S. Digital Elevation Model** (DEM) data provided estimates of slope, aspect and elevation which was utilized by the Most Similar Neighbor procedure.

- **Geographical Information Systems** (GIS) generate maps that display landscape elements, processes, functions and patterns. Examples of important landscape elements include the mosaic of stand structure, species composition, and stand density. Examples of important landscape functions include hiding cover and thermal cover. Maps displaying these and other landscape elements and functions are generated for both existing and future conditions.

VEGETATION DATA CLASSIFICATION

Vegetation can be classified using many different procedures. Several common methods of site and vegetation classification include habitat type, fire groupings, and vegetative structural stage.

- **Habitat types** (Daubenmire, 1966) were determined in the field for each stand during timber stand examinations. Habitat Type is a collective term for areas that support or can support the same plant association, or did support it prior to its destruction or modifica-

tion by disturbance (Steele, et al. 1981).

- **Fire Group Classification** are aggregations of forest habitat types. Forest habitat types have been arranged into eleven fire groups based on the response of the tree species to fire and postfire succession (Crane and Fisher, 1986). Both habitat type and fire group indicate successional pathways, but they provide little indication of existing conditions. The landscape element that reflects existing vegetative conditions is the vegetative structural stage.

- **Vegetative Structural Stage (VSS)** is a composite of stand size (horizontal) class, stand canopy closure class, and vertical structure class. The rulebase for calculating structural class is based on algorithms imbedded in the RMSTAND software (USDA, 1992) modified slightly to coincide with the Boise National Forest Land & Resource Management Plan (USDA, 1990). Vegetative Structural Stage is also a variable often associated with wildlife habitat.

All three of these classification systems were utilized to evaluate the potential hazards and risk associated with insects, disease, and wildfire.

HAZARD RATING SYSTEM

Forest sucession in the central and northern Rocky Mountains is dramatically affected by disturbance. The primary disturbance agent for the past several centuries has been fire. Forests are also vulnerable to other major disturbance agents such as bark beetles, root rots, defoliators and pathogens.

In order to assess the current and future hazards associated with these disturbance agents within the Deadwood Landscape, hazard rating algorithms were incorporated into the FVS stand-level projections based on the Hazard Rating System for Central Idaho (Steele et al. 1994). The term hazard implies a relative measure of predisposing conditions for damage (Paine et al., 1993). The rating is a relative measure, usually ranging from one to ten. This rating represents the expected percent mortality of the host species if an insect or disease infestation and/or fire occurred. A hazard rating of three would indicate a potential for 30 percent mortality in the host species.

Hazard rating algorithms were coded directly into the FVS keyword files using variables available in the Event Monitor (Crookston, 1990). The keyword files were then used for projecting stands through time with FVS. As each stand was projected through time, the Event Monitor would calculate variables such as the average diameter of a host species, stand basal area, percentage of a host species in the stand, stand structure, site index, crown scorch volume, scorch height, tons of slash, etc. . . . (keyword files, are available from the ESAT Information Center in Fort Collins).

For some of the hazard ratings, all of the required predictor variables were available within FVS. When this was the case, the Event Monitor would calculate the actual hazard rating and output the results in the report created by BOISE.COMPUTE.PR (an FVS Post-Processor developed by the Fort Collins Service Center for this analysis). Some of the hazard ratings required variables not available to FVS, and so the custom report would contain a subset of the required predictor variables necessary for calculating the hazard rating. The final hazard rating would be calculated within the GIS once the custom report had been downloaded into the GIS database.

LINKING FVS SIMULATION RESULTS TO GIS

Using RMSTAND data as input to the model, FVS is used to generate information on existing and future stand conditions. Future conditions are based on simulations that take into consideration insects, disease, fire, management activities, and other processes that affect the growth and mortality of the vegetation on the site.

Information on specific landscape attributes, identified by the ID Planning Team as being relevant to the analysis, such as stand structure, species composition, and hazard ratings, are transferred directly from FVS into the Lowman Ranger District's GIS via a custom report. The Fort Collins Service Center worked with the Lowman Ranger District to facilitate this transfer of data as efficiently as possible. This custom report contains the simulation results for all stands and is used to populate a new GIS database layer. The information

stored in the GIS database are then used for creating maps that display the spatial and temporal characteristics of those landscape attributes.

The use of site-specific simulations and the resulting attribute files, combined with the spatial analysis and display functionality of GIS, allows us to bridge the gap between site-specific management prescriptions and activities, and the resulting effects on future landscape-scale desired future conditions.

Simulations projecting the no-management alternative allows us to evaluate the short and long-term consequences of not actively managing the Deadwood Landscape. Simulations incorporating the calculation of site-specific hazards for fire, insects, and disease, allows us to observe how those site-specific hazards may be expected to change with time. Maps are then generated to view the pattern of the predominant vegetation (matrix), patches and corridors, structural stage, fire groups, wildlife habitat, and insect/disease/fire hazards.

Additional simulations will be used to evaluate the short and long-term consequences of actively managing the Deadwood Landscape under a variety of management regimes. Algorithms for calculating and predicting site-specific hazards and the mangement strategies for addressing those hazards, will be incorporated into the FVS simulations. Mapping the results of those simulations provides both a temporal and spatial perspective of the consequences of the no management alternative versus proposed management alternatives.

The Lowman Ranger District is now in the process of defining those alternative management actions and will soon be performing the simulations to begin analyzing the effects. The results of that analysis will be published within the context of the NEPA documentation.

CONCLUSIONS

The combination of tools now available to our agency, allows us to bridge the gap between site specific management and landscape level analysis. Although this methodology is both data and computationally intensive, it allows us to continue using concepts and methods we are familiar with.

It also points out that stand level management can play an important role in landscape "ecosystem" management. The Deadwood Landscape Analysis is an excellent example of this approach to landscape management.

Furthermore, for landscapes where on-the-ground inventory or stand-exam data is not available, methods are now being developed and fine-tuned to allow for the objective substitution of data. Moeur et al. (1995) have developed one such approach which was used in this analysis. This substitution of data enables the ID Team to consider every acre within the landscape even though measured field data is only available for a subsample of the landscape.

A single landscape analysis tool which will answer all of the questions, interested citizens and ID Team Members are asking, has yet to be developed. Until such a tool exists, it will be necessary for each Forest Service District to utilize to the best of their ability, the tools currently available to them. Utilization of these tools within the context of landscape analysis, requires the professional experience of Resource Specialists, working together with Operation Research Analysts and Computer Scientists to develop new ways to take advantage of these tools.

Using these tools, we can demonstrate how landscape structure, function, and diversity can be expected to change with time. By identifying desirable landscape attributes and functions, we can begin to predict the affect that changing vegetation structure and composition will have on identified desired future conditions. Welcome to a preview of landscape "ecosystem" management analysis in the 21st century.

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APPENDIX

The Forest Vegetation Simulator (FVS) is a distance independent growth and yield model. FVS was originally called PROGNOSIS and was developed for North Idaho by Al Stage and other researchers at the Intermountain Forest and Range Experiment Station in Moscow, Idaho. The PROGNOSIS model was used extensively in the Northern Region of the Forest Service throughout the 1980's. It was used in both strategic planning and project level planning. Over the past ten years, the Forest Management Service Center staff in Fort Collins, Colorado, have calibrated sixteen addi-

tional "variants" of the model to specific geographic areas throughout the west, midwest, and northeastern United States. The Central Idaho Prognosis variant of FVS was used for the Deadwood Landscape Analysis.

There are now FVS geographic variants for (1) Southern Oregon/North Central California (SORNEC), (2) Utah, (3) the Tetons, (4) Southeast Alaska (SEAPROG), (5) Eastern Montana, (6) Western Sierras (WESSIN), (7) Blue Mountains, (8) East Cascades, (9) West Cascades, (10) Central Idaho, (10) Northern Idaho, (11) Central Rockies, (12) Klamath Mountains, (13) Black Hills, (14) Northeastern United States, (15) Lake States, and (16) Central States. In 1996 three new variants: Pacific Coast Range, Northern California, and Southeastern United States, are scheduled for release.

The Forest Management Service Center in Fort Collins, Colorado, maintains the current variants, develops new variants, and provides user support and training. Information on FVS can be obtained from the ESAT Information Center (ESAT:W04A).

FVS extensions include: (1) insect and disease models, to simulate growth reductions, damage, and mortality due to bark beetles, dwarf mistletoe, defoliators, and root disease; (2) a REGENERATION/ESTABLISHMENT model, to incorporate new seedlings into the simulation; (3) the Parallel Processor, where multiple stands are projected simultaneously incorporating inter-stand effects; (4) a COVER model, for predicting the development of understory vegetation; and (4) the Event Monitor, which allows for the conditional scheduling of activities based on changing stand conditions.

Stand management activities are often contingent upon many factors. A harvest may be scheduled if a stand is too dense or if a certain condition predisposes it to particular insect or pathogen damage. Hazard ratings are often used to assess those conditions. Usually, forest growth simulation models must be able to foretell the occurrence of stand conditions that require management actions and preschedule the program options that represent those actions. Not so with the FVS model.

The FVS Event Monitor offers an alternative method of scheduling activities. The user specifies a set of conditions that must occur. This condition is called an event. The user also specifies a set of mangement activities for the model to simulate if and when the event occurs.

For example, suppose you wish to reduce the density of a stand by scheduling a thinning when the hazard rating for bark beetles exceeds a certain value. The Event Monitor is designed to facilitate such a scenario. Taken together, the event and it's associated management activity may be viewed as a mangement rule. There are no limits to how many management rules can be incorporated into a single simulation.

It is also the Event Monitor that provides the capability to calculate user-defined, "custom," stand and tree level variables. These "custom" variables are then incorporated into algorithms used to calculate stand hazards, vegetation structural stage, and other stand level attributes of interest.

Two types of input data are required by FVS. First is a data file in the form of tree records commonly obtained from various inventory methods. Second is a keyword file consisting of FVS keyword records and their associated parameters which provide the model with operating instructions. Keywords provide information about the inventory sample design, geographic location, length of projection, and a whole set of other parameters needed to define the projection.

Keywords can also be used for calculating custom variables. This method of creating variables is facilitated via the use of the Event Monitor's COMPUTE option. The COMPUTE option allows the user to define variables that can be used in logical expressions, in other COMPUTE options, and as parameters on keyword records.

For the Deadwood Landscape Analysis, the COMPUTE option was used during the FVS simulations to calculate vegetation structural stage, and a series of hazard ratings. The Forest Management Service Center working with the Lowman Ranger District developed a Post-Processor called BOISE.COMPUTE.PR to generate custom reports containing the results of these internal calculations. This custom report was then used as input into the District's Geographic Information System (GIS) for developing additional map layers for the analysis. Individuals, interested in obtaining more about FVS can contact the Forest Management Service Center at 970-498-1772.

Partnerships

Developing Technology—
A Forest Health Partnership

John W. Barry[1] and Harold W. Thistle[2]

Abstract.—Since the early 1960's Missoula Technology and Development Center (MTDC) and Forest Pest Management (FPM) have worked in partnership developing technology to support forest health and silviculture. Traditionally this partnership has included cooperators from other agencies, States, foreign governments, academia, industry, and individual landowners. The FPM sponsored projects have focused on engineering development of delivery systems and methods to mitigate environmental impact, protect personnel, and reduce costs while meeting resource manager forest health objectives. This paper summarizes program accomplishments, takes a look how the accomplishments were realized, and references the current 5-Year Forest Pest Management/Missoula Technology and Development Center Plan—Supporting Forest Health.

INTRODUCTION

The purpose of this paper is to review the role of the USDA Forest Service (Forest Service) Missoula Technology and Development Center (MTDC) in delivering technology to support forestry. To illustrate the technology development process, we will provide examples of delivered technology that supports forest health and silviculture. Through this review forest health managers and silviculturists should be introduced or reacquainted with MTDC capabilities that exist to meet needs of forest resource managers.

World competitiveness and the demand for resources are challenging our creativity, entrepreneurship, efficiency, and productivity in all sectors of the public and private economy. Survivors are blazing new trails into the unknown. To those of us in research and development the message is clear—fix it whether it's broken or not because if we don't someone else will.

BACKGROUND

MTDC Mission

The mission of MTDC is the systematic applications of engineering principles and scientific knowledge to create new or substantially improved equipment, systems, materials, processes, techniques, and procedures that will perform a useful function or be suitable to meet the objectives of advanced forest management and utilization.

The Forest Service Technology and Development program began shortly after World War II. The program was originally established in Arcadia, CA and Missoula, MT in 1945 (Simila 1995). A forest pest management program was well established at MTDC by 1964 with some projects initiated in FY 1960 (USDA Forest Service 1974).

Program Management and Funding

MTDC is managed by a manager who reports to Director, Washington Office Engineering, currently through an assistant director. Most of the Forest Service traditional functional organizations are sponsors (customers) including Forest Pest Man-

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agement (Forest Health Protection) and Timber Management. Funding is provided to MTDC by the sponsors and coordinated through the Washington Office; although FPM offices at Regional, Area, Forest, and District offices have provided project funding directly to MTDC. MTDC operates under industrial funding, that is its project funding comes from its sponsors. This funding is "zero-based," thus ending at fiscal year end. Each sponsor has one or more projects (collectively these are a program) at MTDC with each project assigned to an engineer or engineering technician (project leader). The project leader is responsible for delivering the technology (eg, hardware, methodology or manual) to the sponsor. In the case of FPM there is a single point of contact and coordination of the FPM projects. We refer to this person as the sponsor/coordinator.

Sponsor/Project Leader Relationship and Expectations

Critical to project success is the professional relationship between the project leader and the sponsor/coordinator. For the project to be successful, delivered in a timely manner, and implemented, the project leader and sponsor/coordinator must function as a team. As with any contract, the sponsor expects a quality product delivered at the time specified within the agreed price. In addition the sponsor expects status reports during the development. It is emphasized that the sponsor/coordinator share responsibility for these deliverables with the project leader.

Adaptive Engineering

A successful cost-effective approach to engineering development is adapting existing hardware and other technology to meet sponsor needs. Therefore one of the major efforts of MTDC engineers is researching new world-wide technologies; and establishing professional contracts within other agencies, academia, and private sector. These efforts often result in cost effective and mutually benefitting partnerships. Over the past decade, as an example, MTDC has established a long-lasting and productive partnership with Department of Defense in technology exchange and development.

TECHNOLOGY DEVELOPMENT PROCESS

Projects normally originate from a committee or even an individual representing one of the sponsoring groups, as opposed to the project being proposed by an MTDC engineer. Ideally, MTDC engineers, interacting in meetings at the field level, are alert to identifying needs and join actively in preliminary discussions on how the need might be addressed jointly with the potential sponsor. The other, but less common approach, is a direct call to MTDC from a field person who has a technical need. The key here is also for immediate follow up by MTDC to scope the need and discuss options with the potential sponsor. Responsiveness and enthusiasm are the essential elements and genesis of most successful projects.

Planning is basic to success—it provides for delivering the product that's needed, it helps to avoid misunderstandings, it builds rapport between project leader and sponsor, it supports timely delivery, and it helps to avoid cost overruns. Problems in planning are more likely to occur when project leaders, engineers, and sponsors are inexperienced. A solid and detailed project work plan supported by the sponsor is basic to a well planned project. Experience plays a major role in successful development but a work plan is a must. Development is laced with surprises, disappointments, and unanticipated outcomes, both favorable and unfavorable. Development is also risky and rewarding. The inexperienced developer, sponsor, or manager might be tempted to give up at the brink of success. Sponsors and managers need to realize the risks and uniqueness of development, while the project leader must be empowered with flexibility to exercise creativity in meeting unexpected challenges.

Accountability, if lacking on part of either party, might doom the project. Accountability, like technology transfer, should be laced throughout the project and includes delivering, as specified, within the project scope and contract.

Completion of the project by meeting sponsor customer expectations (quality, timely, and fullness) should be the project leader's guiding principles. Team recognition will help to promote future successes.

TECHNOLOGY TRANSFER

Implementing new technology is one of the major challenges of the technology development process. It's probably a greater challenge in the public sector, where unlike the private sector, it's not driven by competition and profits nor supported by marketing expertise. The public technology developer is, therefore, driven by fewer motivators—a challenge to the federal manager. The Chief, Forest Service, recognizing the lack of public incentives, established a major recognition award for technology transfer. Congress has established policies to encourage private and public cooperation in technology transfer. The FPM program at MTDC has generated technology transfer agreements between the Forest Service and its partners including Canada, New Zealand, and the major agricultural chemical companies in the US.

Technology transfer is threaded throughout the development process. It begins when the potential sponsor first proposes the idea and begins to establish rapport between the sponsor and project leader —the team responsible for technology transfer. Technology developed without a sponsor and without the spirit of cooperation is the most difficult to transfer and implement. Technology transfer should be part of the entire development process—beginning at first discussions and continued until all the potential users have adapted the technology.

"The Forest Service approaches technology transfer as a continuing process that ideally begins during the conceptual phase of product development, and continues through product adoption and improvement. The end user's needs and participation should be in the forefront and incorporated into the process to enhance product acceptance. Sharing ownership in and during the process are key to successful technology transfer. Previously, the Forest Service failed to implement promising research and development simply because the end use was not part of the process.

However, the Forest Service is committed to the process of technology transfer to improve productivity and competitiveness. This commitment promotes the development of new technologies within the Forest Service, stimulates the use of federally funded technologies by others, and encourages the recognition and exchange of scientific and technical personnel among academia, industry and the Forest Service" (Barry, et al. 1991).

FPM FOREST HEALTH PROGRAM

MTDC/FPM Program

The present FPM program is guided by a 5-year plan (Thistle 1995) that was initially prepared jointly by MTDC and FPM and approved by the Director, FPM in December 1991. The program describes processes, describes projects and deliverables, and lists budget estimates. The plan is a living document for use in managing the program and supporting technology transfer, and a reference document for conducting program review to include project deletion, modification, additions, or cancellation.

National Steering Committees

FPM sponsors eight national steering committees that have the role of identifying technology development needs. The committees, composed of members that represent the Forest Service and its cooperators, meet annually to review and identify technology needs and agree on priority for funding. The committee process has worked well since its inception in 1988. MTDC is a participant in these committees interacting directly with potential technology users. Several of the projects in the MTDC/FPM 5-Year Program originated during various committee discussions.

Examples of Successful Projects

Two examples of successful projects are given— one a long-range development effort, the other a short-range. FPM and MTDC joined efforts in the mid–1970's along with sponsorship of the USDA Douglas-fir Tussock Moth Research and Development Program (Brookes, Stark, and Campbell 1978) to develop a computer model that predicted the dispersion drift, deposition and fate of aerial sprays (Teske et al. 1993). The US Army provided the base computer model and remained cooperating partners during development. In addition several Forest Service cooperators, universities, and the National Aeronautical and Space Administration provided

assistance. Significant developmental challenges were successfully met and with funding support from the US Army and FPM, we developed a model that has become the accepted spray model by forest and agricultural practitioners and regulators in Canada, New Zealand, and US. The US-EPA is in the process of accepting a version of this model for use in satisfying registration and labeling of pesticides.

The second example is a project that delivered operational technology to the field within 3 months of its inception compared to years in the case reviewed above. Need for a single tree spray system was originated by an FPM steering committee and by Tom Catchpole, silviculturist, Pineridge Ranger District, Sierra NF, CA, who expressed interest in protecting critically needed and high value sugar pine seed from insect damage. Tom contacted Nancy Rappaport, research entomologist, Pacific Southwest Research Station. The question was how to apply the spray to sugar pine that tower over 100 feet, do it without the aid of a helicopter, and insure minimal contamination of adjoining trees. Nancy's husband, Harvey Rappaport, suggested mounting lawn type sprinklers in the tree crown and pumping the insecticide from a mobile ground system. The need for repeated insecticide application and its estimated low cost made the idea theoretically practical. Immediate follow-up prototype testing by MTDC, PSW, and Sierra NF personnel was conducted on the Pineridge District. Another test was conducted at the Forest Service Coeur d' Alene Nursery, ID. Continued success with this technology has encouraged its evaluation in eastern seed orchards operated by Weyerhaeuser, the Forest Service, and Florida Department of Forestry. MTDC designed the system, however, it was the enthusiastic support and hands-on participation and team approach that caused this idea to be a success and the system to become operational technology within a few months.

Everyone was a winner in these two contrasting projects.

REGENERATION AND FOREST HEALTH PROJECTS

Regeneration Projects

Over the years, MTDC has been involved in many aspects of forest regeneration. This section gives a few examples of projects related to regeneration which MTDC has conducted in the past 2 years. The nature of the projects ranges from statistical evaluation of methods to the actual development of electromechanical systems to reduce labor and improve efficiency in regeneration practices. The project topics cover activities from seed protection through site preparation, storage, and transport to planting and establishment. The brief descriptions given here can be reviewed in given references or by contacting MTDC.

Steep Slope Site Preparation

Mechanical site preparation is generally restricted to slopes of less than 35 percent. With a mind to ecological considerations, more residual matter is being left after timber harvests. New methods are needed to adequately treat brush and logging debris and to prepare planting sites on slopes of more than 35 percent with heavy slash. MTDC conducted a market and literature search to seek equipment and techniques available for steep slope work. All applicable equipment from large excavators to small four wheel drive ATVs was considered for Forest Service tasks. Results of the MTDC investigation revealed a variety of equipment that would satisfy these needs (Karsky 1993).

Mulch for Seedlings

Ground mulch is commonly used in the ornamental and landscape business to reduce vegetative competition and improve soil moisture around newly planted trees and shrubs. Forest Service researchers determined that ground mulch could significantly improve seedling survival and promote early growth. As part of a nationwide cooperative research effort, MTDC collected data on various types of mulch material, current techniques, and equipment used to place the material around newly planted trees. MTDC has also helped collect the final data on a cooperative mulch test project with the Lolo NF. Results of this project will be published in a report which is intended to serve as a reference for field foresters. The report will include information on commercial mulches, suggested installation techniques, a quick

overview of past mulch study results including the cooperative mulch test and recommendations, and a comprehensive bibliography (Windell 1995a).

Root Pruner

Tree seedlings are pruned in the packing shed to provide seedlings with a uniform root length. This is currently done with hand operated, office type paper cutters. This system has a number of problems. The hand cutting is difficult and workers tire quickly. The operators are subject to carpel tunnel injury and are at continuous risk of laceration from the cutters. The work is slow and typically requires that temporary personnel and equipment be brought in to keep up with production. Finally, contractors have difficulty meeting USDA Forest Service root length specifications.

MTDC was asked to develop a root pruner to automate the pruning process and increase packing shed safety and efficiency. The prototype MTDC developed accommodates up to an 8-inch diameter seedling bundle and carries it to the cutting area on plastic conveyor chain. When these bundles enter the cutting area, the shear is activated and the bundles are pruned to the correct length. The bundles are then transported to the end of the unit and then packed in boxes. The cutting area is completely enclosed with a Lexan guard, which provides a barrier between the operator and the cutting mechanism, yet still allows the necessary visibility. The system has been refined based on field tests (Lowman 1995).

Seedling Protection

MTDC has been working with the Southern Region to evaluate commercially available devices that can be used to protect seedlings from animal damage and to promote growth. Seedling protectors have been successfully used in Europe and in some parts of the US for years. Along with protecting the young plant from animal browsing, these devices can create a microclimate around the seedling that will improve survival and promote early growth (Windell 1995b).

Machine Vision Computerized Sorting and Grading System for Tree Seedlings

Forest Service tree nurseries tailor their seedlings to specific Forest and District needs. In doing so, these nurseries must have an effective quality control system. Currently, lifted seedlings are delivered to packing sheds for grading and packing. In this process graders sort seedlings by hand, cull the unacceptable plants, and sort the others by stem diameter, top length, root area, and overall quality. They then place the acceptable seedlings on a packing belt for final processing and packaging. Quality control checkers further monitor this operation by picking samples and overseeing grader performance. This is a labor intensive and expensive process. MTDC was asked to automate the quality control and grading in an effort to reduce these costs.

Under contract to MTDC, Oklahoma State University delivered a machine vision quality control inspection station to the J. Herbert Stone Nursery in February 1994. The system utilizes high resolution line-scan camera technology and an IBM/AT bus compatible personal computer. Ten tree seedling morphological features are measured at rates up to ten seedlings per second. Initial performance tests demonstrated measurement precision equal to or greater than manual measurements. The seedling inspection station can be expanded upon for automating production line grading. Several related aspects of defect detection and seedling handling must, however, be addressed to achieve a comprehensive automated system. Investigation of color detection of defects such as chlorotic foliage and stripped root laterals showed promising results. Also a positioning and sorting mechanism for handling the seedlings after grading was found to be marginally suitable to support automated root pruning (Gasvoda 1994).

FOREST HEALTH PROJECTS

Complex Terrain Droplet Dispersion

The Forest Service Cramer-Barry-Grim (FSCBG) model is a modeling system used to simulate the dispersion, deposition, and drift of pesticides into

the atmosphere (Teske et al. 1993). The modeling approach focuses on describing the movement of particles or drops (typically 5–500 microns in diameter) released from an airborne spray system. In the near field the approach is to solve a Lagrangian trajectory equation, in the far-field the Lagrangian model is used to provide a source term to either a Gaussian dispersion algorithm or a phenomenological valley drift model (VALDRIFT) which utilizes conservation of mass and momentum to calculate material moving in flow tubes parallel to the axis of a valley. It had long been observed that the upslope (anabatic) winds that often occur in mountain valleys during the day and downslope (katabatic) winds which often occur at night, control the movement of spray material released in these valleys. VALDRIFT models these mountain wind cells. In the FSCBG modeling approach, the near field equations are solved analytically based on detailed descriptions of the release scenario (aircraft type, weight, number of nozzles, nozzle spacing, initial droplet size distribution, release height, and others). The near field solution is used to a distance where the source momentum is a small percentage of the total momentum. In the first case, the material not 'depleted' from the plume in the near field is available as the source term of a Gaussian line source or as the initial concentration in a valley flow-tube.

The VALDRIFT model is the result of cooperative work between the Forest Service and Battelle PNL Laboratories. Since much of the domain of the Forest Service operations is mountainous, it is critical to consider the effects of the mountains on the dispersion field. This model was initially developed by Battelle for the US-EPA and has been substantially modified to suit Forest Service applications (Allwine et al. 1995).

Thermal Insect Control

The objective of this project is to control insect larvae in seed orchards before they emerge from the cones or from the duff layer. It has been shown that this is an opportune time in the insect's life cycle to lessen the effect of the insect. Historically, prescribed fire has been found effective in controlling larvae but ideal burning conditions do not always occur prior to emergence. If the insect emerges during the rainy season, prescribed fire is useless because it will not propagate through the orchard. This project investigates the use of burner equipment (adapted or developed) for the control of seed cone and duff layer pests during their vulnerable larvae stage. The exact temperature and duration of heat required to control different pests is unknown. This project was given priority by FPM's National Steering Committee for Management of Seed, Cone, and Regeneration Insects. This approach could offer a non-chemical, relatively economical method to control insects in seed orchards. Results of tests in the spring of 1995 indicate that target temperatures can be met in the duff layer under dry conditions. Concerns remain regarding the dependence of the effectiveness of the equipment due to weather, since there is a narrow entomological time window available. Also, human safety and fire control are concerns (Thistle 1995).

Orchard Sanitation

Non-chemical orchard sanitization techniques such as sweeping, vacuuming, and steaming may be safe, effective means of controlling cone and duff pests from seed orchards. Infestations such as cone beetle have a substantial economic impact on Forest Service seed orchards and orchard pests. Seed orchard managers are becoming more and more reluctant to use chemicals. Various non-chemical sanitization approaches have been proposed. This project has evolved out of the Thermal Insect Control Project. While recent tests have shown promising results for thermal control, they have not conclusively demonstrated its effectiveness and there are safety concerns with burning regarding explosions, smoke exposure, and wildfires. Sanitation may offer a viable alternative and this technique is already used by the lumber industry in the southeast. The Non-chemical Orchard Sanitization Project addresses needs reported by one of the FPM steering committees. As costs associated with the use of chemical pesticides increase, orchard managers are left with fewer and fewer tools to combat economically important pests. This project has potential of providing managers with efficacious and economi-

cally feasible tools to combat pests in seed orchards (Thistle 1995).

DGPS Aircraft Guidance

The field of Global Positioning System (GPS) based navigation is rapidly growing and is positively impacting the effectiveness of Forest Service and cooperator operations. This technology is based on the reception of signals from a constellation of satellites. These satellites were originally intended for military use but the capabilities of civilian applications of GPS technology are increasing rapidly. Currently, instrumentation using the signals from this satellite constellation can yield positions on the surface of the earth with less than two meters absolute error under optimal conditions. (A technology known as carrier phase DGPS increases this accuracy to 2 centimeters and is now the state-of-the-art in surveying.) The applications of this type of accurate positioning are numerous. Of great interest to FPM (investigation and implementation of this technology has been noted as a priority by the Forest Pest Management National Spray Model and Application Technology Steering Committee, the National Steering Committee for Gypsy Moth and Eastern Defoliators, and other groups within the Forest Service) is the ability to accurately know and log to a stored file the exact position of an aerial or ground spray system during an application event. This ability can: (1) help eliminate the problem of treating the wrong area, consequently reducing the need for flaggers and block marking; (2) provide aircraft tracking and guidance, allowing the spray material to be applied more evenly; (3) provide detailed position vs time records for quality control and post spray environmental and legal challenges; (4) eliminate need for flaggers and associated safety and cost factors; (5) reduce or eliminate lost pilot time due to finding home and costs associated with returning to base for reloading and returning to the exact position where application ceased; and (6) indicate misses or gaps immediately by the applicator or operational manager allowing corrective action to be taken in a timely manner.

In general, costs can be lowered, safety improved, and efficiency increased when GPS navigation systems are integrated into FPM pesticide application operations (Thistle et al. 1994). There was substantial interest within FPM to see this technology demonstrated and to have the manufacturers and developers' claims independently verified. Demonstrations and tests held on the Ninemile Ranger District west of Missoula, MT indicated that the accuracy claimed for these systems can be demonstrated. However, a further observation was that the systems have been designed for crop work and face a substantially different set of circumstances when deployed on forestry projects in mountainous terrain. Some further development by system developers will greatly benefit forestry. This technology is making a major impact on the way in which Forest Service personnel perform various resource management tasks.

Computer Assisted Sketchmapping

The advent of GPS positioning and high speed computer based GIS systems is influencing many established, hard map based procedures. In forest health aerial survey work, it may be feasible to replace hand marking of topographic maps by the direct entry of data into a GIS system which scrolls over a map based on input from a GPS unit. This type of moving map display exists but the logistical considerations involved in integrating, installing, and operating this type of airborne system are substantial. Currently, FPM conducts an aerial survey of the national forest land annually and compiles statistics relating to infestation and general forest health. The current method is to fly at low altitude with a pilot and a FPM specialist who marks directly onto a paper map. The correct location on the map is generally found using drainages in Region 1, while Region 6 uses a regular flight path and a map grid to determine the map location. GPS and GIS technology combined now offer a possible alternative which would eliminate the encumbrances of maps in the aircraft and then reducing data off maps after the survey flight. Spatial statistics and graphics could be produced directly from the GIS. The GPS interface would also improve survey accuracy in areas where the surveyor does not have topographical or other features to determine accurate map location.

This project was initiated directly from the Regions via FPM sponsor/coordinator. The state of

the technology will allow the aerial survey sketchmapping to be done more efficiently. The computer file which is produced should download directly to Forest Service Project 615 systems. The number of systems that perform similar applications is growing daily and thorough examination of available technology will be a critical part of this project (Thistle 1995a).

SUMMARY

- Engineers are available to assist field practitioners in support of forest health needs to meet advanced technical needs of natural resource managers.
- MTDC has a long-term and productive relationship with FPM, TM, and other staffs in developing forest-use technologies.
- Partnerships in technology transfer are critical to success.
- Future of the MTDC type organization is dependent, as in the private sector, upon customer satisfaction through delivery of a quality product at a competitive unit price, delivered in a timely manner.

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Building Partnerships to Evaluate Wood Utilization Options for Improving Forest Health

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Abstract.—Silvicultural practices used on national forests are changing as a result of the shift to ecosystem management. As a result, the species mix, size, quality, and quantity of woody material that may be removed are changing. In a combined, multidisciplinary effort, Forest Service research units at the Forest Products Laboratory, Pacific Northwest and Southern Research Stations, Northeastern Forest Experiment Station, and national forests in Regions 6, 8, and 9 have been identifying wood utilization options for managing specific ecosystems. Teams have been focusing research on three conditions: dense small-diameter stands in the West, uneven-aged pine/mixed hardwood stands in the South, and central Appalachian hardwood forests in the Northeast. The teams are evaluating alternatives for silvicultural treatments, forest operations, and wood products, as well as the economic feasibility of these alternatives. The project objective is to provide information and methods for evaluating opportunities for current and future products from woody materials that may be removed from the forests.

INTRODUCTION

Forest Service research units at the Forest Products Laboratory, Pacific Northwest and Southern Research Stations, Northeast Forest Experiment Station; and national forests in Regions 6, 8, and 9 are completing the first year of research of the Wood Utilization for Ecosystem Management Project. The project involves many types of studies aimed at developing methods to identify and evaluate utilization options for managing specific ecosystem conditions.

The research is coordinated by a national steering committee and conducted by three teams. Each team has been focusing on a particular ecosystem condition: (1) dense small-diameter stands in the West, (2) uneven-aged pine/mixed hardwood stands in the Piedmont region of the South, and (3) central Appalachian hardwoods in the Northeast. Using an ecosystem approach to management, land managers in these areas are seeking workable silvicultural practices to achieve many interrelated outcomes:

- restoring the natural range of variation in disturbance patterns
- restoring wildlife habitat
- maintaining healthy and aesthetically desirable forests
- mitigating the impact of insects and diseases
- reducing the risk of catastrophic fire
- restoring a mix of vegetation within the natural range of variation

Treatments needed to achieve these outcomes may require removal of woody material, as with

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traditional practices, but there may be differences in the species mix, size, quality, and quantity of materials to be removed when compared to traditional practices.

The overall objective of this project is to provide information and methods needed to evaluate current and future product opportunities for woody materials that may be removed from forests maintained under ecosystem management regimes. By combining expertise in silviculture, forest operations, wood utilization, and economic feasibility evaluation, this project provides scientific and technical knowledge relevant to planning and implementing ecosystem management for specific ecosystem conditions.

To financially support the removal of woody materials on national forests and to aid local economies we need to obtain the highest value products possible from these materials at the lowest operating cost. The information from this research may also help community leaders to determine where wood utilization proposals can realistically provide jobs and income.

APPROACH

Regional research teams are studying widespread ecosystem conditions. Team members on the national forests identify the outcomes needed for the ecosystems and work with scientists to identify possible alternative silvicultural treatments. The research teams (1) collect information that links possible treatments to characteristics of wood to be removed and to possible products and product qualities, (2) evaluate woody material for use in alternative high value products, (3) evaluate alternative forest operations for removing woody material, and (4) evaluate the economic feasibility of alternatives. Utilization options are being evaluated for woody material to be removed both now and in the future.

DENSE SMALL-DIAMETER STANDS IN THE WEST

Dense, small-diameter stands are widespread in the West. To improve ecosystem health and biological diversity will require thinning and other silvi-

cultural treatments. The research objectives for this ecosystem condition are (1) to evaluate the effect of alternative silvicultural treatments on forest conditions, (2) to evaluate logging costs, product yield, and price of alternative forest operations, (3) to examine alternative high value products, and (4) to prepare a tool for analyzing the economic feasibility of alternative products.

Current Forest Conditions

Fire suppression has resulted in the development of small-diameter, densely stocked stands throughout the interior West. These stands typically lack vegetative and structural diversity and exhibit an increased susceptibility to attack from insects and disease. Mortality from competition, insects, or disease leads to an increase in fuel materials (fuel loading) and consequent increased risk of catastrophic fires.

Under a program known as Creating Opportunities (CROP), the Colville National Forest (NF) surveyed 110,000 acres (44,516 ha) of densely stocked small-diameter stands (4–7 inches [102–178 mm] dbh, 1300–2000 stems/acre) (USDA FS 1994a). Natural development has led to stands commonly consisting of fire-origin lodgepole pine (*Pinus contorta* var. *latifolia*), western larch (*Larix occidentalis*), and Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). These stand conditions are common in northeast Washington, northern Idaho, and northwest Montana. A heavy western redcedar (*Thuja placata*) understory is also present in many stands on the east side of the Colville NF.

Average stem size varies in the Colville stands, but at least half the trees fall below the minimum size required for conventional lumber utilization at local mills. The Rocky timber sale area, which encompasses 5,600 acres (2,266 ha), has been selected for studying how active management can produce a range of ecosystem characteristics.

Desired Forest Ecosystem Conditions

The desired outcome for Colville stands is to create healthy, vigorous stands that contain structural components (age, species) within the historic range of variation for the region and that support

wildlife. The reference for variation is the pattern and abundance of structural stages within watersheds in the region during the 19th century (USDA FS 1994b). To achieve this outcome requires creating a higher proportion of late successional forest structure as quickly as possible. The objective is to improve wildlife habitat, forest health, and forest aesthetics. Standards and guidelines for managing these stands are contained in the Colville NF Plan (USDA FS 1988), as amended by the Regional Forester's Interim Management Direction for Eastside National Forests.

Alternative Silvicultural Treatments

To evaluate silvicultural alternatives for the Colville NF, Dr. Steven Tesch and David Ryland[8] of Oregon State University have simulated four silvicultural prescriptions and a no treatment scenario for a range of stand types using the Inland Empire variant of the Forest Vegetation Simulator (FVS) (Wykoff 1986, Wykoff et al. 1982). The alternatives are thinning, a small clearcut with green tree retention, group selection, and single tree selection. The last two are treatments for uneven-aged management. For thinning, the objectives are to remove trees with poor form or vigor, remove trees that pose a health risk, reduce competition, and increase growing space to develop larger trees. For the clearcut, 12 to 15 green trees per acre are retained after the harvest, larch seedings are planted at a density of 360 seedings per acre, and other species regenerate naturally. Group selection is used for western larch/Douglas-fir stands—0.75-acre (0.3-ha) areas are harvested on a 30-year cycle; one-fourth of the area is harvested each 30 years, resulting in a 120-year rotation. Single tree selection is limited to western redcedar stands where a majority of understory and overstory species are shade tolerant. Treatments are scheduled every 30 years and leave no more than 150 ft²/acre (35 m²/ha) in size distribution, characterized by a reverse J-shaped distribution with a diminution quotient of 1.3.

The FVS projections suggest that without intervention the Colville NF will not meet the desired

future conditions for these dense, small-diameter stands. The projections show that for the no treatment option, stands will develop slowly and it is unlikely they will ever reach the tree size or species objectives. Simulations show greater success for growing stands with the desired tree size and species diversity through the small clearcut with green tree retention, thinning, and uneven-aged management options.

Alternative Forest Operations

Actual thinning operations on the Rocky timber sale area were studied to determine the relationship of stand characteristics (tree size, density) to harvest costs and product volume–value recovery under current local mill utilization standards (Barbour et al. 1995).

Stands were marked to remove trees attacked by *Armillaria* and mistletoe, to release understory trees, to reduce potential fire risk, to create winter browse sites, and to move stands toward a late successional stage. Harvesting equipment included one rubber-tired harvester, three tracked harvesters, and two rubber-tired forwarders.

Costs for harvesting were developed along with estimated volume and value of dimension lumber and chips that could be produced in local mills. Estimated harvesting costs and value of recovered products were highly sensitive to differences in average diameter of trees harvested. For dense stands with mean tree dbh of 5–10 inches (127–254 mm), harvest costs increased and traditional product revenue declined sharply with even slight decreases in mean tree dbh. A stand averaging a few tenths of an inch smaller in average diameter provided a third less lumber per unit volume of logs harvested.

Alternative Wood Products

Some small trees that will be removed under ecosystem management are large enough to produce structural lumber. Stud-grade 2x4s would be a traditional choice for some mills.[9] However, some of the larger logs might be made into machine-

[8]Ryland, David B. Evaluating the impact of four silvicultural prescriptions on stand growth and structure in North East Washington—a modeling approach. Submitted to Western Journal of Applied Forestry.

[9]2x4 refers to nominal 2- by 4-inch lumber (standard 38 by 89 mm).

stress-rated lumber (MSR) or laminated veneer lumber (LVL). MSR and LVL lumber are worth from 20 to 400 percent more than Stud-grade lumber. However, the grade of MSR and LVL is determined by nondestructive testing of wood properties in addition to visual assessment of growth characteristics, such as knots. Current grading procedures for logs are based solely on visual assessment of log characteristics. Identification of logs most likely to produce high quality MSR lumber or veneer for LVL lumber could help get the maximum value from small-diameter logs.

The Forest Products Laboratory (FPL) is evaluating a nondestructive method to test logs for stiffness and link test results to mechanical properties of lumber or other products made from the logs. Results of initial studies on red oak, balsam fir, and eastern spruce indicate that longitudinal stress wave techniques may be used to relate log properties to lumber properties.[10] A cooperative study between the FPL and the Pacific Northwest Forest and Range Experiment Station is using this stress-wave technique with small-diameter Douglas-fir and Hem–Fir logs. The objectives of the study are to establish a relationship between log and lumber properties and to combine visual measurements of growth knots with the nondestructive measurement of log properties to predict the yield of MSR lumber from the logs.

The FPL and the University of Washington are conducting mechanical and chemical pulping trials, respectively, of small-diameter trees from the Colville NF. These trees may contain large concentrations of juvenile wood, compression wood, bark, and extractives that could be detrimental to both pulping processes and pulp and paper characteristics. Tests are examining fiber quality differences associated with different tree characteristics. Mechanical pulping is done by thermomechanical and chemithermomechanical pulping procedures; electrical energy consumption during pulping is a primary concern. The kraft pulping procedure is used for chemical pulping, where the primary concerns are cooking conditions and pulp yield.

Pulp characteristics will be identified for each processing method. Paper made from the resultant pulp is tested for strength and optical properties.

Washington State University is conducting research on the relationship between characteristics of wood from the Colville NF and options for composite products.

Evaluation of Economic Feasibility

A simulation tool will be developed to conduct sensitivity analysis of economic feasibility of alternative treatments of dense small-diameter stands. The tool will show how costs and revenues for particular silvicultural treatments change with changes in stand conditions (size, density, species), available alternative products, efficiency of conversion to products, manufacturing costs, and product prices. The analysis will help identify the conditions where silvicultural treatments, forest operations, and utilization options combine to achieve ecological objectives economically.

UNEVEN-AGED MIXED-SPECIES FORESTS IN PIEDMONT REGION

The Piedmont physiographic region is located east and south of the Appalachian Mountains and west and north of the fall-line of the Coastal Plain in the Southeast. The Piedmont contains about 21 million acres (8,500 thousand hectares).

Before European settlers arrived in the Piedmont, nearly one-half of the area was probably occupied by pine–mixed hardwood stands and the other half by predominantly hardwood stands. The rolling hills of the Piedmont, among the most fertile in the South, had been extensively cleared for cotton and other row crop production by 1860. By the 1930s, most top soil had eroded away and further productive cultivation was difficult because of large gullies and poor soils. Subsequent abandonment of agriculture and the reforestation of vast areas stabilized the land, and by 1990 only a small percentage of the Piedmont was still row cropped. Most agricultural land has been converted to pasture, naturally seeded to pine forests, or planted to pine plantations.

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[10]Ross, R.; Green, D.; McDonald, K; Schad, K. Stress wave nondestructive evaluation of logs to predict structrual product quality. In preparation as a journal report. Schad, K.; Kretschmann, D.; McDonald, K.; Ross, R.;Green, D. Stress wave techniques for determining quality of red oak switch ties. In preparation as a FPL Technical Note.

Current Forest Conditions

Based on the latest forest inventory data, the Piedmont contains 31 billion ft^3 (8.78 × 10^8 m^3) of growing stock—44 percent pine, 1 percent other softwoods, 26 percent soft hardwoods, and 29 percent hard hardwoods. The NF land in the Piedmont region was purchased by the Federal government in the 1930s; prior to that time, it was private agricultural land. At present, Piedmont national forests contain 58 percent of growing stock in pine, 3 percent in other softwoods, 18 percent in soft hardwoods, and 21 percent in hard hardwoods. The NF lands account for only 2 percent of all timberland in the Piedmont. The majority of stands are natural even-aged pine or pine/hardwood on abandoned agricultural lands.

Desired Forest Ecosystem Conditions

Forest soils are in a highly depleted condition. In many cases, centuries of careful management will be needed to restore the soils to a condition similar to their original fertility. Nevertheless, the general health of Piedmont forests is good, except for problems with fusiform rust and small outbreaks of southern pine beetle.

The NF lands have been managed under the multiple-use concept since the 1960s. Under this concept, timber management objectives were to improve the health, quality, and volume of pine stands. Older pine stands were often clear cut and replanted with pine or harvested using seedtree cuts to regenerate pine. Younger stands were thinned using various partial-cut management systems to stimulate pine sawtimber growth.

Under ecosystem management objectives, pine and pine/hardwood stands on national forests in the Piedmont are sometimes converted from even-age to uneven-age stand management for pine and mixed species stands. Other practices include traditional even-age, modified even-age, and modified uneven-age methods and systems.

The research objective for the Piedmont region is to identify the implications of various ecosystem management strategies and resultant silvicultural treatments on species composition, tree growth, tree survival, wood properties, and product quality.

Alternative Silvicultural Treatments

A series of study plots with histories representative of a range of ecosystem management practices is being established, measured, and retained for future monitoring in pine and mixed pine/hardwood stands in the Piedmont. Forest practices represented are seed tree, group selection, partial cuts, and reserved.

Plots are located on the Oconee NF and Piedmont Wildlife Refuge in Georgia, the Sumter NF and Savannah River Forest Station in South Carolina, and the Uwharrie NF in North Carolina. Study plots will be inventoried every 5 years, after any natural disturbance, and prior to and following harvest treatments. Selected study plots are relatively even-aged, representing five 20-year age classes (1, 20, 40, 60, and 80 years) and two broad site-index (SI) classes (SI < 80 and SI > 80).

On each study plot, three 1/5-acre (0.081-ha) circular permanent subplots are being established. Trees > 5.0-inch (> 127 mm) dbh are being inventoried by individual species, diameter at breast height, total height, merchantable height, crown class, tree grade, and defect indicators. Rate of growth and wood properties will be estimated from increment cores collected from a sample of trees from each subplot. Five 1/300-acre (0.001-ha) subplots are being installed in each plot to measure reproduction and trees 1.0 to 4.9 inches (25.4 to 124.5 mm) dbh.

Alternative Wood Products

Wood properties and tree characteristics will be linked to lumber and veneer yield by grade. Equations will be developed that link tree characteristics to product yield by grade. Using the equations and field measurements of tree characteristics, total product potential by grade will be determined for trees and stands managed under various ecosystem management regimes.

In a cooperative study, the FPL and the Southern Station are evaluating the use of longitudinal stress wave techniques to relate log properties to properties of MSR lumber. Southern Pine logs from both plantation and natural stands under uneven-age management schemes will be used to assess the

techniques. Preliminary results indicate a useful correlation between log and lumber properties.

Alternative Forest Operations

Implementing intermediate cuts under uneven-age regimes and for stand improvements is difficult and costly in the southern United States. Higher costs are associated with harvesting low volumes and scattered trees, as well as an increased risk of residual tree damage, especially when protecting the hardwood component in mixed species stands. Current harvesting systems are designed for large volume, large area operations and are not conducive to intermediate cutting activities. Recent studies have shown that harvesting costs and residual tree damage increase inversely with cutting volumes and that site disturbance increases directly with cutting volumes for conventional chainsaw/skidder systems. New technologies and techniques are needed to improve harvesting efficiency, to reduce site impacts and residual tree damage, and to optimize wood recovery.

Forest operations need to be completed in a way that minimizes residual tree damage, soil surface disturbance, and impact to the physical properties of the soil. Multiple entries into the stand may lead to cumulative impacts and potential growth loss unless the operations are managed carefully, using improved technologies. Current research is assessing the costs and impacts associated with different technologies in implementing various intermediate stand cuts and in identifying improved methods and alternatives, such as cut-to-length systems and smaller machines. The scientific and technical knowledge from such research will aid the development of new technologies and operating guidelines that will benefit the forest manager in implementing partial cuts.

Evaluation of Economic Feasibility

Prediction models will be developed to estimate potential timber product yields for various stand conditions and treatment regimes. The models will estimate current and predicted yields of total biomass and timber products per acre for pine and hardwoods. The predicted yields will be based on stand variables, including species mix, stand age, basal area, trees per acre, and site index. A model is being developed to project growth and yield for uneven-aged loblolly pine stands in the South. An optimization model will also be developed to work with the growth yield model to evaluate the economic return and stand species and size diversity for alternative silvicultural treatments. The optimization model will use information about potential products from stands grown under different treatment regimes.

CENTRAL APPALACHIAN HARDWOOD FORESTS

The initial phase of research in the Northeast is focusing on central Appalachian hardwood stands on the Monongahela NF. Innovative silvicultural practices are being evaluated as a means for meeting ecosystem objectives for a wide variety of forest types and stand conditions. No single forest type, age class, or species association is being targeted.

Current Forest Conditions

According to a 1989 Forest Service inventory, 79 percent of West Virginia is forested, with 12.1 million acres (1,270 thousand ha) of forest land (DiGiovanni 1990). Two-thirds of this forestland is fully stocked or overstocked. Survey results also indicate that sawtimber stands predominate, which indicates the maturing of the central Appalachian forest resource. One-third of the timberland has sawtimber volumes exceeding 6000 board feet per acre.[11] However, a problem common to much of the eastern hardwood region is that two-thirds of the sawtimber volume is in low-value grades 3 and 4 logs. Although oak/hickory and northern hardwood forest types dominate, species composition on a single treatment area can be extremely variable, given variation in elevation, aspect, and stand history. Thus, the timber resource for ecosystem management treatments is very diverse.

Desired Forest Ecosystem Conditions

The ecosystem management concerns associated with the central Appalachian hardwood forests are

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[11] 1 board foot = 0.0024 m^3.

(1) maintaining forest health and vigor, (2) maintaining diversity of tree species, (3) maintaining and regenerating oak species, and (4) minimizing residual stand damage from forest operations.

Given the relatively high proportion of sawtimber stands and fully or overstocked stands, maintaining forest health and vigor will require the regeneration of maturing sawtimber stands and intermediate cuts in other fully stocked and overstocked stands.

Intolerant species such as yellow-poplar and black cherry cannot be adequately regenerated with the light partial cuts or diameter-limit cuts common on private lands, and clearcutting is seldom an option on NF lands. These shade-intolerant species are very important to wildlife and the forest industry. Many wildlife species also require tree height or crown structure diversity.

Oak species are essential to several species of wildlife and are very important to the forest industry. Frequently, light cutting on mesic sites does not regenerate oak species; with heavy cutting, the oak regeneration cannot compete with intolerant species. Preliminary research indicates that removing the understory without creating canopy openings may be the key to regenerating oaks on mesic sites. Relying on commercial harvesting operations to remove the understory would pose a significant challenge for harvesting and utilization research. Timber stands with an oak component are also threatened by gypsy moth defoliation. Silvicultural treatments are needed to reduce susceptibility of these stands to defoliation and their vulnerability to mortality.

Residual stand damage resulting from intermediate partial cuts that may occur over longer rotations will need to be minimized. Several partial cuts also increase the likelihood that logging damage will result in significant losses to decay and reduction in quality. Cable yarding on steep slopes creates an additional challenge to moderating residual stand damage.

Alternative Silvicultural Treatments

Innovative silvicultural systems or treatments required to implement ecosystem management and address forest health issues include two-age management, crop tree release, and thinning to reduce the susceptibility and vulnerabillity of stands threatened by gypsy moth defoliation. These treatments and systems were identified in meetings with managers on the Monongahela NF.

Two-age management can regenerate intolerant tree species without the adverse impact on esthetic (visual) quality associated with clearcutting (Smith and others 1989). Two-age harvest cuts conducted thus far have left 20 to 30 ft^2 (1.9 to 2.8 m^2) of basal area in sawtimber-size trees. Even though two-age management is now being implemented, information is lacking on the effects of pretreatment stand and residual tree characteristics on residual stand growth, quality, and vigor. We also need to determine the effect of site quality and the composition, density, and crown expansion of the residual overstory on the subsequent species composition and quality of reproduction. Future wood utilization options will be determined by the growth and quality of residual trees and the species composition of the regeneration. Research is being planned to address these issues.

Crop tree release is thinning that provides crown release for designated crop trees (Perkey and others 1994). With lengthening rotations and increasing reliance on intermediate cuts, crop tree release can become an important management tool. Crop tree release can also be applied to the management of non-timber resources. For example, selecting desired mast-bearing species for release can improve wildlife habitat. Unlike a two-aged cut, which is primarily a regeneration tool applied to mature stands, crop tree release can be applied to a much wider range of stand conditions—from poletimber to large-diameter sawtimber stands.

Presalvage thinnings or sanitation thinnings can be used to treat immature timber stands at risk from gypsy moth attacks. Presalvage thinnings remove vulnerable trees and increase the vigor of residual trees. Sanitation thinnings eliminate trees that are prospective targets of infestation (Gottschalk 1993). Since stands with a heavy oak component are the most susceptible to gypsy moth and are important to wildlife, maintaining a viable oak component is very important.

Alternative Forest Operations

One objective of research on harvesting will be to obtain information required to model harvesting

system production and to estimate harvesting costs as a function of cut stand attributes and wood utilization options. These cost estimates are needed for economic analysis of treatment/harvesting/utilization alternatives. Harvesting systems will include conventional ground-based systems employing rubber-tired skidders and skyline yarding. Cut stand attributes will be determined by initial stand conditions and the prescribed silvicultural treatments. For two-age cuts, which remove larger volumes and larger trees, research will focus on the relationship between wood utilization limitations (minimum merchantable tree dbh and minimum stem dib) and harvesting costs. For thinnings and crop tree release, which remove smaller trees, research will focus on the relationship between cut stand attributes and harvesting costs.

Research will also consider the environmental impact of harvesting operations, including soil disturbance, visual quality, and residual stand damage. Skyline yarding has generally been limited to large clearcut units, and there is concern about residual stand damage when this technology is applied to the partial cuts now required on NF lands. Skyline yarding is also expected to increase harvesting costs, which could limit applications when low-value stands are to be treated.

Research plans include a study of cable yarding and ground-based skidding on a timber sale that includes two-age cuts, crop tree release cuts, and thinnings in stands threatened by the gypsy moth. Variables of interest include production rates, cost, stand damage, soil disturbance, and effects of soil disturbance on revegetation and regeneration. A study has been completed on thinnings of cable yarding, two-age cuts, and shelterwood cuts. This case study was conducted in cooperation with national forests in North Carolina to assess the cost, production, and environmental impact of cable yarding partial cuts (Baumgras and LeDoux 1995). Results indicate that light thinnings and shelterwood cuts removing only 30 percent of basal area produce very little net revenue. Heavy thinnings, two-age cuts, and shelterwood cuts removing more than 50 percent of basal area all showed excellent economic returns. The two-age and shelterwood cuts destroyed or heavily damaged 30 percent of the residual basal area, indicating that residual stand damage can be a serious

concern when cable yarding technology is applied to partial cuts in Appalachian hardwoods.

Alternative Wood Products

Research will identify types of primary products that can be harvested from specific treatments and develop methods of estimating product yields from the cut stand attributes. This information is essential for estimating the marketability of wood harvested, identifying methods of allocating roundwood to the most valuable end-uses, and determining the extent to which new products or processes could expand the merchantability of wood products available from ecosystem management activities or forest health treatments.

Research is underway to estimate potential roundwood product yields, given tree attributes (such as species, diameter, total and merchantable heights) and bole quality attributes. This information will be used to develop equations required to estimate potential product yields from tree attributes for a wide array of products—factory-grade logs, local use logs, sawbolts or pallet bolts, LVL, oriented strandboard, rails, posts, pulpwood, and fuelwood. Research is also planned to validate the product yield models, measuring actual product yields from harvested trees.

A cooperative study between the FPL and the Northeastern Station will evaluate using longitudinal stress-wave techniques to relate log properties to veneer properties. These techniques have been used to sort veneer into "grades" for commercial production of LVL. Traditionally, LVL has been produced using only Southern Pine and Douglas-fir. Recently, however, Trus Joist MacMillian has begun production of LVL using yellow-poplar, and there is interest in the potential for using other species as well. If successful, this log testing approach could help foster the use of smaller diameter logs of underutilized Appalachian species for higher valued LVL lumber. Initial studies will probably focus on yellow-poplar and red maple.

Evaluation of Economic Feasibility

Research will be aimed at determining how the economic feasibility of a silvicultural treatment and

associated harvesting operations is affected by alternative market conditions for products. For specific sets of harvesting and marketing conditions (defined by a set of cut stand attributes, potential product yields, markets, and prices), economic feasibility will be determined by deducting harvesting and transportation costs from the value of wood delivered to mills (value of processed wood minus conversion costs). Additional research will also establish values and conversion costs for the production of lumber, veneer, oriented strandboard, and LVL, given tree species, log quality, and log dimensions. The results will link future stand conditions to the value of the available roundwood.

Because many variables in the economic analyses cannot be estimated with precision, sensitivity analyses will be conducted to determine the effects of markets on net revenue from specific management activities. These results will indicate combinations of price levels, market locations, and initial stand attributes required to implement specific ecosystem management activities.

CONCLUSION

We expect that the combined efforts of a multidisciplinary group of researchers and forest managers will increase the likelihood of finding viable and economical wood utilization options for improving forest health. By coordinating and evaluating research on several specific ecosystem conditions, we can identify common elements of solutions that may be applied to a wider range of ecosystem conditions. Future work under consideration includes expanding outreach efforts to communicate results to forest managers, studying additional ecosystem conditions, and expanding our capability to evaluate various species and qualities of wood for composite panel products.

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The Applegate Adaptive Management Area Ecosystem Health Assessment

Thomas Atzet[1]

Abstract.—As requested by the Applegate Partnership, the Medford District Bureau of Land Management, the Rogue River and Siskiyou National Forests, a team of six specialists (Dr. Tom Atzet, USFS ecologist, Dr. Mike Amaranthus, PNW soil scientist, Dr. Don Goheen, USFS pathologist and entomologist, Tom Sensenig, BLM silviculturist, Dr. Dave Perry, Oregon State University conservation biologist and Dr. Kevin Preister, Rogue Institute of Ecology and Economy, social anthropologist, Sue Rolle and Dr. Diane White coordinated the effort and edited the manuscript respectively) were given two weeks to assess ecosystem health of the Applegate Adaptive Management Area using existing information. The assessment sets context for provincial scale processes and *watershed analysis*. It includes historic, current and future desired ranges of conditions, research and monitoring strategies, findings and recommendations. The assessment integrates goals and objectives of the Applegate Partnership, the President's Plan and Record of Decision, the Regional Ecological Assessment Report and forest and district land use planning documents. The team found stand densities two to three times historic levels, high tree mortality rates, increasing insect and disease populations, and increasing fire hazard. This extractive report features recommendations.

INTRODUCTION

Most people were fed up. Eight years of drought brought forest health problems and frustration to a head. Insect populations, taking advantage of drought weakened trees, were increasing. Tree mortality was evident throughout the valley and spreading into the higher elevation forests. Fuels loads were accumulating, recent fires seemed to be more severe, the number of houses burned in the urban-forest interface was increasing, and public concern for safety was growing. Mills were closing, county timber receipts were decreasing, and the secondary social and economic effects were being felt throughout southwest Oregon.

The "preservation versus use" debate was becoming more polarized. Proposed actions generated law suits, were appealed, or protested. Extreme positions, consistently reported in the media, provided little new information nor contributed toward establishing common goals or solutions. Although continued debate benefited some special interest groups, it did little to provide for ecosystem health. (Here I define ecosystem health as including human effects *and* needs).

A Society of American Foresters meeting (Spring 1992) billed as an opportunity to hear both side's viewpoint, provided an unforeseen opportunity for cooperation. Jack Shipley of Headwaters and Greg Miller of the Southern Oregon Timber Industry Alliance, who quietly listened to one another before their presentations, found their vision for the Applegate ecosystem (biologically, economically, and socially) was surprisingly similar. They decided to emphasis their common goals, and combine resources to find solutions. Their discussions were the seed for the Applegate Partnership that grew into a diverse collection or citizens working together for ecosystem health.

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Today the Partnership continues to work toward common goals, build understanding and cooperation, provide the public with information and educational opportunities, and develop local solutions for ecosystem health problems. Over five projects have been planned; one has been completed. However, lawsuits, appeals, demonstrations, and protests still delay implementation of projects and obscure focus, as overall forest and ecosystem health continues to decline.

OBJECTIVES

The team's objectives were to provide a first approximation *ecological assessment of ecosystem health* within the Applegate Adaptive Management Area (AMA) and *develop a general strategy for restoring and maintaining ecosystem health*. According to the President's plan, (formally called the Pacific Northwest Forest Plan) the objectives for an AMA are: "Development and testing of forest management practices, including partial cutting, prescribed burning, and low impact approaches to forest harvest (e.g. aerial systems) that provide for a broad range of forest values, including late-successional forest and high quality riparian habitat." Recommended strategies and projects are consistent with the President's Plan.

DEFINITIONS

Each team member's definition of ecosystem health varied. Human needs and effects were the focus. While humans undeniably affect nature, there is no basis for requiring that ecosystems provide for human needs to be healthy. On the other hand, healthy ecosystems are the foundation for long-term economic health. Although we felt social and economic factors should be part of the definition, we emphasized the biological. (It is important to understand that insects, disease, wildfire, and mortality are all natural processes, and are not, in themselves, indicative of health problems. However, when population numbers, intensity of fire, or rates of mortality increase significantly, the effects are often perceived as "catastrophic" or socially negative.) Healthy ecosystems are often defined as being *diverse*, *resistant* to catastrophic change, *resilient* or quick to recover, and *productive*. However universal, these terms are vague, and need precise definitions to be *measurable*, a criterion necessary for evaluation and monitoring.

The team chose to evaluate the *amount and distribution of seral stages*, including those effected by humans, the *level and trends of beetle caused mortality*, the *vigor or growth rates of stands* using basal area, and the *risk or probability of "catastrophic" change*, as measurable indicators of forest health. These variables are only part of a full health evaluation profile, but the information was readily available. Preister used age diversity, population change, land use patterns, private land logging, absentee ownership, work routines, employment mix, wage structure, poverty level unemployment level, balance of timber harvesting methods, rate of locally-awarded federal agency contracts, Value-added incentives to timber sales, capital access and economic multipliers for evaluating and monitoring social and economic health. However, in our assessment Kevin points out: "*This process incorporates indicators to monitor the social and economic well-being of the resident culture in the Applegate area. It is somewhat confounded by scale; for example wood extracted from the Applegate watershed density management projects may provide local economic benefits such as milling and manufacturing employment, but may not necessarily be limited to the residents of the Applegate valley. Methods of dealing with these problems need to be explored and tested.*"

THE PROVINCIAL SETTING

Klamath Geological Province

The Applegate AMA is within the Klamath Geological Province (one of the most floristicly diverse areas in the United States) which straddles the Oregon-California border extending from Redding, California to Tiller, Oregon on the east edge, and from Eureka, California to Bandon, Oregon on the Coastal edge. It joins the Cascade Range with the Sierra Nevada Range on the east and the Oregon and California coast ranges on the west. This "H" configuration provides for both north-south and east-west migratory travel. The Province includes two major river basins: the Rogue and Klamath Basins. Both cut through the

Klamath Mountains to the Pacific Ocean, are important anadromous streams, provide water needs for many species, including humans, and are renowned for their recreational values. The Province has been and continues to be a sink and source for genetic diversity and main migratory pathway for the Pacific Northwest.

The Rogue River Basin

Key aquatic and riparian species are: chinook and coho salmon, rainbow and cutthroat trout, fur-bearing animals, and other wetland-dependent species of birds and amphibians. Declines in fish populations characterize the area. Chinook salmon are particularly dependent on low gradient segments where spawning gravels are abundant. Where this habitat has been altered, these species tend to inhabit less productive upstream reaches on National Forest or BLM land. Elevated summer stream temperatures, simplified habitat, and water withdrawals have rendered much of the low gradient habitat unusable by salmonids and other aquatic and riparian species.

Past fire regimes were dominated by frequent, low intensity fires. Consequently, forests were widely-spaced, with early seral tree species, such as Douglas-fir, Ponderosa pine and sugar pine with light understory shrub cover (fig. 1). The landscape

mosaic included few areas of dense stands and late seral species. With fire suppression stand basal areas increased to two to three times greater than the site can maintain in a healthy, insect resistant state. Today the AMA has high insect populations, with at least nine species of bark beetles and wood borers, resulting in insignificant tree mortality. White pine blister rust, dwarf mistletoes, and root diseases are also significantly affecting forest health.

The AMA supports at least 60 rare or threatened plant species. Seventeen have been identified as at risk of disappearing due to the spread of non-native species, fire suppression, and other causes. Several threatened, endangered, or protected animal species also occur, including the peregrine falcon and spotted owl. Other species, such as the Siskiyou salamander and Townsend's big-earred bat, occur in the AMA at least partially because of the presence of unique habitats.

Major social and economic changes have affected the basin in the last thirty years. Among them:

- Strong population influx and residential development;
- Dispersed settlement patterns have created widespread urban-forest interface;
- In-migration of retired people who are changing community character;
- Influx of young, educated ex-urbanites with strong environmental values and community interest;
- Shrinking of the traditional economic base (ranching, farming and timber employment);
- Strong representation and economic contribution of "lone eagles" and "global entrepreneurs" with few ties to the local economy;
- Weakening ties to the land for economic contributions and reliance on commuting to urban employment sites;
- Newcomers are less integrated in and less knowledgeable about the ecosystem and community
- An increase in a wide-range of recreation activities on public lands, creating endemic conflict between users and management challenges of incorporating different interests.
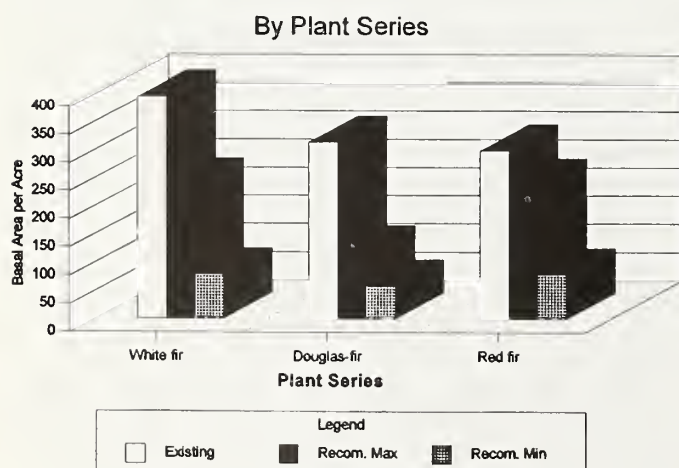

Figure 1.—Existing and recommended basal area.

RECOMMENDATIONS

Provincial Scale

- Provide suitable, *connected, dispersal and migration habitat* associated with Late Seral Reserves, Riparian Areas, and other "protected" land designations.
- Establish and maintain a *mix of quality habitats* for indigenous species. Quality habitat provides food and shelter, is relatively stable against catastrophic disturbance, and is secure against excessive predation.
- Identify, protect or restore special and rare habitats such as wetlands, meadows, etc.
- Encourage the development of value-added industry that uses small wood, and inexpensive approaches to aerial lift. Assist communities in securing low interest loans.

Landscape Scale

- *Burn* (Reintroduce fire, limit the proportion of high severity fire by plant series).
- *Grow* forested landscapes dominated by larger, older trees, particularly shade intolerant species such as Ponderosa pine, sugar pine and Douglas-fir.
- *Blend* seral stages across the landscape over time. Riparian zones, northerly aspects and various plant associations can carry more late seral habitat longer.
- Avoid building new roads.
- Secure money for preventive measures.

Implementation. Identify landscapes with the highest priority for restoration activities. These include: the forest-urban interface; forests rated at highest risk of catastrophic loss to insects and/or fire; high risk forests bordering special habitats (treatment should not compromise habitat); and high risk forests in accessible areas. *Prevention and/or maintenance* cost less than restoration and should be given preference where other considerations are equal. Density management in riparian zones should be conducted to preserve or enhance the unique functional roles (e.g. shading, stabilizing banks, providing large dead wood for in-stream structure).

Money is available for correction or restoration after catastrophic fire or epidemics. But securing funding for prevention (a less costly and more effective strategy) is difficult. Awareness of potential savings in fire suppression and pest suppression funds is increasing. In 1994, for example, on the Applegate District, 31 lightning fires burned 175 acres. Nine hundred and eighty four thousand dollars ($984,000) were spent on suppression (over $5600 per acre).

Stand Scale

- Use density treatments that emulate historic disturbance intensity, frequency and extent as a reference point, if specific desired condition or acceptable ranges are not known.
- Integrate with other disciplines, particularly wildlife biologists, for structural needs.
- Thin from below so that mean diameter of the residual trees exceeds mean tree diameter prior to treatment.
- Reduce density to below 120 square feet of basal area per acre (Insect threshold). A higher upper threshold of 140 square feet per acre is suggested for riparian areas.

Implementation. Space pine leave-trees to avoid the likelihood of beetle infestation. Clear all small trees and shrubs from within the drip line. Do not leave pines, especially large pines, in clumps unless they are slated to serve as replacement snags. Some large trees must be removed if the pine component is to be beetle-resistant. Historic pine stands with large tree components had few trees per acre. Densities should be maintained well below the insect susceptibility thresholds for the plant association (general levels given above). Leave trees in order of preference for the Douglas-fir and White fir Series include: Pines, incense cedar, Douglas-fir, and true firs.

Species Scale

- Spotted owls. Forests that currently serve as nesting habitat should not be harvested. The ROD provides specific direction for protection of mapped and unmapped late successional reserves. Some late successional reserve areas

may be extremely vulnerable to loss by wildfire, insects, or disease. Consider an extremely low intensity treatment aimed solely at removing understory fire ladders. In this case, underburning may be preferable to thinning, depending on fuel conditions.

- Goshawks. Goshawk nest sites should be identified within any project area, and the core nest and needed habitat protected based on the wildlife biologist's recommendations.
- Salamanders. Salamanders require special habitat; most do not have lungs, therefore must have moist environments that allow breathing through the skin. Of particular concern is the Siskiyou Mountains Salamander, which occurs only in Jackson, Josephine, and Siskiyou counties; eighty percent of the population is within the Applegate basin. We are uncertain what management these species can tolerate.
- Other species of particular concern are the great gray owl, fisher, lady slipper, and neotropical migrant birds, especially the bandtailed pigeon (a candidate for listing under the ESA). Neotropical migrants and fishers require a hardwood component across the landscape. Bandtailed pigeon numbers may be related to the abundance of dewberry.

- White pine blister rust, dwarf mistletoes, and root diseases (the two most common are Armillaria root disease, caused by *Armillaria ostoyae*, and annosus root disease, caused by *Heterobasidion annosum* S-strain). Pathogens play integral ecosystem roles and effects on tree populations tend to be gradual. Both thinning and burning can help keep populations at endemic levels.
- Bark beetles and wood borers. Bark beetle and wood borer populations are somewhat density dependent and tend to remain at endemic levels in low density, healthy stands.

MONITORING

- Encourage stand-level research, particularly spacing required by large trees.
- Design treatments to simplify subsequent monitoring.
- Implement a monitoring program as part of each prescription.
- Use information gained from early stand treatments to improve future prescriptions.
- Use treated stands as demonstration areas.
- Take all opportunities to use results for educational purposes.

Effects of Thinnings on Growth and Yield in Natural *Pinus Arizonica* and *Pinus Durangensis* Stands in the El Largo-Madera Region in Chihuahua State

Oscar Estrada Murrieta,[1] Luis A. Domínguez Pereda,[2] and Marcelo Zepeda Bautista[3]

Abstract.—This paper presents the result of the first dasometric analysis made with the data of some permanent thinning plots established at different times since 1964 in the Unit of Conservation and Forest Development #2 in Chihuahua State, Mexico. The results show the benefits of thinnings on the growth rates of residual stands, the increment's redistribution, and the potential mortality.

INTRODUCTION

The need to know the dynamics of the forest through time, the direct and indirect impacts of humans, and natural disturbance agents has moved many foresters all over the world to establish and periodically measure different kinds of plots, which we call "permanent sites or plots."

In Mexico, interest in following the steps of forest growth moved the technical staff of the Unit of Conservation and Forest Development (UCODEFO)#2 "El Largo-Madera" to establish several permanent plots since 1964 in this Unit.

The plots were named, according to their objectives, "observation," "demonstrative," and "experimental."

Some of these plots can be criticized from the statistic point of view. However, they are practical in representing some silvicultural conditions of the "El Largo-Madera" region, and they have a historic

value because they are the only ones of their kind in the UCODEFO #2 region that have been measured many times. To avoid confusion in this paper, we call all the plots "Parcelas Permanentes de Observación Silvícola" (PPOS).

Each PPOS's group is representative of a specific silvicultural condition of all that exists in the area. That's why the analysis is so useful. It enables us to know more about the growing dynamic of the presented conditions and, of course, to back up management decisions for similar areas.

This paper presents the results of basic dasometric analysis of the PPOS.

DESCRIPTION OF THE AREA

The area of the UCODEFO #2 is located in the Northwest part of Chihuahua State, between the meridians 108° 5' and 108° 45' to the west of Greenwich's Meridian, and between the parallels 28° 45' and 30° 00' of North Latitude (fig. 1).

The UCODEFO #2 is situated in the "Sierra Madre Occidental" and it is mainly forestry land. It is shaped of ravines and large mesetas and the altitude is between 5,900 and 9,400 feet. There are many streams and rivers. Although all the rivers

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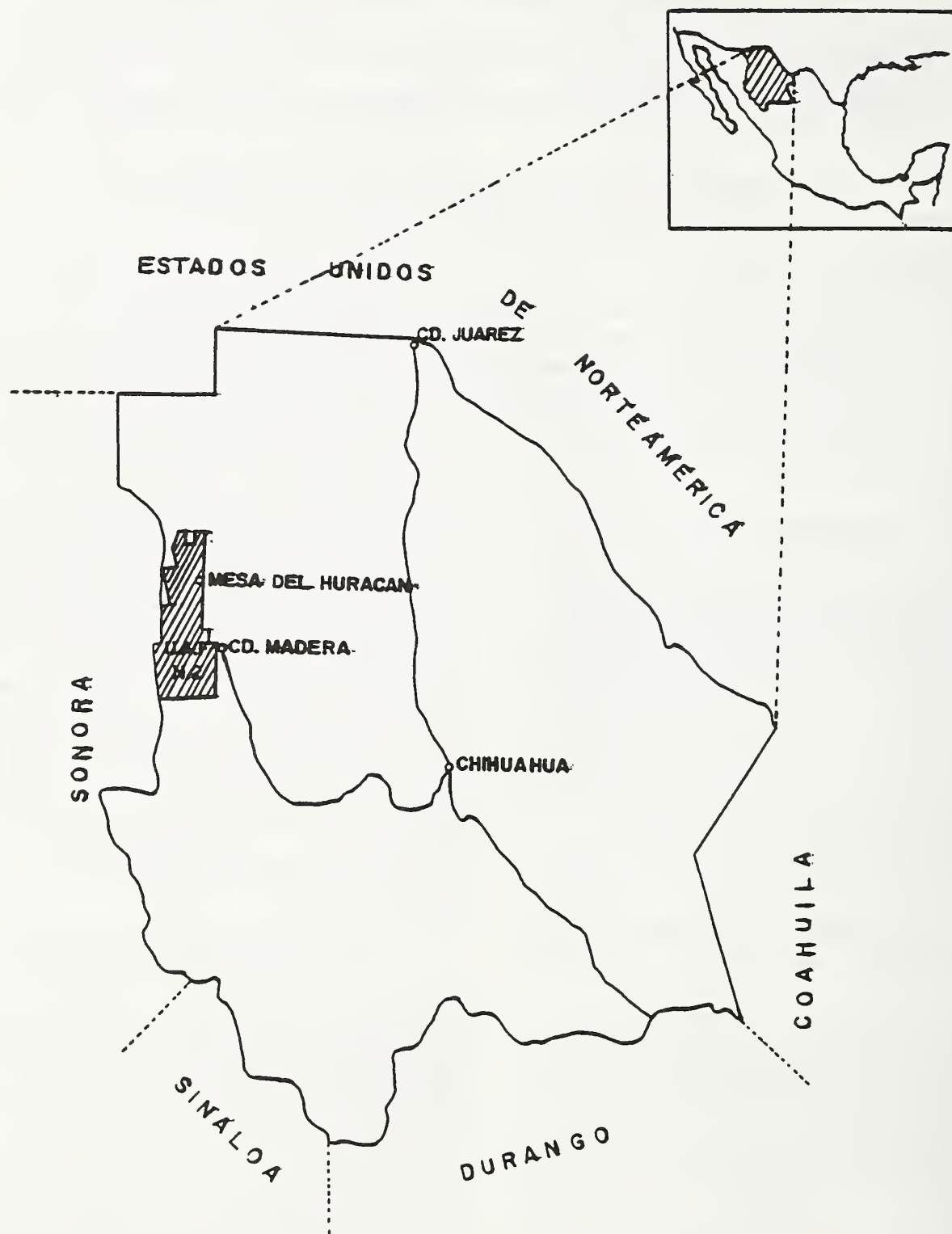[3]*Profesor Investigador. Universidad Autónoma de Chapingo. Chapingo, México.*

Figure 1.—Ulicación del área de estudio.

are permanent, they transport very little water in the dry season, mostly in the upper part of the watersheds.

The soils are volcanic, brown, red, gray, and combinations of these. Depth is from 0 to 65 inches and the average is 18 inches. Predominant materials are rocks and flat stones. The texture is clay, clay-sandy.

The maximum average temperature is 50.7° F and the minimum average is 35.6° F. The coldest months are January and February. Freezes are normal beginning in October. The average number of freeze days is 152 and the average amount of rain during a year is 32 inches. The summer rainy season begins in late June to late September, and the winter rainy season is from late November to March.

FOREST CHARACTERISTICS

The forests are composed mostly of pure or almost pure even-aged natural stands. The main tree species are *Pinus arizonica*, *Pinus durangensis*, and *Pinus engelmannii*. The structure presents two height classes. The higher is from the original forest and the lower is composed of second-growth forest, growing in high densities.

Such density indicates the need to manage those forests under a thinnings regime. This creates the need to have permanent plots to test several silvicultural treatments to know the effects of those treatments on the residual stands. Table 1 shows some control data of PPOS.

CAPTURE AND DEPURATION OF DATA

The dasometric data of the PPOS, gathered at different times, were captured in a magnetic device using a data base program. The data were captured in an easy way in 20 small data bases as follows:

Observation plots: 5 files (PARCO? .DTS)
Demostrative plots: 5 files (PARCD?. DTS
Experimental plots: 10 files (PARCE?. DTS)
    Total: 20 files.

The symbol "?" correspond to a "substitute," i.e., a variable that takes in each case its value to the plot number. Once all the data were captured, we compared it and corrected it until the database was depurated.

STATISTICAL ANALYSIS

This was to get the average, variation, and totals, DBH, total height, number of trees, basal area, and volume by area unit. We also sought to graphically display the behavior of each variable over time. To do that, we preparee the computer programs, some on SAS language and other on turbo-pascal.

SUMMARY AND CONCLUSIONS

The question that always comes up in managing forest resources for timber objectives, What is the effect of thinnings over time on production and yield of the forest? As shown in the attached charts, we can see the historic behavior of the four growth forms (diameter, height, basal area, and volume) for some of the PPOS in this analysis. Included are the responses to intermediate cuts and the effect of these on accumulated growth for each of the four forms.

Table 1.—Characteristics of three permanent plots.

Plot	Type	Square feet	Date	Age * (years)	Species (pines)
1	O	4,300	April '64	20	*arizonica*
					durangensis
2	O	4,300	April '64	18	*arizonica*
3	O	4,300	April '64	16	*arizonica*
4	O	4,300	April '64	16	*arizonica*
5	O	4,300	April '64	16	*arizonica*
1	D	53,820	April '78	27	*arizónica*
2	D	53,820	April '79	24	*durangensis*
3	D	53,820	April '80	31	*durangensis*
4	D	53,820	April '79	26	*durangensis*
5	D	53,820	April '80	26	*arizónica*
1	E	6,730	April '70	25	*durangensis*
2	E	6,730	April '70	25	*durangensis*
3	E	6,730	April '70	25	*durangensis*
4	E	6,730	April '70	25	*durangensis*
5	E	6,730	April '70	25	*durangensis*
7	E	6,730	Sept. '70	25	*durangensis*
8	E	6,730	Sept. '70	25	*durangensis*
9	E	6,730	Sept. '70	25	*durangensis*
10	E	6,730	Sept. '70	25	*durangensis*
C	E	6,730	Sept. '70	25	*durangensis*

Average age at the time of first measurement. C=Control; O=Observation; D=Demonstrative; E=Experimental.

We deduce from the charts that basal area and volume are very high in all the plots. Stands at "El Largo-Madera" region have responded rapidly to intermediate cuts, and once they have recuperated from the thinning "shock," they inmediately close their crowns.

Thinning "shock" appears to pass at "El Largo-Madera" region in similar stands to those presented by the PPOS in a period of five years if they are cut at similar intensity to the PPOS. We can also speculate that these stands can resist higher cuts than those made in these plots. We know that the drastic cuts made initially were not so drastic, but in other ways they would assimilate faster cuts.

Even the density as the volume increases is very high in the three groups of plots compared with those presented in the rest of Chihuahua State's Forests. These results are good only for the conditions they represent.

In non-thinned stands, mortality is normally higher than in thinned stands, and it is possible that it is higher than if the stands were reduced in volume through incremental thinning. It is pre-sumed that thinnings can increase the final yield of stands but not their total volume production.

Finally, it is very important to establish permanent plots to know the dynamics of the different forests. They can show more than just measurements; they can also show the behavior of individual trees. The plots described in this paper can be used as a live example from which we can get the experience to make the best management decisions for forestry technicians and landowners.

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EXPERIMENTAL PLOT NUMBER 1

Date	Number of trees/acre	D.B.H. in	Height ft.	Basal Area Sq. Ft./acre	Volume Cu. Ft./acre	Vol. Cut Cu. Ft./acre	Vol. Inst. Inc. Cu. Ft./acre/year
1970	350	3.46	16.89	24.36	299.08	976.61	
1975	311	5.07	20.13	45.35	636.39		67.48
1982 B.C.*	291	7.16	27.51	92.80	1,790.93	282.85	164.93
1982 A.C.**	277	7.83	28.83	77.31	1,508.00		
1985	227	8.54	33.81	91.52	2,088.24		193.41
1990 B.C.	227	10.00	37.78	128.26	3,256.57	823.40	233.66
1990 A.C.	149	10.59	38.27	94.70	2,433.17		

*Before cut

**After cut

EXPERIMENTAL PLOT NUMBER 4

Date	Number of trees/acre	D.B.H. in	Height ft.	Basal Area Sq. Ft./acre	Volume Cu. Ft./acre	Vol. Cut Cu. Ft./acre	Vol. Inst. Inc. Cu. Ft./acre/year
1970	214	4.84	21.02	29.96	468.99	341.39	
1975	207	6.65	25.68	53.20	279.19		102.03
1982 B.C.*	201	8.50	33.81	99.52	2,456.33	130.79	211.01
1982 A.C.**	181	9.56	36.08	93.46	2,325.48		
1985	181	10.11	39.22	114.02	3,092.40		255.64
1990 B.C.	181	11.45	49.65	134.09	4,561.78	1,268.38	293.87
1990 A.C.	130	11.53	49.92	96.94	3,293.40		

*Before cut

**After cut

EXPERIMENTAL PLOT NUMBER 7

Date	Number of trees/acre	D.B.H. In	Height ft.	Basal Area Sq. Ft./acre	Volume Cu. Ft./acre	Vol. Cut Cu. Ft./acre	Vol. Inst. Inc. Cu. Ft./acre/year
1970	648	5.07	25.09	95.87	1,650.91	299.31	
1975	589	6.06	30.01	123.64	2,537.62		177.34
1982 B.C.*	576	7.00	37.06	167.44	4,287.61	1,371.73	249.99
1982 A.C.**	343	7.59	37.65	113.16	2,915.88		
1985	337	8.18	43.88	127.95	3,810.91		298.34
1990 B.C.	337	9.25	48.31	163.37	5,370.64	1,086.59	311.95
1990 A.C.	246	9.64	48.87	128.87	4,284.06		

*Before cut
**After cut

EXPERIMENTAL PLOT NUMBER 9

Date	Number of trees/acre	D.B.H. in	Height ft.	Basal Area Sq. Ft./acre	Volume Cu. Ft./acre	Vol. Cut Cu. Ft./acre	Vol. Inst. Inc. Cu. Ft./acre/year
1970	686	3.89	19.94	62.54	914.64	12.80	
1975	680	4.76	23.41	93.78	1,595.83		136.23
1982 B.C.*	680	5.74	30.73	143.43	3,044.84	743.60	206.99
1982 A.C.**	414	6.45	31.52	101.89	2,300.89		
1985	401	6.96	37.35	102.22	3,066.91		255.22
1990 B.C.	401	7.83	42.41	146.16	4,373.68	728.74	261.35
1990 A.C.	291	8.38	43.16	120.11	3,644.93		

*Before cut
**After cut

EXPERIMENTAL CONTROL PLOT

Date	Number of trees/acre	D.B.H. in	Height ft.	Basal Area Sq. Ft./acre	Volume Cu. Ft./acre	Vol. Cut Cu. Ft./acre	Vol. Inst. Inc. Cu. Ft./acre/year
1970	2,383	2.55	17.51	120.31	1,910.93		
1975	2,007	3.18	21.58	152.50	2,880.48		193.90
1982 B.C.*	1,567	4.09	27.32	184.95	4,165.55		183.87
1982 A.C.**							
1985	1,302	4.64	32.27	191.56	5,044.71		292.38
1990 B.C.	919	5.66	39.16	194.54	5,921.65		175.38
1990 A.C.							

*Before cut
**After cut

Role of Silviculture

Two-Age Silviculture—An Innovative Tool for Enhancing Species Diversity and Vertical Structure in Appalachian Hardwoods

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Abstract.—Silvicultural practices that promote a two-age stand structure provide an opportunity to maintain diversity of woody species and vertical structure for extended periods of time in Appalachian hardwoods. Data from four two-age stands initiated by deferment cutting in West Virginia are summarized for the first 10 to 15 years after treatment. Results indicated that 15 commercial hardwood species regenerated successfully and that height growth of the new cohort provides a predictable change in vertical structure over time. Growth, quality, and vigor of residual trees after treatment varied by species and initial condition. Diversity in vertical structure seems to improve habitat suitability for some wildlife species. Songbird counts were compared for 2 consecutive years, beginning at least 10 years after treatment, in even-age and two-age stands. For two-age stands, songbird density estimates were higher in both study years, whereas nesting survival was lower the first year compared to that in even-age stands. Preliminary implications of two-age regeneration methods for meeting forest health objectives and future research needs are discussed.

INTRODUCTION

Increased emphasis on managing forest ecosystems to maintain forest health and to produce multiple benefits calls for innovative silvicultural practices. For example, clearcutting in the Appalachians promotes reproduction of both shade-tolerant and shade-intolerant commercial hardwoods and attracts a diversity of wildlife species, including songbirds. However, clearcutting continues to draw public criticism for perceived negative impacts on aesthetics. Two-age reproduction methods have been proposed and applied as a viable alternative to clearcutting, but forest managers need key information to fully evaluate the

impact of such practices on forest health. How do residual trees develop? What is the composition and quality of reproduction? What is the impact of a two-age stand structure on other forest ecosystem components such as songbirds?

The application of two-age regeneration methods to manage eastern hardwoods for multiple benefits is growing rapidly. From 1979 to 1983, deferment cutting was applied in mature hardwood stands on the Monongahela National Forest and Fernow Experimental Forest in West Virginia to study the effects of two-age stand structures on residual tree development and natural regeneration. Silvicultural systems that promote a two-age stand structure have since been initiated on other national forests, state forests, industrial forests, and to a lesser degree on nonindustrial private forests in many eastern states. Two-age methods were used to achieve two management goals: 1) to regenerate a variety of hardwood species, particularly those that are shade-intolerant, and 2) to

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mitigate the perceived negative visual impacts of clearcutting.

Immediately after logging, two-age stands resemble those following a seed-tree cut (figure 1). Such practices leave 15 to 20 codominant residual trees/acre, and perhaps some flowering shrubs, mast trees, and den trees for aesthetics and wildlife; and all other stems are cut. Residual basal area averages 20 to 30 ft^2/acre, depending on stand age and site quality. By contrast to seed-tree methods, residual trees in two-age stands are retained for many years, perhaps as long as a typical even-age rotation. In the central Appalachians, forest managers usually plan to apply two-age regeneration methods every 40 to 80 years.

Similar to natural regeneration in clearcut stands, natural regeneration resulting from two-age regeneration methods includes a variety of both shade-tolerant and shade-intolerant commercial hardwoods (Miller and Schuler 1995). Unlike clearcutting, however, the presence of residual overstory trees in the two-age stands improves aesthetics (Pings and Hollenhorst 1993) and maintains a more diverse vertical stand structure that may benefit certain wildlife species. As the new cohort of seedlings develops beneath the large overstory residuals, the stand exhibits two distinct height strata. These strata provide a diverse habitat and provide for songbirds that forage in high-canopy trees (Wood and Nichols 1995), as well as those that require a brushy cover characteristic of a young even-age stand (DeGraaf and others 1991).

This report summarizes three aspects of stand development 10 years after two-age regeneration

Figure 1.—A two-age central Appalachian hardwood stand 5 years after a regeneration harvest; residual trees are 85 years old.

harvests were applied in four central Appalachian hardwood stands: 1) growth, quality, and vigor of residual overstory trees, 2) composition, distribution, and quality of natural reproduction, and 3) species richness, density estimates, and nest survival of songbirds in the study areas. The implications of two-age regeneration methods for meeting forest health objectives are discussed. Finally, research needed to refine two-age methods as a useful silvicultural tool for enhancing forest health is suggested.

STUDY AREAS

Study areas are located in north-central West Virginia. The topography consists of low valleys dissected by northeast-southwest ridges. Elevations range from 1,800 to 3,600 feet above sea level. In general, soils are medium textured and well drained, derived from sandstone shale with occasional limestone influence. The average soil depth exceeds 3 feet. Annual precipitation averages 59 inches and is well distributed throughout the year. The growing season averages 145 frost-free days.

The initial stands were unmanaged second-growth Appalachian hardwoods with an average age of 75 years that became established after heavy logging in the early 1900's. Periodic fire was common throughout the local area as the stands became established. Chestnut blight also killed some large trees during the 1930's and resulted in some patchy reproduction before and during World War II. Forest types included cove hardwoods, Allegheny hardwoods, and oak-hickory. Stand size ranged from 10 to 15 acres for the two-age treatments and from 10 to 28 acres for the clearcuts used to study songbirds.

METHODS

Deferment cutting, a two-age regeneration method, was applied in four central Appalachian hardwood stands by retaining 12 to 15 codominant trees per acre and cutting all other stems 1.0 inch diameter breast height (d.b.h.) and larger (Smith and Miller 1991). Sawtimber trees were skidded tree-length in three stands using a wheeled skidder and in one stand using a truck-crane cable system.

All other cut trees were left on the site. Each harvest operation was completed by a three-person logging crew, instructed to take special care to avoid damage to the few residual trees.

Residual trees were marked to achieve an average residual stocking of 20 ft^2/acre. In general, trees with the greatest potential value as high-quality sawtimber and veneer products were chosen using the following criteria:

- Species—northern red oak, black cherry, yellow-poplar
- Crown class—dominant or codominant
- Vigor—no evidence of epicormic branches or other sign of stress
- Risk—no disease, low forks, shallow roots, or other risk factors
- Quality—current or potential high-quality butt log
- Spacing—residual trees well distributed throughout the stand

Data for residual trees and reproduction surveys were recorded before and after treatment, followed by remeasurements 2, 5, and 10 years later. Species, d.b.h., crown class, crown width, total height, merchantable height (to the nearest 8-foot half log), butt-log grade, and number of epicormic branches were recorded for each residual tree. Live epicormic branches at least 1 foot long were counted by 8-foot bole sections to the top of the second 16-foot log. Residual trees also were examined to assess logging damage, and the length and width of sapwood wounds were recorded.

Tree reproduction data were obtained from 172 permanent sample points located along systematic grids in each stand. At each point, small reproduction (1.0 foot tall to 0.99 inch d.b.h.) was tallied within a 1/1000-acre circular plot, and large reproduction (1.0 inch d.b.h. and larger) was tallied within a 1/100-acre circular plot. Species, d.b.h., stem origin, quality, and crown class were recorded for each tree observed on a plot. Trees with the potential to become sawtimber crop trees in the future were classified as good. Trees with low forks, crooked or leaning stems, weak crowns, or other evidence of low vigor were classified as poor.

Songbird data were collected on six clearcut and six two-age stands that were treated 9 to 14 years

before initiation of the bird study. Four of the two-age stands provided data on the development of residual trees and woody reproduction. Songbird counts were conducted at permanent points using the variable circular plot method (Reynolds and others 1980) within and on the periphery of each treated stand. Density estimates were determined from bird counts recorded at each sample point 5 times during May and June 1993 and 1994. Nest survival was calculated from 141 nests monitored during the same period. Nest status was checked every 3 to 4 days to determine incubation, nestling stage, fledgling stage, and to quantify predation and parasitism. Songbird density estimates were compared using analysis of variance, and nest survival was compared with the z-statistic. Wood and Nichols (1995) provide detailed descriptions of all field and statistical methods used.

RESULTS

Overstory species composition before two-age treatment included yellow-poplar, northern red oak, chestnut oak, hickory, black cherry, white oak, basswood, white ash, American beech, red maple, and sugar maple. Initial basal area averaged 127 ft^2/acre and merchantable volume averaged 15.9 Mbf/acre (Table 1). The two-age regeneration

harvests removed 84 percent of the basal area and 78 percent of the board-foot volume. Basal area in the residual stands averaged 20.2 ft^2/acre in 13.8 high-quality, codominant trees/acre, while residual volume averaged 3.5 Mbf/acre. Species composition in the residual stands was dominated by northern red oak, yellow-poplar, black cherry, and white oak. During the 10-year period after treatment, residual stand basal area increased 0.6 ft^2/acre/year to an average of 26.6 ft^2/acre. Net volume growth was 140 bf/acre/year, with volume averaging 4.9 Mbf/acre after the study period.

Individual Tree Growth

In general, residual trees after deferment cutting exhibited faster diameter growth compared to control trees in similar uncut stands over the 10-year study period, though analysis of variance indicated that growth response varied by individual species (fig. 2). Growth response did not vary by study area. Deferment trees were free-to-grow with an average crown growing space of 20 feet to adjacent residual tree crowns after treatment (Miller and Schuler 1995). Control trees are located in stands that were similar to treated stands before two-age regeneration cuts were applied. Control trees also were codominant, but they had crown

Table 1.—Summary data for central Appalachian hardwood stands before and 10 years after a two-age regeneration harvest.

Stand	Number of trees		Basal area		Volume			Average d.b.h.	
	5.0–10.9[a]	11.0+	5.0–10.9	11.0+	5.0–10.9	11.0+	11.0+	5.0–10.9	11.0+
	------ No./acre ------		------ Ft^2/acre ------		------ Ft^3/acre ------		------ Bf/acre[b] ------	------ Inches ------	
					SI 70—26.9 acres				
Initial	111.3	73.7	36.4	94.5	641	2,378	14,187	7.7	15.3
Cut	110.0	61.2	35.7	77.2	627	1,937	11,511	7.7	15.2
Residual	1.3	12.5	0.7	17.3	14	441	2,676	9.9	15.9
After 10 years	0.0	11.9	0.0	22.4	0	581	3,706	0.0	18.6
					SI 80—23.3 acres[c]				
Initial	75.9	68.3	24.2	99.2	452	2,671	17,824	7.6	16.3
Cut	75.6	54.9	24.1	76.5	448	2,050	13,362	7.6	16.0
Residual	0.3	13.4	0.1	22.7	4	621	4,462	9.6	17.6
After 10 years	0.0	13.0	0.0	31.4	0	880	6,359	0.0	21.0

[a]Inches d.b.h.

[b]International 1/4-inch rule.

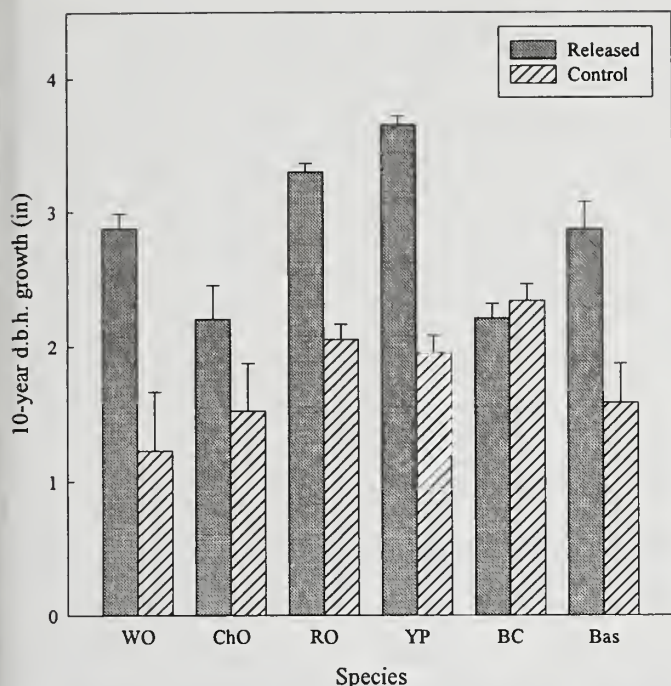[c]Data combined for two stands on each site index.

Figure 2.—Mean 10-year d.b.h. growth of residual trees released by a two-age cut compared to unreleased control trees; one standard error is shown above each bar.

competition on all sides during the study period. Growth of control trees and residual trees in two-age stands was compared using a *t*-statistic for independent samples. For black cherry, average d.b.h. growth of untreated controls exceeded that of released trees, though the difference was not statistically significant (P = 0.301). For all other species tested, released trees had greater average d.b.h. growth than the control trees.

D.b.h. growth of released trees was 45 to 134 percent greater than controls, led by white oak, yellow-poplar, basswood, and red oak. White oak, chestnut oak, red oak, and basswood grew faster the second 5 years compared to the first 5 years after treatment. For yellow-poplar, deferment trees grew faster during the first 5 years after treatment, though growth during the second 5 years continued to exceed that of controls.

Survival and Quality Development of Residual Trees

Within the four study areas, 667 trees were selected as residuals. After 10 years, 89 percent of the residual trees had survived. Six trees (1 percent) were destroyed or removed due to inadvertent damage during logging. After logging, 22 trees (3 percent) died after 2 years, and an additional 38 trees (6 percent) died between the 2nd and the 5th year. Mortality after the 5th year was greatly reduced; only an additional 7 trees (1 percent) died by the end of the 10th year. Mortality was greatest for black cherry (more than 20 percent), least for yellow-poplar (less than 5 percent). For white oak, chestnut oak, red oak, and basswood mortality was 12, 14, 9, and 18 percent, respectively.

Epicormic branching increased for all species within 2 years after treatment. Between year 2 and 10 there was no significant increase in the number of epicormic branches on the butt 16-foot log sections (Miller 1995). Epicormics continued to increase on the second 16-foot-log section for black cherry, red oak, and yellow-poplar between years 2 and 10. The net effect on quality was that 12 percent of the residual trees exhibited reduced butt-log grade due to new epicormic branches during the study period (Table 2). Of the few grade reductions observed, white oak, northern red oak, and black cherry were most susceptible, while less than 1 percent of the yellow-poplar trees had lower grades due to epicormic branching.

Logging operations resulted in bark wounds (exposed sapwood) on about one-third of the residual trees. For wounded trees that survived the 10-year study period, 16 percent had wounds less than 50 in^2, and 16 percent had larger wounds. Most of the wounds were located on the lower portions of the bole and were caused by skidding logs too close to residual trees. More than 95 percent of the logging wounds that were less than 50 in^2 callused over and were closed within 10 years after logging. The rate of healing over a 10-year period indicates that larger wounds up to 200 in^2 will close within 15 to 20 years after logging (Smith and others 1994).

Quality and Development of Reproduction

Before deferment cutting, small reproduction (1.0 foot tall to 0.99 inches d.b.h.) averaged 3,019 stems/acre, with 50 percent in shade-tolerant species (maples and American beech), 37 percent in

Table 2.—Average number of epicormic branches and change in butt-log grade for residual trees 10 years after deferment cutting.

| Species | Number of trees | Initial d.b.h. | Number of epicormics | | Change in butt-log grade | | | Grade loss due to epicormics |
			Initial	10-years	Reduced	None	Improved	
		Inches			-------------------- Number of trees (pct) --------------------			
White oak	59	14.4	0.64a[a]	2.61a	16(27)	22(37)	21(36)	14(24)
Chestnut oak	12	14.4	0.00b	0.00b	1(8)	2(17)	9(75)	0(0)
Red oak	200	16.7	0.03b	1.62b	25(12)	103(52)	72(36)	24(12)
Yellow-poplar	190	17.8	0.01b	0.26b	9(5)	137(72)	44(23)	2(1)
Black cherry	66	14.2	0.00b	2.58a	14(21)	24(36)	28(42)	15(23)
Basswood	18	15.1	0.11b	2.89a	3(17)	6(33)	9(50)	3(17)
All species	545	16.2	0.09	1.37	68(12)	294(54)	183(34)	64(12)

[a]*Values in columns followed by the same letter are not significantly different (p>0.01) using Tukey-Kramer HSD.*

shade-intolerant species (black cherry and yellow-poplar), and 13 percent in intermediate-shade-tolerant species (oaks and white ash). More than 80 percent of the survey plots had at least one commercial hardwood species, and more than 60 percent of the survey plots contained sugar maple or American beech.

Two years after harvest, small reproduction in the study areas averaged 9,100 commercial stems/acre composed of 60 percent seedling-origin and 40 percent sprout-origin stems. Also, there were more than 14,000 noncommercial woody stems/acre. At least one commercial stem occurred in more than 95 percent of the survey plots. Five years after harvest, the canopy of the new age class developing beneath the residual overstory had not closed. Large woody reproduction (1.0 inch d.b.h. and larger) at 5 years included more than 300 commercial and 100 noncommercial stems/acre.

After 10 years, the canopy of the new age class developing beneath the residual trees was nearly closed, and codominant trees averaged 35 feet tall. Large reproduction included 991 commercial stems/acre, with 450 codominant stems/acre classified as good—exhibiting the potential to become high-quality crop trees in the future (Miller and Schuler 1995). On excellent growing sites, northern red oak reproduction was sparse, averaging only 10 potential crop trees/acre (Table 3). Other codominant, commercial reproduction included a variety of both shade-tolerant and shade-intolerant species distributed over 74 percent of the stand area.

Table 3.—Summary of reproduction of commercial species 10 years after a two-age regeneration harvest.

Species	Total	Codominant	Good, Codominants
	------------------- No. stems/acre -------------------		
		SI70	
Black cherry	392	316	220
Beech	110	59	35
Red maple	105	63	47
Red oak	86	54	45
Black birch	77	54	52
Sugar maple	50	26	13
Chestnut oak	48	32	22
Yellow-poplar	44	21	16
Other	87	48	38
Total	999	673	488
		SI 80	
Yellow-poplar	383	206	190
Sugar maple	136	49	40
Black birch	85	50	46
Beech	65	20	10
Red maple	45	19	12
Basswood	36	9	9
Red oak	31	11	10
White ash	29	10	6
Other	172	91	84
Total	982	465	407

Density Estimates and Nest Survival of Songbirds

Forest-interior species had similar density estimates (F=0.65, P=0.63) in the two treatments

(two-age = 207 birds/40 ha, clearcut = 190 birds/40 ha). By contrast, interior-edge (359 vs. 320 birds/40 ha) and edge (83 vs. 12 birds/40 ha) species were more abundant in the two-age treatment (P < 0.001). Thus, overall songbird density estimates were significantly higher (F=19.08, P < 0.001) in the two-age treatment (649 vs. 522 birds/40 ha). Species composition was similar in these two treatments; however, some species were observed in only one treatment. Ten species that occurred in the two-age stands were absent from the even-age stands: least flycatcher, cerulean warbler, Canada warbler, Kentucky warbler, winter wren, yellowthroat, mourning warbler, purple finch, American goldfinch, and brown thrasher. Four species observed in even-age stands were absent from the two-age stands: blackburnian warbler, worm-eating warbler, black-billed cuckoo, and great crested flycatcher.

Nest survival trends differed during the 2 years of study. In 1993, nest survival was lower (P < 0.05) in the two-age treatment (36.4 percent) than in the even-age treatment (59.3 percent). In 1994, survival was higher in the two-age stands, 59.4 percent compared to 47.1 percent in the even-age stands; however, the difference was not significant (P > 0.10). Predation by mammals was the most common cause of nest failure in all treatments. Only three nests failed due to cowbird parasitism.

DISCUSSION

Stand information reported here is from a relatively narrow range of two-age management alternatives. Residual basal area ranged from 17 to 25 ft^2/acre, with all residual stocking in codominant, mature trees. In each treatment area, all trees 1.0 inch d.b.h. and larger, except for the selected overstory residuals, were cut. No saplings or poles were left after harvest, though in practice this is certainly an option. In the central Appalachians, residual basal area in two-age stands could probably be as great as 60 ft^2/acre if all residual trees are near sawtimber rotation age and located in a codominant crown position. However, if younger trees are retained, maximum residual basal area will be reduced to allow for crown expansion as the overstory trees mature.

Two-age regeneration harvests should be applied no more frequently than one-half the recommended sawtimber rotation for local conditions. In the central Appalachians, economic sawtimber rotations are 90, 80, and 70 years for northern red oak SI 60, 70, and 80, respectively. As a result, two-age harvests could be applied as frequently as every 40 to 50 years. A concern with relatively frequent harvests is that many large poles and small sawtimber need to be cut at short intervals to provide adequate light for regeneration of a new age class. At age 40, even-aged stands in the region contain 75 to 100 codominant stems per acre, with an average d.b.h. of only 12 to 14 inches (Smith and Miller 1987). To maintain a two-age stand structure, 20 to 30 of the best codominant trees will be retained to reach maturity, while the remaining trees will be cut. A disadvantage of short cutting intervals is that many cut trees will be removed at a time when their potential growth and value increase are at a maximum.

The benefits of two-age silviculture are consistent with general forest health concepts (Kolb and others 1994). Selecting superior phenotypes for residual trees has the potential to maintain vigor and resistance to pathogens and insects in present and future generations. Natural regeneration includes a variety of species, early and late successional species, shade-tolerant and shade-intolerant species. This enhanced diversity of woody species provides a resilience to host-specific insects and reduces the impact of insects and pathogens that thrive in monocultures (Gottschalk 1993). From a utilitarian view, merchantable products can be removed periodically, and stands have the capability to renew themselves, thus meeting management objectives for sustained yield of wood products. From the ecosystems view, diversity of woody species, vertical structure, and, in this study, songbird density were enhanced. Moreover, with appropriate planning of two-age regeneration harvests over a landscape, a diversity of seral stages and stand structures can be maintained to enhance wildlife habitat. For example, while American beech reproduction in clearcuts would not produce mast for many years, trees old enough to produce mast could be retained in two-age stands, thus maintaining an important benefit of older seral stages.

As two-age regeneration methods are employed to meet forest management objectives, additional

research is needed to better understand the implications of this innovative practice. It is important to define linkages among abiotic and biotic ecosystem components that may be affected by maintaining two vertical strata of woody vegetation over extended periods of time. For example, a supplement to the songbird study will include a survey of insect populations to determine the relationships between vertical stand structure and insect populations that are important food sources for many species of songbirds observed in the treatment areas. Research also is needed to define habitat potential for other wildlife species and to define the susceptibility of residual trees to attacks by insects and pathogens over much longer time periods. Two-age methods show promise for application in the central Appalachian hardwood region. With additional information from long-term observations, this practice and its many potential variations may provide forest managers with an ecosystem management tool for the future.

ACKNOWLEDGMENT

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Application of the Forest Vegetation Simulator in Evaluating Management for Old-Growth Characteristics in Southwestern Mixed Conifer Forests

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Abstract.—We used the Forest Vegetation Simulator (FVS) and GRAFFVS graphics display to investigate conditions associated with the stability of an old-growth stand and to evaluate the potential for two managed stands of contrasting but representative conditions to develop structures similar to the old-growth stand. Simulations indicate that the example old-growth stand can retain old-growth characteristics for up to 100 years in the absence of catastrophic disturbance. Modeling also indicated that silvicultural intervention could enhance the future old-growth potential of the two managed stands.

INTRODUCTION

Management for forest health concerns should maintain landscapes of appropriate mixes of cover type and seral stage distribution. Spatial patterns present on landscapes influence ecosystem processes that operate at landscape scales (Baker 1989; Burke 1989; Fahrig and Merriam 1994; Gilpin and Hanski 1991; Pastor and Post 1986; Risser 1990; Saunders et al. 1991; Turner 1987; Turner and Romme 1994). Significant alterations of landscape structure increase the potential to alter or disrupt these processes with serious ecosystem consequences. For example, when landscapes that are naturally heterogeneous in terms of distributions of cover types, structural conditions, and seral stages are converted to more homogenous conditions, the potential for catastrophic fire to occur at unnaturally large extents is increased (Turner et al. 1989; Turner and Romme 1994). Similarly, fragmentation of old-growth forests may affect processes associated with the viability of species that are dependent upon these habitats (Thomas et al. 1988).

The amount of old-growth forests in southwestern landscapes has been reduced in the last century and remaining old-growth is often in small, isolated fragments (Kaufmann et al. 1992). Species that are dependent on old-growth forests for habitat are susceptible to fragmentation due to loss of habitat, population isolation, and edge effects. It is therefore important for forest managers to determine the amount and spatial distribution of existing old-growth forests. Furthermore, it is critical to identify those stands that have the potential to become old growth within a management time frame to effectively manage landscapes for a desired pattern of future old growth. It may be necessary to employ vegetation management practices to enhance the potential for candidate stands to achieve a desired old-growth structure.

Our objectives are to 1) explore the potential for utilizing a simulation model and graphical tech-

niques to identify stands that have the potential to become old growth within 100 years; and 2) use these approaches to evaluate the effectiveness of silvicultural treatments for enhancing the ability to achieve old growth structure within a 100 year time frame.

BACKGROUND

Assessments indicated that less than 2 percent of inventoried commercial forest lands on the Lincoln National Forest exhibit old-growth characteristics (USDA 1986a). This determination is based on a generic definition of old growth included in the Lincoln National Forest Plan (USDA 1986b). The Lincoln Plan calls for managing to have 7 percent of the Forest in an old-growth condition. To do this, managers must understand the complexity and variation associated with old growth across a range of environments. They must also determine appropriate and potential landscape distributions of the old-growth component.

The old growth definition used by the Lincoln National Forest in planning, inventory, and management efforts and cited in the Forest Plan (USDA 1986b) is:

> A stand that is past full maturity and showing decadence. Fifteen or more live trees per acre over 21 inches dbh and with 0.5 snags per acre over 21 inches dbh. Two or more canopy levels with overstory closure of 10–40%, usually with a shrub-sapling layer combined exceeding 70% closure. Logs obvious on the ground.

Ongoing research in the Sacramento Mountains is directed at testing the adequacy of this definition by studying the variation in and developmental processes of local old-growth mixed conifer forests. One objective of this effort is to predict those stand conditions that reflect a younger or managed stand's potential to attain old-growth characteristics. Identifying potential old-growth is important for replacing existing old growth that might be lost to disturbance or to increase the absolute amount of old growth on the landscape.

Human activities have significantly altered forest stand conditions and landscape structures in the Sacramento Mountains. The area has been intensively logged over the last century. The influences of logging combined with domestic livestock grazing and fire suppression have rescaled, both temporally and spatially, fire regimes and other natural disturbance processes. Little of the Sacramento Mountain landscape is in an old-growth condition and most of the landscape is in a much earlier stage of stand development. The overall diversity and pattern of seral stage distribution in the landscape is altered. Stand conditions are unnaturally dense and stagnated, and species compositions have been shifted. It is critical, then, to determine which stand conditions have the greatest potential as future old growth. Accomplishing this will allow for the determination of future old growth in a spatially explicit way for long-term landscape management prescriptions.

MODELING APPROACH

Simulation modeling provides an effective way for us to explore questions about the long-term future of forest stands. It is a logical way to approximate stand stabilities, stand trajectories, and potential old growth. We have used the Central Rockies Variant (Dixon 1991) of the Forest Vegetation Simulator, FVS, to project conditions in our stands. The FVS is an individual tree-based stand projection system that is widely used in the Forest Service (Wykoff et al. 1982). The Central Rockies Variant contains equations and relationships from the GENGYM model (Edminster et al. 1991), which is a variable density stand table projection system based on 1-inch diameter classes. This variant has been calibrated to Southwestern coniferous forests.

The GRAFFVS system was used for visual displays of simulation results. This data visualization program is an updated version of the program described by Shepperd (1995). Stand attributes of interest in our analyses which are easily simulated with FVS and illustrated by GRAFFVS include diameter distributions, basal area by species, tree density by species, large tree diameters and heights, and vertical canopy structure. Other old-growth attributes, including standing dead trees, coarse woody debris, canopy cover, and spatial heterogeneity will be addressed in future analyses.

We selected one stand, Peake Canyon, to serve as an example of an old-growth condition. This stand was measured in 1993 for several attributes of structure and composition and is considered to typify late seral potential of stands over much of the Sacramento Mountain landscape. The stand has never been logged, has at least one cohort of old trees, and has a spatial heterogeneity indicative of a stand maintained by small scale gap-phase processes. Basal area, large tree diameters, density of standing dead trees, vertical complexity of the canopy, and amounts of coarse woody debris all meet minimal levels of the old growth definition included in the Lincoln Forest Plan (USDA 1986b). It is beyond the scope of this analysis to address the suitability of the current condition of Peake Canyon as representative of a desired old-growth condition. However, we do recognize that the existing condition is probably heavily stocked in the understory and reflects an altered composition due to fire suppression over the last century.

To calibrate FVS to sites used in our analyses, we used data from Peake Canyon as input, grew the stand to 1995 as a starting point, and then projected the stand for 100 years. We assumed that the structural condition of Peake Canyon could remain stable through the next 100 years in the absence of catastrophic disturbance. Calibration consisted of making adjustments in the model to achieve stability. Stability was achieved by adjusting the recruitment of new stems and the mortality rates of small and very large trees to arrive at a diameter distribution in 100 years that is similar to the current conditions. No adjustment was accepted unless we felt that it was realistic given what is known about the biology and ecology of these forests. We incorporated the assumptions needed to achieve stability into each model run so that these conditions served as a baseline for all simulations. This allowed a uniform comparison of management options and disturbance scenarios.

Historical evidence suggests patterns of repeated, low intensity natural disturbances in these forests that did not result in complete stand replacement. Mean fire intervals of 10 years have been documented for the Peake Canyon stand (Huckaby and Brown 1995). We do not yet have a clear understanding of patterns of mortality in younger age classes, but we do know that older cohorts have experienced several fires as indicated by the fire history data. Western spruce budworm is another disturbance factor which has been studied in similar southwestern mixed conifer forests (Swetnam and Lynch 1989, 1993). These data provide support for exploring the range of conditions that might be expected at Peake Canyon under spruce budworm scenarios over the next 100 years. Results from the baseline and spruce budworm disturbance scenarios provide a reference point of variation in stand conditions for evaluating the old-growth potential of other stands.

Two stands, Sacramento Canyon and Apache Point, were used for the assessment of the potential for achieving old-growth structure. These stands were selected from the Lincoln National Forest RMRIS database to provide contrasting conditions and reflect characteristics typical of previously managed forests in the Sacramento Mountains. We selected stands with growth potentials similar to those of the Peake Canyon stand. Habitat type, site index, and elevation criteria were considered in matching stand potentials.

Sacramento Canyon has no documented management history but was apparently selectively logged earlier in this century. There is minimal evidence of logging in the current stand. The stand has a dense understory and may be representative of overstocked, stagnated conditions of many older stands in the area. Apache Point was thinned in the mid–1960's and then commercially thinned in the late 1980's. This treatment scenario is similar to that applied to many stands on the Forest in recent management history.

The assumptions established for baseline stability of the Peake Canyon stand were applied to each of the experimental stands. Each stand was grown for 100 years with no treatment and again under simple silvicultural prescriptions. Simulation results and graphical output were evaluated to assess the old-growth potential of each of the treated stands.

RESULTS AND DISCUSSION

Initial Stand Comparisons

Data for each stand were input into FVS and the stands were grown to 1995 as a starting point for

old growth development projections. Stand attributes used for matching stand potentials are given in Table 1. Stand structures in 1995, the initial year of our 100 year projection, are given in Table 2. Basal area and quadratic mean diameter (QMD) are lowest and stem density is highest at Apache Point, which is the intensively managed stand. QMD is also low at Peake Canyon and Sacramento Canyon, reflecting a high density of small sized trees that may have increased with a decrease in post-settlement fire frequency. The QMD of the largest 10 percent of the trees on each site characterizes a difference among sites, indicating the greater proportion of large trees at Peake Canyon and Sacramento Canyon. Douglas-fir is the dominant species at Peake Canyon. Dominance is shared by Douglas-fir and white fir at the two managed stands. We assumed a maximum stand density index of 595 for Douglas fir and 845 for white fir at each site.

Peake Canyon Old-Growth

Several modeling steps or adjustments were required to approximate stabilization of baseline growth of the Peake Canyon stand over the 100 year projection period. Excessive aspen sprouting was reduced using the NO-SPROUT option. The NATURAL keyword was used to regenerate all species. It was necessary to reduce height growth of aspen to avoid excessively large trees at the end of the projection. The model appeared to be underestimating mortality for aspen trees and small trees of other species. We increased mortality of aspen over 16 inches dbh and we used a thinning option to reduce stocking of small trees and avoid severe stagnation. We based recruitment of young trees into the future stand on existing understory stocking, assumed a 20 year growth period to dbh, and assumed only 20 percent of the understory stocking would survive to reach dbh.

Diameter distributions at Peake Canyon approximated a Q of 1.2 in both 1995 and at the end of the projection period in 2095 (fig. 1). Basal area increased to just over 300 ft^2/acre in 2095, with Douglas-fir dominant throughout the projection period (fig. 2). GRAFFVS displays illustrate the species diversity and vertical canopy complexity of the stand in 1995 (fig. 3a) and tree growth to 2095 (fig. 3b).

Spruce Budworm in the Peake Canyon Old-Growth

We assumed 13-year budworm defoliation periods and 35 year intervals between outbreaks (Swetnam and Lynch 1989, 1993). For Douglas-fir and white fir, we assumed 10 percent topkill, 15

Table 1.—Attributes of Peake Canyon, Sacramento Canyon, and Apache Point stands used for evaluating site potentials.

	Elevation	Habitat Type	Site Index[b]
Peake Canyon	9000 ft	ABCO/QUGA[a]	84
Sacramento Canyon	9000 ft	ABCO/QUGA[a]	84
Apache Point	9100 ft	ABCO/QUGA[a]	84

[a]ABCO/QUGA is the White fir/Gambel oak habitat type.
[b]Based on a reference age of 100 years (Edminster et al. 1991).

Table 2.—Initial conditions of Peake Canyon, Sacramento Canyon, and Apache Point based on FVS projections from the date of data collection to 1995.

	BA	Density	QMD	Large tree QMD[a]	BA by Species	
					PSME[b]	ABCO[c]
Peake Canyon	244	635	8.4	34.2	128	80
Sacramento Canyon	222	440	9.6	31.9	103	105
Apache Point	159	823	5.9	16.7	50	53

[a]Large tree QMD is quadratic mean diameter based on the largest 10% of the trees.
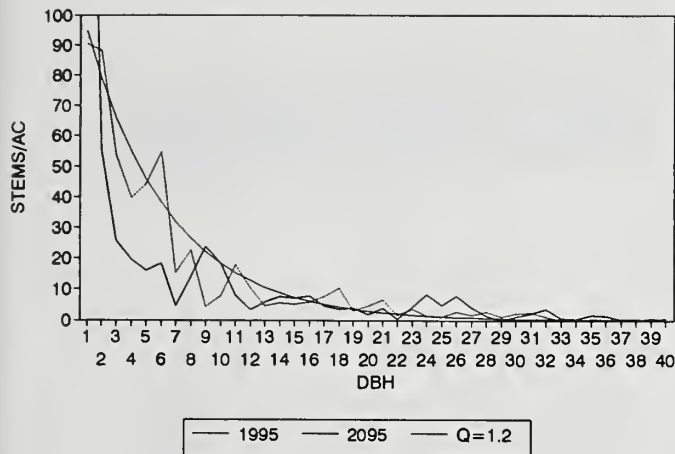[b]PSME is Douglas fir.
[c]ABCO is white fir.

Figure 1.—Projected diameter distributions of the Peake Canyon old-growth stand with no treatment, 1995 and 2095.

Figure 2.—Projected basal area growth of the Peake Canyon old-growth stand with no treatment. Projection period is 1995 to 2095. DF is Douglas-fir, WF is white fir, PP is ponderosa pine, OH is other hardwoods, AS is aspen, and WP is southwestern white pine.

percent mortality in the overstory, 50 percent mortality in dbh classes up to 5 inches, and 75 percent reduction in recruitment was associated with the outbreaks in our simulations (Lynch pers. comm.). In addition, growth was stopped during outbreaks in our simulations. The first budworm attack caused a reduction in stocking, but stand basal area recovered and increased after subsequent attacks (fig. 4).

Target Old-growth Conditions

Ranges of selected structural attributes, based on data from Peake Canyon in 1995 and on simulation results, are given in column one of Table 3 as targets for assessing the potential of previously managed stands in achieving old-growth conditions. Goals for old-growth include an uneven-aged diameter distribution with an approximate Q of 1.2, a large tree qmd ≥34 inches, dominance by Douglas-fir, total basal area ≥244, and multiple canopy layers.

Projections in Managed Stands

Assumptions for no treatment projections of Sacramento Canyon and Apache Point are identical to those used in the Peake Canyon stabilization projections. The current (1995) diameter distribu-

Table 3.—Comparison of targeted old growth conditions and simulated structures with thinning of Sacramento Canyon and Apache Point in 2095.

	Old Growth	Sacramento Canyon	Apache Point
Total basal area (ft^2/ac)	244–295	295	275
PSME[a] basal area	128–186	164	120
ABCO[b] basal area	50–80	82	87
Total stems/acre	635–754	293	431
PSME stems/acre	270	163	146
ABCO stems/acre	189	82	79
Large tree QMD[c] (in)	34–36	33	25
Diameter distribution (Q)	1.2	1.3	1.3
Canopy layers	4	2	2

[a]PSME is Douglas fir

[b]ABCO is white fir

[c]Large tree QMD is quadratic mean diameter based on the largest 10% of the trees.

tion of Sacramento Canyon roughly approximates a Q of 1.3, with an overabundance of individuals in 2 inch and 8 inch size classes (fig. 5). When the stand is grown for 100 years with no treatment, the distribution shows marginal improvement and more closely approximates a Q of 1.3, the 2 inch peak has been shifted to 4 inches and has been reduced, and the 8 inch peak has been shifted to 12 inches.

GRAFFVS – STAND : PEAK2   MGMTID :NONE
   WP ⟐ OS ⚘ DF ⟐ WF ◇ OH ▽ AS ⟐ BS ⟐ ES ⟐ AF ⚘ PP ⟐ PJ ⟐ -- ⚘

- 100 FT.

                              210 FT.
STAND DATA : CYCLE   YEAR   BA   TPA   QMD   SDI   TCF   MCF   BFS
                 1   1995   244   635   8.4   480 6361 5916 28987
                              GRAPH ANOTHER? (Y OR N)

Figure 3a.—GRAFFVS display of the Peake Canyon old-growth stand with no treatment in 1995.

GRAFFVS – STAND : PEAK2   MGMTID :NONE
   WP ⟐ OS ⚘ DF ⟐ WF ◇ OH ▽ AS ⟐ BS ⟐ ES ⟐ AF ⚘ PP ⟐ PJ ⟐ -- ⚘

- 100 FT.
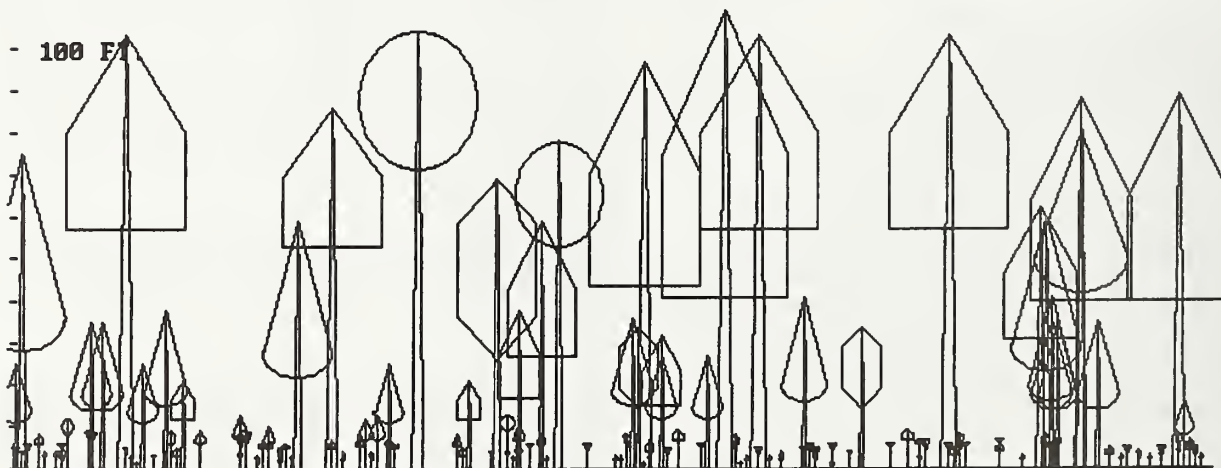
                              210 FT.
STAND DATA : CYCLE   YEAR   BA   TPA   QMD   SDI   TCF   MCF   BFS
                37   2095   294   754   8.4   576 8206 7804 40824
                              GRAPH ANOTHER? (Y OR N)

Figure 3b.—GRAFFVS display of the Peake Canyon old-growth stand with no treatment at the end of the projection
     period in 2095.
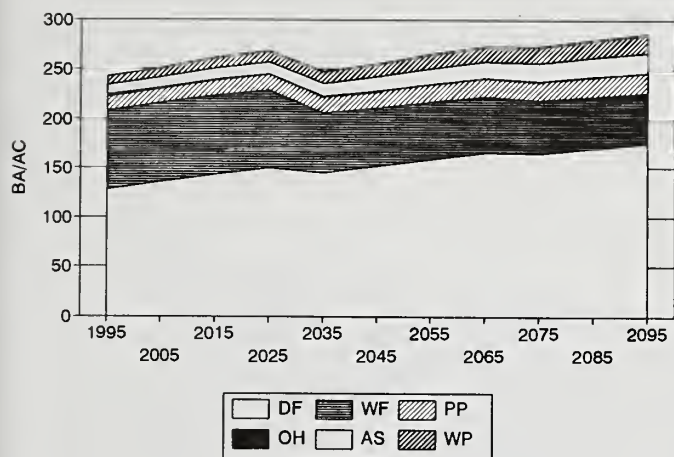
Figure 4.—Projected basal area growth of the Peake Canyon old-growth stand under a simulated spruce budworm regime. Projection period is 1995 to 2095.

Figure 5.—Projected diameter distributions of Sacramento Canyon with no treatment, 1995 and 2095, and with simulated thinning, 2095.

To deal with these disproportions in the diameter distribution, which are largely white fir, we simulated thinning in Sacramento Canyon from below to remove excessive white fir stocking from the understory and to stimulate growth in larger diameter classes. The thinning treatment deals with disproportions in the diameter distribution and results in a better approximation of a Q of 1.3 by the year 2095 (fig. 5). Growth results in a large tree qmd closer to the target. In addition, thinning takes the stand to the targeted basal area and begins to correct the overabundance of white fir in the stand (fig. 6).

GRAFFVS displays (fig. 7a) illustrate that currently, Sacramento Canyon does not have the vertical canopy complexity, tree size, or species composition to match Peake Canyon (fig. 3a). Figure 7b suggests that, with thinning of understory white fir, problems of tree size and species composition are addressed but that the paucity of individuals in understory and seedling layers is still evident. Simulations suggest that our thinning treatment has not adequately promoted recruitment or achieved vertical complexity.

Apache Point has similar disproportions in the diameter distribution and has few trees greater than 25 inches in diameter in 1995 (fig. 8). When the stand is grown for 100 years with no treatment,

Figure 6.—Projected basal area growth of Sacramento Canyon with simulated thinning. Projection period is 1995 to 2095.

there continue to be major deviations from a Q of 1.2, disproportions in the diameter distribution, and an absence of diameters larger than 25 inches. We again applied a thinning from below, with over-represented diameter classes and white fir targeted for removal. This treatment improved some of the understory overstocking but did not result in the targeted Q of 1.2 and did not result in

- 100 FT.

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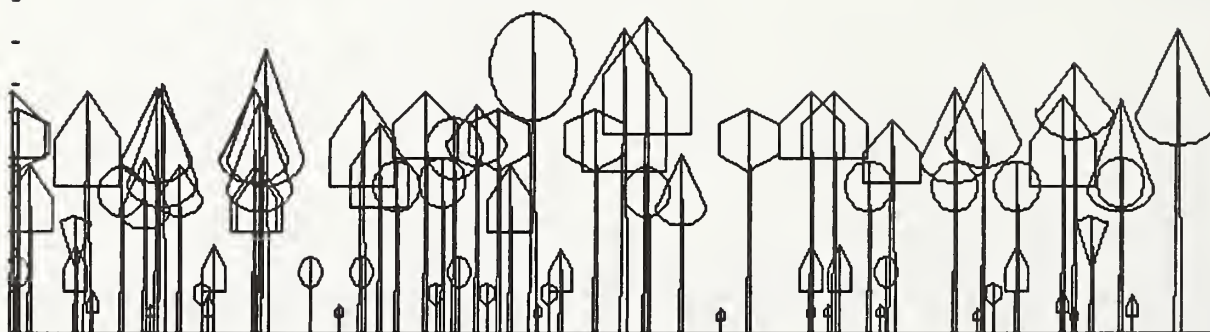
210 FT.

STAND DATA: CYCLE   YEAR   BA   TPA   QMD   SDI   TCF   MCF   BFS
             3   1995   222   440   9.6   414   5162   4762 20420
                                   GRAPH ANOTHER? (Y OR N)

Figure 7a.—GRAFFVS display of Sacramento Canyon in 1995.

- 100 FT.

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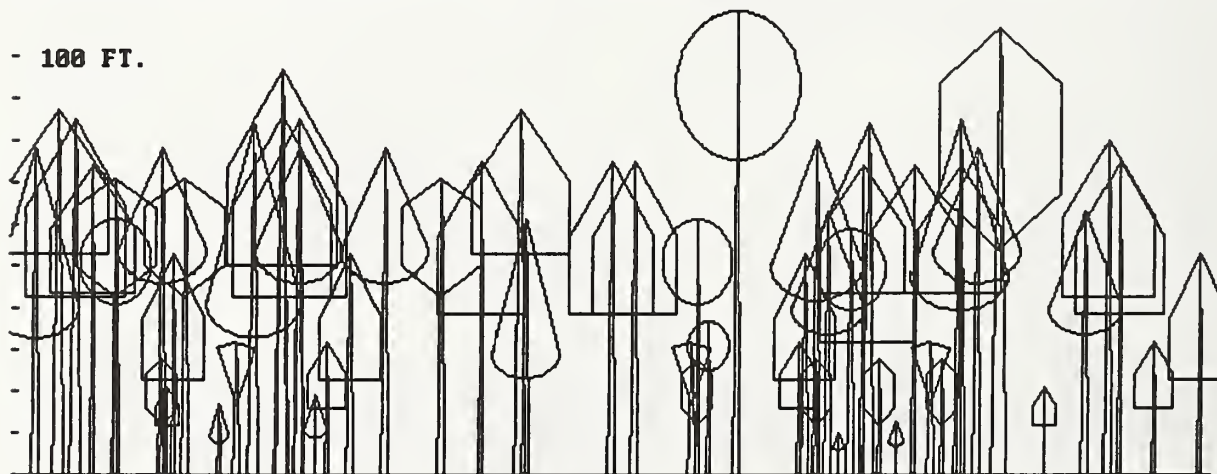
210 FT.

STAND DATA: CYCLE   YEAR   BA   TPA   QMD   SDI   TCF   MCF   BFS
             21   2095   295   293 13.6   478   8073   7688 38244
                                   GRAPH ANOTHER? (Y OR N)

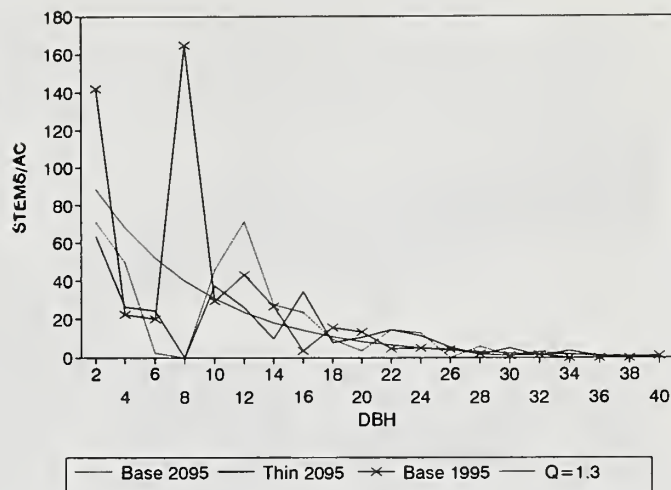Figure 7b.—GRAFFVS display of Sacramento Canyon after simulated thinning, 2095.

Figure 8.—Projected diameter distributions of Apache Point with no treatment, 1995 and 2095, and with simulated thinning, 2095.

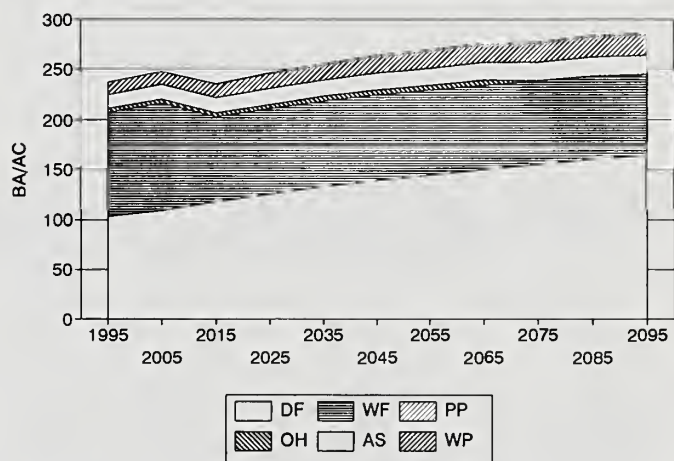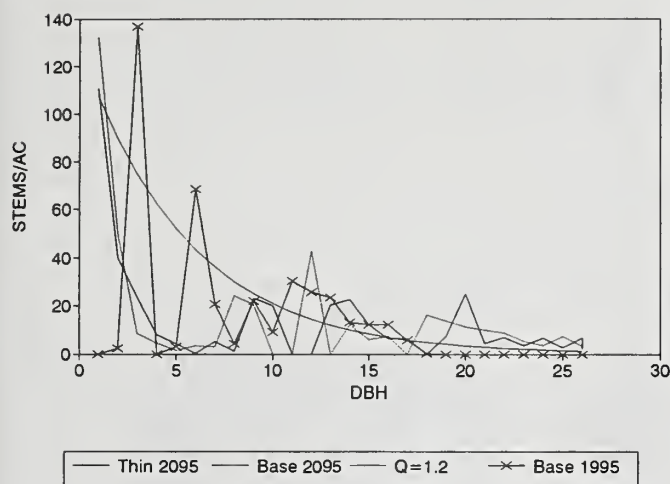Figure 9.—Projected basal area growth of Apache Point with simulated thinning. Projection period is 1995 to 2095.

larger diameter individuals (fig. 8). Basal area has increased to just over 250 ft²/acre in 2095, but it is still disproportionately high in white fir (fig. 9). GRAFFVS displays again illustrate lack of vertical complexity, overabundance of white fir, and smaller tree size at Apache Point when compared to Peake Canyon (figure 10a). Again, our thinning treatment was effective in dealing with disproportions in species composition and in stimulating growth, but did not achieved the vertical complexity represented by Peake Canyon (fig. 10b).

Simulations suggest that, with treatment, Sacramento Canyon has the potential to achieve some of the targeted old-growth structural attributes at the end of the projection period (Table 3). However, the diameter distribution does not yet approximate the Q of 1.2 and the vertical canopy complexity has not reached four identifiable layers. Projected conditions at Apache Point are not yet old growth, although some of the structural targets are achieved (Table 3). White fir basal area is still high, canopy complexity is low, and large tree qmd is low when compared to target conditions.

CONCLUSIONS

Adjusting the mortality and recruitment in FVS projections allowed us to achieve stability in the Peake Canyon old growth stand in the absence of

catastrophic disturbance over the next 100 years. Existing and future conditions of Peake Canyon as well as projections of the Peake Canyon stand under a simulated spruce budworm regime provide a range of target conditions for evaluating old-growth potential of two previously managed stands. Target conditions were not achieved in either of the two stands under simulations with no treatment. In the Sacramento Canyon stand, we found that a simple silvicultural prescription began to promote a stand structure similar to the old-growth target. There is also opportunity for additional treatment to achieve the structural complexity targeted. In the Apache Point stand, we found that our prescription would not approximate target conditions within the projection period.

We found certain aspects of the small tree model of FVS to be problematic in application to our stands in the Sacramento Mountains. For example, FVS did not deal effectively with Gambel oak, which occurs on all of the sites that we modeled. We encountered difficulties with oak becoming large trees, inadequate oak mortality, and extreme competition by oak after disturbance. There is a need to strengthen the assumptions associated with the small tree model in FVS to more appropriately deal with recruitment, growth, and mortality of this component of the forest. Information is needed on the ecology of oak as well as other hardwoods in the range of environments in these Southwestern mixed conifer forests.

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Figure 10a.—GRAFFVS display of Apache Point in 1995.
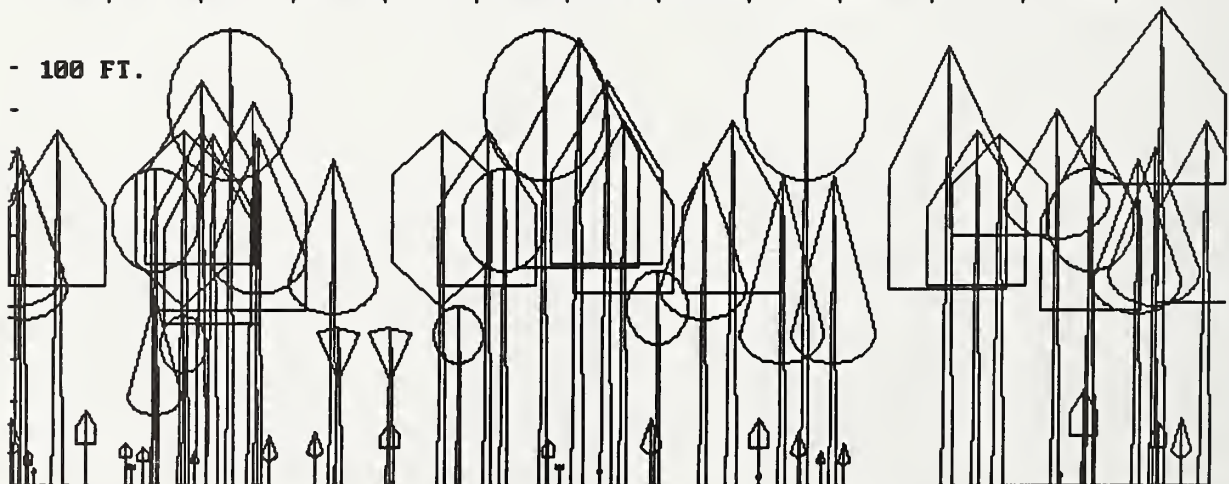
Figure 10b.—GRAFFVS display of Apache Point after simulated thinning, 2095.

However, FVS does offer the opportunity to explore ecological questions about these forests in addition to the more traditional growth and yield questions usually addressed. The model helped identify existing stand conditions that have old-growth potential. Clearly, there is an opportunity to address the question of potential old-growth in the Sacramento Mountains by investigating the full range of existing stand conditions, environments, and natural disturbance scenarios and making future projections using simulation modeling. A desirable goal for future work would be to couple FVS with GIS data from the Forest for a spatially explicit, landscape scale analysis of potential future landscapes, including investigation into the influence of pattern of old-growth distribution on ecological processes.

Finally, our simulation analysis, which is preliminary in terms of addressing questions related to the potential for old growth, indicates that there is a role for silviculture in generating future old-growth forests from previously managed stands. Our very simplistic prescriptions indicated that, in some situations, we could approach the structural targets within the projection period. Furthermore, the model helped identify existing stand conditions that do not appear to be suitable for reaching old-growth status. More complex silvicultural prescriptions should be applied in future simulations to effectively address appropriate vegetation management for the full range of structural attributes associated with these old-growth forests.

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Putting White Pine in Its Place on the Hiawatha National Forest

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Abstract—White pine was once a very important part of the ecosystem in the northern lake states. Turn of the century logging and wildfires removed white pine from many of the ecosystems of which it was an integral part. Early reforestation efforts were largely unsuccessful. The native white pine weevil and the exotic white pine blister rust made white pine establishment difficult at best. Both of these pests pose management challenges. However silvicultural practices can give white pine a distinct advantage over the pests. These practices include regenerating white pine under the shelter of overhead canopy, using genetically selected seed source, dense stocking, pathological and corrective pruning. Careful management is helping white pine once again return as a major component of the ecosystem.

INTRODUCTION

White pine invaded the lake states shortly after the retreat of the glaciers from the Lake Superior region. Paleoecological evidence suggests that white pine was extremely abundant during the mid-holocene era when climate was warmer and drier (Jacobson 1992). White pine may play a more important role in lake states forests if global warming and greenhouse effects are a reality.

A search of government land office survey notes indicates that white pine was a major forest component and often the largest trees on a site during the land surveys which took place in the 1840's and 50's. The first assessment of the nation's timber supply published in 1909 estimated the area of northern forests of which white pine was a principal member, as nearly 150 million acres supporting "not less than 1,000 billion board feet" of all species (Kellogg 1909). Many of these forests had their origin during the little ice age dating from 1450 to 1850, a period of highly variable climatic condi-

tions and frequent disturbance which favored white pine (Stern 1992). Many stands were subjected to light or moderate ground fires on a 20 to 40 year frequency. Fires kept the stands from succeeding to more tolerant species (Heinselman 1981).

HISTORY

Lake states forests were used by a growing nation which had and still has a tremendous appetite for wood products. Logging and post logging fires significantly changed the northern forests. Vast areas remained open until the 1930's when establishment of the national forests (including the Hiawatha), fire control and the Civilian Conservation Corps led to reforestation efforts. At least 2000 acres of white pine were planted during the CCC's on the Hiawatha. Most of these stands were managed exactly like red pine in that they were planted in open fields or in stands where all overstory trees were removed. Attempts at managing these white pine plantations during the 40's and 50's left forest managers frustrated by the problems associated with the species. Today white pine maintains only a fraction of its original impor-

tance. In fact the 1993 Michigan inventory of the Hiawatha shows all conifers except tamarack are more common than white pine. This is true both as a type and as individual trees.

Silvical Review

Before discussing management strategies for white pine, it would be appropriate to quickly review white pine's silvical characteristics. Eastern or northern white pine (Pinus strobus) is the only 5-needled pine growing in eastern North America (Stearns 1992). It is the largest of eastern conifers capable of growing to 150 feet or more in height and in excess of 3 feet in diameter (Harlow). It is capable of growing on a wide range of sites, from dry rocky ridges to wet bogs. It grows best on moist sandy loam soils. White pine is intermediate in shade tolerance and produces good seed crops every 3 to 5 years, but some seed is produced almost every year (Harlow 1968). It also has a wide genetic variability lending itself to a successful tree improvement program (Meier 1992).

Importance

White pine has played a major role in northern forests both ecologically and economically. Many wildlife species utilize white pine throughout its life cycle. Young white pine are often fed upon by hares and deer. Old trees are sought as refuge sites for bear or nest sites for many birds, especially eagle and osprey (Rogers 1992). History has proven the economic significance of white pine. Even today logs cut in the 1800's are being salvaged from the bottom of Lake Superior (Swerkstrom 1994).

PROBLEM

Many insects and diseases are associated with white pine (Jones 1992).Unquestionably the most serious problems associated with white pine are white pine blister rust and the white pine weevil (Katovich 1992). White pine blister rust, Cronartium ribicola, is a stem disease believed to have been brought to North America on seedlings transplanted from Europe. It is a fungus which uses, gooseberry, ribes spp., as an alternate host (Hepting

1971). In the white pine it causes cankers on the stem which will eventually girdle the stem. Growth loss results if the infection involves only a lateral branch. Mortality results if the main stem is involved. Infection on to a host white pine requires exacting conditions of temperature and moisture when the wind born spores are transmitted from the ribes to the white pine needles. Silvicultural practices can reduce the risk of blister rust to acceptable levels (Jones 1992). These practices include: careful site selection, avoiding openings and high ribes populations, underplanting, and pathological pruning. White pine weevil, Pissodes strobi, unlike blister rust, is not capable of directly killing the white pine. This native pest deforms trees by laying eggs in the terminals. Hatching larva feed under the bark of the previous year's terminal, killing the terminal. Usually one or more of the laterals take over causing noticeable crook or forking in the stem (Katovich 1992). The dead terminal will persist for many years often serving as an entry point for red rot. The weevil problem too, can be controlled by careful attention to management practices. These practices include: planting under overhead shade, corrective pruning and insecticide application.

MANAGEMENT OPPORTUNITIES

These two pests, white pine weevil and blister rust, create management challenges. Fortunately there is some common ground in the techniques that allow for successful management of white pine. First sites should be selected which are not high risk areas for blister rust. This would include: avoiding the base of slopes, avoiding small openings and avoiding areas that have a large amount of ribes. These areas have cooler temperatures, higher relative humidities, and higher inoculum source, all of which increases blister rust incidence.

Secondly, an overstory should be maintained at 40 to 50% crown closure. This overstory makes unfavorable conditions for both blister rust and the weevil. The shade retards both evening cooling and subsequent increases in relative humidity, conditions needed for blister rust inoculation. Shade also causes smaller terminal diameters which are unfavorable to the weevil. Excessive shade on the other hand will retard the growth of

the white pine seedlings. Growth on 8 year old seedlings should be at least 15 inches per year. Shorter growth suggests too much shade (Katovich 1993). There is a fine line between having enough shade and too much. The forest manager needs to be observant on white pine sites to learn where that balance is and what kind of growth rates to expect.

Thirdly, white pine stocking should be maintained at between 800 (7×8) and 1200 (6×6) trees per acre (Katovich & Mielke 1993). This stocking level allows for some loss to blister rust, forces self correction after weevil attack, and increases natural self pruning. These stocking recomendations assume that the objective is for a pure stand of white pine. These numbers can be reduced if other natural regeneration will be coming on the site. On some sites on the Hiawatha we are planting as few as 10 seedlings per acre where our objective is strictly restoring a small component of white pine to a stand.

A fourth and final management recommendation is to prune up to 350 trees per acre. This pruning needs to fill two purposes. Pathological pruning will remove any branch anywhere on the tree which shows incidence of rust formation plus removes all branches in the lower third of the tree. This eliminates potential deadly cankers and significantly reduces the risk of additional infections. Research has shown that 99% of all blister rust infections occur within 9 feet of the ground (Katovich/Mielke 1993). The second function that pruning needs to fulfill is to correct any deformations caused by weevil attacks. This is done by removing the destroyed leader and all but one lateral directly below the destroyed terminal. This forces the tree to develop a new terminal and increases the chances of developing a single straight stem. Corrective pruning is most effective if done in late July or early August with removed dead terminals being burned or removed from the site. This removal destroys some of the next year's egg laying weevils (Katovich, 1993).

HIAWATHA'S APPROACH

After the CCC era and up to the 1980's, very little white pine was planted on the Hiawatha National Forest. Managers felt the risk from rust and weevil were too high. In the early 80's white pine seedlings from Region 9's Tree Improvement Program began to be available from the Oconto River Seed Orchard. We also started looking at the forest with an eye for improving natural biodiversity and restoring some of the missing components to our ecosystems. One of the first operational white pine plantings undertaken on the Hiawatha was underplanting a low quality hardwood stand on a sandy outwash plain near Munising (Wetmore outwash LTA). The site index for northern hardwoods was measured at 36 feet with a corresponding site index of 56 feet for white pine (Saberniak 1983). This would be an ELTP of 40. The stand was non-commercially thinned to a crown closure of 50%. The following spring 700 3–0 genetically selected white pine were planted per acre. A year and half later the trees were spot released using glyphosate. Several hand releases using prison labor have also taken place to keep the trees growing free of hardwood sprout competition. At age 7 we did a pathological pruning though little rust was evident. During 1993 and 1994 growing seasons we began to notice some weevil damage in the stand. We plan an additional pathological and corrective pruning within the next two summers. It appears that this stand is well on its way to again having white pine as a major component.

Since the first planting in 1984 we have planted 500 acres on the district to white pine, approximately 2000 acres forest wide. Our most successful attempts have been in underplanting poor quality low site index northern hardwoods especially red maple. We have found the lowest cost treatments to involve whole tree chipping to set up the initial shelterwood. These have been done by describing the objective then issuing a timber sale contract to "designate by description" the timber to be removed or left. A recent timber sale will prepare in excess of 400 acres for underplanting. Efforts have been concentrated on sites without white pine seed trees. The objective of these plantings has never been to create a pure stand of white pine but rather to manage stands of white pine mixed with northern hardwoods.

Until 1990 the Oconto River seed orchard was not able to produce all the geneticly improved seed

we needed. As a result seed was collected from selected individual trees on the forest. Outplantings have been done with this Hiawatha woods run seed source. In 1989 the Hiawatha, in conjunction with North Central Forest Experiment Station and Northeastern Area State and Private Forestry, established an administrative study to compare: Hiawatha vs. Oconto Seed Orchard stock, pruned vs. unpruned, and planting in clearcut vs. planting in shelterwood. After six growing seasons trends in survival and growth among treatments continue. Tree survival was nearly identical between Oconto and Hiawatha stock, and similar among treatments. Trees from the Oconto River seed orchard stock are slightly taller than from the Hiawatha stock and trees in the clearcut continue to outgrow trees in the shelterwood plots (fig. 1). Weevil damage was present only on trees within the clearcut plots with an average incidence of 6 percent (Ostry 1994). If weevil damage increases in the future, growth on the shelterwood plots will likely catch or surpass the clearcut plots. Blister rust is also an unknown at this time. Meier estimates the Oconto River seed source to be about 30 percent superior in terms of rust resistance; however, this is not yet proven.

Active management of white pine continues through shelterwood cutting and planting. However there are many more areas where a white pine component is coming in naturally. The 1993 forest inventory shows that there are in excess of 35 thousand acres on the Hiawatha which have an adequate white pine understory. As mentioned earlier white pine is the second least common overstory conifer; however, it is the second most common understory conifer. Most of this regeneration is under 20 years old. Several factors are likely contributing to this surge of regeneration. First, while pine blister rust has probably run its initial most devastating course having taken out the most susceptible population members. Also attempts at ribies irradication while not total were effective at reducing alternate host populations. Second, scattered residual white pine seed trees have grown to large size and are of an age that seed production is more prolific. Finally and perhaps most importantly our forests have made significant ecological recovery since the cut and burn days of the 19th century. Moderate level disturbances brought on by thinnings and selection harvests in hardwoods or age and stand break up in aspen and jack pine are again opening canopy gaps in the extremely dense second growth stands which came back after clearcutting. These naturally regenerating white pine are capable of hanging on under dense competition and show good growth response within one to five years after release (Kelty & Entcheoa 1993). This certainly opens a door of opportunity for silvicultural treatments like selection harvests to further aid in returning white pine to the main canopy.

OSTRY, 1994

Figure 1.—Six-year survival and height growth of white pine, Hiawatha NF, October 1994.

SUMMARY

White pine was once a very important component of Lake States forests. Turn of the century logging and catastrophic fires greatly reduced white pine abundance. Hampered by insect, disease, reduced seed sources and a lack of manage-

ment, white pine is making a slow comeback. White pine can be successfully managed and returned to the ecosystems it has been removed from, thereby benefiting diversity. Regenerating it under a shelterwood system or perhaps even a multi-aged system will strengthen its place in the ecosystem. The role of fire in these systems needs to be investigated and better understood. A choice needs to be made, we as managers can either use the silvicultural tools available to us and return white pine to its natural place in our northern ecosystems, or we can do nothing and take our chances that white pine may be missing from future generations of forests.

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The Role of Genetics in Improving Forest Health

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Abstract.—An often ignored tool to improve forest health is the application of genetics. Tree improvement programs in the Inland West utilize genetic principles to develop seed transfer guidelines to avoid the problems associated with off-site plantings and to improve characteristics in conifers related to forest health. PC-based expert systems have been developed to aid in seed transfer in ponderosa pine and Douglas-fir. Genetic gains in adaptation, and insect and disease resistance, continue to be made in western white pine, western larch, ponderosa pine, Douglas-fir, and lodgepole pine. While progress has been made in the white pine blister rust program, restoring western white pine to Inland Northwest forests requires a continued commitment to selective breeding. Other insect and disease problems should also receive strong consideration in selective breeding programs, to prevent erosion of existing genetic resistance, and when warranted, to sustain and enhance this resistance.

INTRODUCTION

The general objectives of a tree improvement program are: (1) improving forest health, (2) conserving biodiversity, (3) ensuring an adapted seed supply for restoration and reforestation, and (4) meeting demands for wood products. These objectives are met by common garden studies (genecological studies) employed to develop seed transfer guidelines, by applying safe seed transfer, and via selective breeding. This paper highlights the role genetics and tree improvement plays in improving forest health in the Inland West.

Declining forest health conditions popularized in the media focus on improper species composition and stocking levels, insect and disease problems, and changing climatic conditions, such as sustained droughts, resulting in catastrophic wildfires. Dysgenic selection practices (high-grade logging) have also contributed to poor forest health conditions, by leaving trees with poor vigor and insect and disease problems, to become the parents of the next generation. The Western Forest Health Initiative (1994) and previous papers in this Workshop,

include the common solutions of salvage logging, prescribed fire, and intermediate harvests to improve forest health conditions. Broadcast spraying of biological and chemical insecticides have also been used to control insect problems. Depending upon the condition and species involved, these treatments can be short or long-lived.

A comprehensive program for improving forest health also needs to evaluate the efficacy of including genetics as a long-lived treatment application. Genetics plays a role in improving forest health by reducing maladaptation by following seed transfer guidelines and by selective breeding for insect and disease resistance.

SEED TRANSFER GUIDELINES

Tree improvement activities begin with identifying patterns of genetic variation within a species. This information can be later utilized to develop seed transfer guidelines, identify and establish seed collection and seed production areas, and/or to develop selective breeding programs, culminating in the establishment of production seed orchards.

Common garden studies facilitate developing seed transfer guidelines based on adaptive traits.

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Adaptive traits include survival, cold hardiness, bud break and bud set, to name but a few. Seed transfer guidelines provide assurance that trees will be adapted to the environment in which they are planted, without significant risks to survival, growth and/or susceptibility to insect and disease problems. These guidelines set limits on the distance that seeds can be moved from their point of origin. To be effective, seed transfer guidelines must be based on genetic differences among populations that reflect adaptations to natural environments (Rehfeldt 1994).

Seed transfer in the Inland West is predominantly based on changes in elevation, then latitude and longitude (Rehfeldt 1994, 1991). Habitat types have yet to play a significant role in contributing to the patterns of genetic variation within conifer species (Rehfeldt 1981, 1979a 1979b, 1978). Seed zone map(s) and associated guidelines are found in Regional Seed Handbooks (FSH 2409.26f). These seed zone maps become obsolete once a PC rule-based system has been developed for each species. An expert system determines suitable planting sites for a target seedlot or identifies suitable collection areas for a target planting site. The hallmark of an expert system is that it combines the flexibility of both discrete and floating seed zones, i.e., recognizing that similar genotypes occur at different geographically separated localities (Rehfeldt 1991).

The National Forest System and Research Branch of the Forest Service have worked jointly to develop four expert systems in the Inland West. These seed transfer programs are distinct by species and in some cases, by variety. The first three PC-based expert systems are for ponderosa pine: (1) *Pinus ponderosa* var. *ponderosa* in eastern Washington, the entire state of Idaho, and western Montana, (2) *Pinus ponderosa* var. *scopulorum* for Utah and Nevada, and (3) *Pinus ponderosa* var. *scopulorum* for Arizona and New Mexico (Rehfeldt 1991, Monserud 1990). An interior Douglas-fir (*Pseudotsuga menzeseii* var. *glauca*) expert system is available for the combined areas of eastern Washington, and all of Idaho and Montana. Development is continuing for Engelmann spruce (*Picea engelmannii*) in the Intermountain Region (southern Idaho and Utah).

Seed transfer guidelines are also closely tied to conserving biodiversity and thereby improving forest health. An often ignored aspect of conserving genetic diversity is pollen management. Once off-site plantings reach reproductive maturity, these non-native sources can contaminate native gene pools.

The use of seed transfer guidelines, be it by seed zone maps or an expert system, have increased the percentage of seedling survival, reduced the loss of growth from poorly adapted seedlings, and reduced the extreme growth variability in planted areas. Seed transfer guidelines reduce maladaptation by eliminating off-site planting, but neither improve or degrade the overall genetic quality of a species. Seed transfer guidelines also facilitate the design of selective breeding programs, particularly when there is biologically significant genetic variation at the provenance or stand level.

SELECTIVE BREEDING PROGRAMS

Selective breeding programs increase our ability to better manage adaptation and increase genetic gain. Improvements in forest health are achieved through selective breeding programs when the traits of interest focus on adaptation and insect and disease resistance. The emphasis on tree species in the Northern and Intermountain Regions include western white pine (*Pinus monticola* Dougl. ex. D. Don), western larch (*Larix occidentalis* Nutt.), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws), Douglas-fir (*Pseudotsuga menziessi* var. *glauca* (Beissn.) Franco), and lodgepole pine (*Pinus contorta* Dougl. ex. Loud.). Table 1 highlights the traits of interest by species. Justifications for tree improvement programs have historically focused on increasing wood productivity per acre. The thumbnail sketch of programs for the Northern and Intermountain Regions (Table 1) place priority emphasis on those traits that contribute to improving forest health, and secondarily on growth. The ability to identify resistant families and individuals within families in our test plantings rely on opportunitistic measurements. Our ability to make progress in these resistance traits depends upon genetic variation in the host, uniform infection, and high enough infection levels to detect differences, in the absence of artificial inoculation and infection procedures.

Table 1.—Traits of interest targeted to improve forest health conditions in selective breeding programs in the Inland West.

Species	Traits of interest (priority order)
Western white pine	Blister rust resistance: adjusted bark reactions, needle lesion frequency, early stem symptoms, tolerance to cankers (horizontal resistance), no spots, needle shed, short shoot response, and bark reaction (vertical resistance). Growth.
Western larch	Cold hardiness Growth Meria needle cast resistance[a]
Ponderosa pine	Growth Western gall rust resistance[a] Tip moth resistance[a]
Douglas-fir	Cold hardiness Growth Root disease resistance[a] *Rhabdocline* and Swiss needle cast resistance[a]
Lodgepole pine	Growth Western gall rust resistance[a] Terminal weevil resistance[a]

[a]Additional family and within-family selection criteria when data are available in test populations.

There are several ways geneticists and land managers can incorporate additional insect and disease resistance into tree species. The process begins with generating a list of pest problems, classifying lands based on presence of a pest and risk associated with the host species, and determining the cause and effect of these pests. The next step involves reviewing effective control measures and their cost-benefit ratio.

From a genetics standpoint, one control measure may be as simple as identifying an appropriate seed source for planting. In other cases, exotic pest problems warrant selective breeding, which strives to build resistance levels in the host population. As a rule of thumb, there needs to be at least five percent of the total variation present at the family level, in one or more traits of interest, to make any progress in adaptation or insect and disease resistance. A good example of an exotic pest problem being effectively "treated" via selective breeding is the western white pine blister rust resistance program.

Blister Rust Resistance in Western White Pine

There are approximately 90 known rust diseases on North American conifers, with two being most serious (Kinloch 1982, Hepting 1971). Fusiform rust (*Cronartium quercum f. sp. fusiforme*) is a native pest of southern pines, while white pine blister rust (*C. ribicola* Fisch.) is an exotic pest of white pines. Diversity of resistance genes is the most effective means of stabilizing pathogen populations, which is why tree improvement programs shouldn't focus on single-gene resistance mechanisms or breeding for immunity.

Land managers and academicians are questioning the utility of continued selective breeding for blister rust resistance in western white pine. Much progress has been made in the Phase I program, with production seed orchards exhibiting resistance levels of 35–65% over standard woodsrun collections (Howe and Smith 1994, Bingham et al. 1971). The Phase I program is certainly a success story, but should carry a "warning label", in that the continued success of the Phase I program rests on no new virulent genes of blister rust getting a foothold in plantings or remnant populations of western white pine. Single-gene resistance in western white pine (McDonald et al. 1984) and sugar pine (Kinloch and Dupper 1987) has already failed in geographically limited areas. Moreover, agricultural crop failures are well documented in the literature, when breeders have relied on single-gene resistance mechanisms to combat native or exotic pest problems (Vanderplank 1984, 1975).

What role does the Phase II program and advanced generation breeding play in restoring western white pine in Interior Cedar/Hemlock/White Pine ecosystems? Restoring western white pine to a significant forest type in the Inland Northwest requires a consistent reforestation program on a large scale. It will also require a continued commitment to research and development to assure that adequate rust resistance is maintained over time in western white pine. Phase I seed orchard donors share a limited genetic base, with resistance based on three, putative single-gene resistance mechansims. Since western white pine has not shared several generations of coevolu-

tion with this exotic pest, it is impractical to assume that the existing resistance levels are permanent.

As knowledge of the resistance mechanisms developed, and the focus of the Phase II program embraced both horizontal and vertical resistance mechanisms, as well as growth, additional plus tree selections were needed to broaden the genetic base to meet the new program goals (Howe and Smith 1994). These 3,098 new selections were completed in 1976. Inoculated seedlines are presently screened for eight resistance traits, four of which suggest polygenic inheritance (Table 1). Scoring these Phase II selections is anticipated to be completed by 2003.

The top Phase II families are selected on the four resistance mechanisms that suggest polygenic inheritance. This selection strategy is like an insurance program. In the event that a new race of rust neutralized a single-gene resistance mechanism, it is highly unlikely it would also contain the appropriate mutations at multiple loci to neutralize the polygenic resistance mechanisms. Packaging this horizontal resistance among families provides resistance levels in the range of 30–35% over woodsrun material. But like an insurance policy, development of stable rust resistance requires that the "insurance premium" be paid, by maintaining a selective breeding program. The selection strategy also chooses individuals within the top families which possess one of the four single-gene traits. When the number of resistant individuals exceeds the selection target, individuals are also selected for superior height-growth performance. This family and within-family selection strategy, coupled with a blocked seed orchard design, should increase resistance levels to 100%, with modest improvements in growth (Mahalovich and Eramian in prep.).

Advanced generation breeding began in 1995 among the Phase II elite families that have been identified to date. The selection strategy continues to develop horizontal and vertical resistance traits and growth, whereas the breeding strategy incorporates small replicate populations (sublines) to manage inbreeding and to maintain the genetic base. These strategies for advanced generations are an extension of the original breeding program (Bingham et al. 1971) in an effort to: (1) stablize the balance between host and pathogen, (2) meet biodiversity objectives, (3) sustain long-term

improvements, and (4) provide flexibility for changes in program direction as knowledge increases and/or product demands change.

Whether it is breeding for adaptation and/or pest resistance, a typical selective breeding program culminates in seed orchard establishment. There must also be an active reforestation program to deploy these seeds, to capture the payoff of improved insect and disease resistance, cold hardiness, and growth. The Western Forest Health Initiative (1994) identifies a series of recommended actions that the Forest Service can take over the next two years. Meeting the annual seed needs to produce 3–4 million rust-resistant seedlings will involve a sustained, long-term commitment in selective breeding to restore Inland Northwest forests.

With little additional effort, inoculation and screening techniques employed to develop blister rust resistance in western white pine can also be extended to improve blister rust resistance in populations of whitebark pine (*Pinus albicaulis* Engelm.) (Hoff and Hagle 1990). Basic research is still needed to unravel patterns of genetic variation in unstudied species to better understand host-pest interactions, and to assist in conserving genetic diversity through seed transfer guidelines and pollen management.

Tree Improvement and Other Insect and Disease Problems

Table 2 and Table 3 list some of the native insect and disease problems in the Inland West where progress could be made in low (cone collections from resistant trees) or high level (selective breeding) programs to build resistance in the parent population. When resistance was observed among individuals, but statistical significance among provenances or families was not explicityly reported, columns report a dash (—). Severity or impact of the pathogen/pest was gleaned from several sources, and lends itself to debate among managers and researchers (Byler et al. 1994, Hagel et al. 1990).

Disease Resistance

Genetic-based resistance to infection resulting from coevolution of forest trees and their patho-

Table 2.—Inland Northwest disease problems with a genetic component in host conifer species.

| Disease of Concern | Impact | Species[a] | Genetic Differences | | Citation |
			Provenance	Family	
Dwarf Mistletoe					
Arceuthobium sp.	High	PP	*[b]		Scharpf and Roth 1992, Roth 1974
Foliar Diseases[c]					
Lecanosticta sp.	Low	WP		**	Hoff and McDonald 1978
Lophodermella concolor	Low	LP	**	**	Hunt et al 1987, Hoff 1985, Rehfeldt 1987, 1985, Hunt 1981
Lophodermium sp.	Low	PP	**	**	Hoff 1988b
Meria laricis	Mod	WL	*	*	Rehfeldt 1992
				**	Mahalovich unpublished data
Rhabdocline sp.	Mod	DF	**	*	Hoff 1987, Stephan 1973
Root Disease					
Armillaria	Low	WL	NS	*	Hoff and
ostoyae	Low	WP	NS	NS	McDonald 1994
Western Gall Rust *Endocronartium harknessii*	Low	LP	**	**	Hoff 1992 van der Kamp 1988, Martinson 1980
	Mod	PP	**	**	Hoff 1991a, 1991b, 1990, 1986
White Pine Blister Rust *Cronartium ribicola*	High	WP	NS	**	Hoff and McDonald 1972, McDonald and Hoff 1975,
	High	WBP		—	Kinloch 1982 Hoff and Hagle 1990

Source (Hoff and McDonald 1994)

[a]*LP=lodgepole, PP=ponderosa, WP=white, WBP=whitebark pines, WL=western larch, and DF=Douglas-fir.*

[b]*** Denotes a significant difference at the 1% level (p=0.01)*

** Denotes a significant difference at the 5–10% level (p=0.05–10)*

NS = No statistically significant difference.

— Resistance observed, needs further testing.

[c]*Impact of needle diseases may be moderately damaging on young trees, but overall impact on growth is generally small.*

gens has been the chief means of disease control in natural ecosystems (Vanderplank 1984). There are a large number of native insects and pathogens that are in a dynamic genetic equilibrium with their host species (Byler et al. 1994). Understanding this resistance, maintaining it and applying seed transfer guidelines, guard against an imbalance that could lead to large-scale problems such as bark beetles, western spruce budworm, root disease, dwarf mistletoe, and western gall rust.

The prevailing management philosophy for native disease problems is that damage can be effectively controlled by silvicultural methods. For example, dwarf mistletoe tends to be host specific so manipulation of tree species composition can reduce infection levels. This philosophy discounts the availability of resistant stock to enhance silvicultural control programs or fails to acknowledge that investments being made in improving other traits would already bear some of the costs for

Table 3.—Inland Northwest insect problems with a genetic component in the host conifer species.

Insect of Concern	Impact	Species[a]	Genetic Differences		Citation
			Provenance	Family	
Gouty Pitch Midge *Cecidomyia piniinopis*	Mod	PP	*[b]	**	Hoff 1989, 1988
Mountain Pine Beetle *Dendroctonus ponderosae*	Low	LP	—	—	Raffa and Berryman 1987
Western Spruce Budworm *Choristoneura occidentalis*	Mod	DF	*	*	McDonald 1985, 1982
Terminal Weevil *Pissodes terminalis*		LP	**	**	Hoff unpublished data
Tip Moth *Rhyacionia* sp.		PP	—	*	Kegley et al. 1994, Mahalovich unpublished data

Source (Hoff and McDonald 1994)

[a]LP=lodgepole, PP=ponderosa, WP=white, WBP=whitebark pines, WL=western larch, and DF=Douglas-fir.
[b]** Denotes a significant difference at the 1% level (p=0.01)
* Denotes a significant difference at the 5–10% level (p=0.05–10)
NS = No statistically significant difference.
— Resistance observed, needs further testing.

building genetic resistance to native diseases (Martinson 1980, Roth 1974). When dwarf mistletoe occurs in pure stands, planting other species or clearcutting to remove the infected stand may not be feasible or silviculturally desirable (Scharpf and Roth 1992). So in some cases, an active selective breeding program may be warranted.

Insect Resistance

McDonald (1982) pointed out that foresters are attracted to resistance because it generally does not require repeated attention and is easily incorporated into integrated pest management plans. Resistance to insects has been found in forest trees (Hoff and McDonald 1994, Hanover 1976, Gerhold 1966). Genetic variation present in hosts to various insects in the Inland Northwest is partially summarized in Table 3.

Building resistance relies on "attraction" elevated to "need", and the ability to develop reliable (repeatable) progeny test screening procedures. For the time being, screening of families and individuals for insect resistance will be handled

opportunistically in genetic tests. This approach has proven effective in identifying families resistant to tip moth (*Rhyacionia* sp.) on ponderosa pine (Mahalovich, unpublished data) and terminal weevil (*Pissodes terminalis*) on lodgepole pine progeny tests (Hoff, unpublished data).

Tip moth infestation in an early selection trial for low-elevation ponderosa pine in Idaho was reported by Kegley et al. 1994. Collaborative efforts with Kegley et al. (1994) made it possible to detect family differences in tip moth damage (Mahalovich, unpublished data). These data were used to incorporate resistance to tip moth damage in production seed and breeding orchards, without reducing gains in height-growth or quality, by adding this additional trait to the selection index.

Recommendations for Building Insect and Disease Resistance

Efforts to build resistance levels can be as simple as identifying resistant parent trees for operational

cone collections, for propagating in seed orchards, or for placing these parent trees in selective breeding programs. Selection of resistant parent trees should be avoided in low infection areas or from infected trees in general. Desirable candidates are those that are in high infection areas but are free of infection or are free of symptoms in spite of being infected. For selective breeding to be a viable option there needs to be: (1) a "market" for resistant planting stock, (2) a good return on the investment (plus tree selections, testing, and seed orchard establishment), and (3) development of reliable inoculation/infection test procedures.

SUMMARY

Forest health means balancing the detrimental effects of endemic insects, pathogens, and other agents on resource values over the short-term, against their beneficial ecological functions over the long-term (Byler et al. 1994). This paper serves to briefly outline the efficacy of applied genetics as one of the tools available to improve forest health. Genetic resistance is essential for restoring our forests, and progress can be maintained with a continued commitment to the western white pine selective breeding program and application of seed transfer guidelines, and further development of expert systems for western larch and lodgepole pine. Moreover, maintaining existing tree improvement programs provides the opportunity to assess and monitor genetic resistance to insects and diseases.

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Silvicultural Practices (Commercial Thinning) Are Influencing the Health of Natural Pine Stands in Eastern California

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Abstract.—Overstocked 70- to 90-year-old stands of ponderosa pine on medium to low quality sites were thinned in 1980 to 40, 55, and 70 percent of normal basal area and compared to an unthinned control. Mortality was recorded annually. Growth was measured every 5 years from 1980 to 1994. After 15 years, mortality, primarily from bark beetles and annosus root disease, was reduced by 100, 96, and 92 percent relative to increasing amounts of reserve basal area. Thinned stands averaged six times more cubic-foot growth than unthinned stands. More growth and less mortality could result from treating similar stands on comparable sites.

INTRODUCTION

Loss of trees to insects and diseases is a serious problem in unmanaged, young-growth stands in the eastside pine type of northeastern California (McCambridge and Stevens 1982). The interior ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) forest type covers about 3.5 million acres of the Modoc Plateau, which is located in the northeastern part of California (Helms 1980). In 1994, the Modoc National Forest, one of several forests located on the Modoc Plateau, had 57,600 acres of mortality caused by new pest infestations. This single-year total represents 2 percent of the total acreage on the Plateau, or 132,758,220 cubic feet of volume. Insects and diseases caused about 75 percent of this mortality. These losses in tree growth and mortality are a direct result of stress.

In many instances, stress, particularly drought stress, is compounded by overstocking. When manipulated, stand density could lead to improved growth rates and discourage the attack of certain insects-especially bark beetles. Research on bark beetles in the western United States indicates that silvicultural practices such as thinning have significantly reduced the impact of insects on forest stands (Hall and Davies 1968).

This paper quantifies the effectiveness of three levels of thinning relative to an uncut control in an overstocked 70- to 90-year-old ponderosa pine stand in northeastern California.

STUDY LOCATION AND ENVIRONMENT

This study, at Poison Lake, is part of a Forest Service Regional Administrative Study on commercial thinning begun in 1974 on several National Forests in northern California. Poison Lake is located in northeastern California on the Eagle Lake District of the Lassen National Forest.

The climate of the study area, which is located at an elevation of about 5600 feet, is characterized by hot, dry summers and cold, moist winters. Temperatures range from –30°F to 110°F with annual mean of 50°F. The growing season is about 120 days. Most precipitation falls as snow and averages about 20 inches per year.

The soils are part of the De Masters/Patio Families. These families consist of moderately deep to deep, well-drained soils formed from weathered

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rhyolite, basalt, and andesite. The area is relatively flat and uniform in terms of aspect, slope, and vegetation, which is primarily ponderosa pine, with an occasional incense-cedar (*Libocedrus decurrens* Torr.). Conifer age ranges from 70 to 90 years. Understory vegetation is sparse and composed of scattered greenleaf manzanita (*Arctostaphylos patula* Greene) and rabbitbrush (*Chrysothamnus* spp.).

METHODS

Beginning in summer 1980, data was recorded annually through the 1994 growing season. The permanent plots in this study are included in the national Forest Pest Management Technology Development Project, Pest Trend-Impact Plots in the West, and as such should continue for several years.

The silvicultural prescription was commercial thinning. Stand characteristics before and after thinning for each treatment and the control were recorded (table 1). Stands to be treated were thinned in summer and fall by removing obviously injured, diseased, and slow-growing trees as well as trees of poor form. In general, only the more vigorous dominant and codominant trees were considered as reserve trees. In a few instances, intermediate trees of good growth and form were left to prevent creating large holes in the treated stands. Incense-cedars, plus all suppressed, most intermediate, and codominant and dominant pine trees with mechanical injury, animal damage, and symptoms of pest damage were removed. Healthy dominants and codominants were harvested if necessary to attain the target basal areas. A general rule was that spacing was considered secondary to leaving vigorous crop trees.

Table 1.—Poison Lake stand characteristics before and after treatment, 1980.

Treatments (% of normal)	Trees		Basal area		
	Before	After	Before	After	Normal[1]
	(no./acre)		(ft²/acre)		
40	768	60	200	80	200
55	617	93	170	100	190
70	712	131	220	140	210
Control	729	729	190	190	200

[1]*From Meyer, 1938. Indicates complete occupancy of the site by trees.*

The objective of this study was to create treated units thinned to 40, 55, and 70 percent of normal stocking, and an unthinned control. Normal stocking indicates full occupancy of a site by the trees. The normal values for the stands in this study were based on those reported by Meyer (1938). Each of these four treatments, including the control, was replicated three times, in a complete randomized block design. Analysis of varience and Tukey tests (Hamilton 1965) were used to analyze the data. Significance in all tests was at $\alpha = 0.05$.

Leave-tree marking and special logging methods were used to minimize injury to pines. Marking the leave trees makes them easy to see and less susceptable to logging damage (Aho and others 1983a). Special considerations included directional felling, limited size and type of logging equipment, straight-line skid trails, endlining of logs, limited log lengths, and no tree-length skidding. All harvested trees were scaled to determine the volume removed. To minimize insect buildup, logging slash was lopped to a 3-inch top and scattered to a maximum height of 18 inches.

To determine the structure of the stands before and after treatment, all trees 1 inch in diameter at breast height (d.b.h.) and larger were measured for basal area, cubic foot volume, and classified for crown class. Trees were also recorded as merchantable or unmerchantable. An unmerchantable tree would not yield a commercial log at least 8 feet long and 6 inches in diameter inside bark at the small end. Stocking of trees less than 1 inch d.b.h. was estimated from ten randomly selected one-fortieth acre plots in each replication. One percent of the dominant and codomimant trees were randomly selected and measured by dendrometer to determine stand volume, and then remeasured at the end of the fifth and tenth growing seasons to determine growth.

Conifer mortality was recorded annually in October and classified by d.b.h., crown class, and associated pests.

RESULTS

In 1980 before treatment, analysis of variance indicated no significant difference in tree mortality (p>0.05). In 1994 the thinned areas differed signifi-

Table 2.—Poison Lake merchantable tree mortality, 15 years after treatment, by normal basal area.

Treatments (% of normal)	Mortality		
	Average (no./acre/year)	Reduction from control (pct.)	Range (no./acre/year)
40	0.0a[1]	100	0
55	0.1a	96	0–0.5
70	0.2a	92	0–0.8
Control	2.5b	0	0–5.2

[1]Values in each column followed by the same letter do not differ statistically at the 0.05 level.

cantly in mortality (p<0.05) from the control regardless of thinning level (table 2). No significant difference in tree mortality among thinning levels was found (p>0.05).

In 1994, or after 15 years, merchantable tree mortality after thinning was almost eliminated. This reduction would have been even more dramatic if all the unmerchantable trees that died in the control were included in the comparison. Bark beetles, alone and in combination with root diseases, were the most common causes of tree mortality. About 30 percent of tree mortality could not be attributed to a specific casual agent, ie. bark beetles, root diseases, etc., because no external signs of damage could be found. In such cases, mortality was attributed to the effect of suppression. Most of the trees in the thinned areas that died were in the intermediate crown class. As noted earlier, these trees were left to prevent large unstocked holes in the stand. Most of the dead trees were later diagnosed as having annosus root disease that was undetected before thinning.

Mortality by d.b.h. class was determined. In the control, 65 percent of mortality was in unmerchantable trees (6 inches or less in d.b.h.). These trees were not potential crop trees, and their loss did not affect the future stocking of the stand. More importantly, 35 percent of the mortality was in merchantable trees. These larger trees would have contributed significantly to the growth of the stand. Several of the largest trees in the control died and this reduced the volume of the stand substantially.

Mortality by crown position for all treatments was also calculated. Eighty-two percent of mortality was in trees of the intermediate and suppressed crown positions. These were usually the smaller, less thrifty trees in the stand and, as noted previously, were not crop trees. In all of the thinned treatments, few if any of these "poor" trees remained. In the control, a large portion of the stocking was in trees of intermediate or suppressed crown positions. But the remaining 18 percent of mortality was trees in the dominant and codominant crown positions and would significantly effect stand growth and yield. Because of limited site resources in the overstocked control, it is doubtful if many of the surviving trees will increase growth enough to make up the loss created by the death of the larger trees.

A factor that can increase pest-induced mortality to trees is injury from the thinning operation. Mortality and loss of tree volume that result from decay initiated by mechanical injuries during the stand management activities can be substantial (Aho and others 1983b), particularily if logged in the spring when the bark is easily dislodged. This was not the case at Poison Lake, however, as these losses were minimized through the use of the specified safeguards. No leave trees were damaged during the thinning operation.

Growth in thinned areas for the first 10 years ranged from 0.61 cubic feet to 1.07 cubic feet per tree per year (table 3). Growth in the control averaged only 0.13 cubic feet per tree per year. The thinning level that produced the most growth, an increase of 713 percent over the control, was 40 percent of normal stocking. The level that produced the least growth was 55 percent of normal (369 percent of control). The 70 percent level produced an intermediate amount of growth (469 percent of control). Taken together, growth of the thinned stands increased an average of 600 percent over the control.

Table 3.—Ponderosa pine growth, Poison Lake, 1980–1990.

Treatments (% of normal)	Growth/tree (ft³/year)	Gain relative to Control (pct.)
40	1.07	713
55	0.61	369
70	0.74	469
Control	0.13	—

If this growth per tree is expanded to growth on a per acre basis, total stand growth for the 1980–1990 period is highest in the control. This is a direct result of number of trees per acre. The control had 13 times as many trees per acre as the average number of trees in the thinned areas. But this growth is spread over more than 700 trees per acre, many of which are unmerchantable and unthrifty. Mortality will continue to remove these trees from the stand, and the volume represented by them will be lost. Even if they did survive until harvest, they would be too small to be merchantable. Common practice is to eliminate these trees during the slash disposal operation after harvest. In contrast, all the growth on the thinned areas is being put on trees that are already merchantable. When time comes for harvesting these stands, this volume will be removed by the harvesting operation and add value to the total yield from the stand.

DISCUSSION

Thinning significantly reduced ponderosa pine mortality in comparison to unthinned controls in a 70-to 90-year-old stand of eastside pine. The significance of this reduction is increased by the fact that during the period of the study, 1980–1994, a severe drought affected the area. In 7 of the 15 years of the study, precipitation was substantially below normal. Unthinned plots lost more than 2 merchantable trees per acre per year. Thinned plots lost only 0.1 to 0.2 trees per acre per year. These trees were of the intermediate crown position. After they died, most were diagnosed as having annosus root disease. No tree mortality occured at stand basal areas of less than 95 square feet (a value that is slightly less than 55 percent of normal) per acre. This value agrees well with that from an earlier study by Oliver (1979) who showed that the optimum stocking level was about 110 square feet per acre in similar stands, implying that mortality below this level of stocking was minimal.

The three levels of thinning tested in this study reduced mortality and affected growth of the ponderosa pines. After 15 years, thinning of the stand to 40 percent resulted in no mortality. And because the desired leave basal area was relatively low compared to the other treatments, the thinning

operation left only rapidly growing trees in this treatment. This complement of rapidly growing trees contributed to the highest per-tree growth performance for the 40 percent treatment, although total growth/acre was penalized by having to remove some of the thrifty dominant and codominant trees in order to reach the desired basal area level. Stands cut to the 70 percent level experienced some mortality, which seemed to be a consequence of leaving less-thrifty trees to reach required stocking levels. Leaving such trees also reduced per-tree growth as compared to the 40 percent treatment, but growth for the 70 percent treatment still ranked intermediate when compared to the other treatments. The 55 percent level experienced less mortality than the 70 percent level and more mortality than the 40 percent level, and ranked last in volume growth compared to the other thinning treatments.

Although overall tree mortality in the treated stands was low, a pattern between cause and timing was evident: if the casual agent was bark beetles, the trees died within 2 years of thinning; if root disease followed by bark beetle attack was the cause, the trees died several years later.

Because of the low incidence of annosus root disease before thinning, no preventative measures were applied to thinned stands in this study. A manager contemplating thinning stands where this disease is prevalent should consider using borax as a means of preventing new infestations.

The notion that pests kill only unthrifty, slow-growing trees is dispelled by this study. Over 30 percent of the mortality in the study was to merchantable trees, almost all in the control. Almost a fifth of the mortality was to dominant and codominant trees, again in the control.

Thinning not only reduces stand mortality and increases growth, but it also yields a positive return to the landowner. Timber sale budget data from the USDA-Forest Service Pacific Southwest Region show that the average bid price for pine of this size and form class is $22 per cunit (1 cunit = 100 cubic feet). Timber management costs for sale preparation and administration were $11 per cunit. Consequently, net revenues realized from thinning stands similar to those in this study amount to $11 per cunit. Data from these plots indicate that a

typical acre of well-stocked eastside pine thinned to 55 percent of normal basal area will yield 800 cubic feet. Fifty-five percent was selected for two reasons: (1) it is the thinning standard recommended for eastside pine by the Forest Service in California, and (2) it provides a conservative estimate of the gain from thinning. Multiplying 8 cunits times $11 per cunit equals $88 per acre - the net yield per acre from thinning.

Improved average growth of thinned stands, 70 to 90 years old, (600 percent of control growth) has strong implications for managers. A manager can apply an additional thinning which would increase the total yield of the stand during the rotation. When applied to the tens of thousands of acres of stands of this age in California, the increase in yield would be substantial.

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Is Self-Thinning in Ponderosa Pine Ruled by *Dendroctonus* Bark Beetles?

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Abstract.—Stand density of even-aged stands of ponderosa pine in California seems to be ruled by *Dendroctonus* bark beetles, rather than the suppression-induced mortality common for other tree species. Size-density trajectories were plotted for 155 permanent plots in both plantations and natural stands. Bark beetle kills created a limiting Stand Density Index of 365 which differed little between stands on poor sites east and good sites west of the crest of the Sierra Nevada and Cascade Range. Although good sites would be expected to carry a greater stand density than would poor sites, more explosive bark beetle populations and density-related stem breakage cancel this site advantage.

INTRODUCTION

Northern California has experienced below normal precipitation for 6 of the last 8 years. This moisture deficit coupled with the rapid build up of stand density common in even-aged ponderosa pine (*Pinus ponderosa* Dougl.ex Laws. var. *ponderosa*), especially plantations, has placed many stands at risk from attack by bark beetles. Eaton (1941) was probably the first to recognize the importance of thinning in "bug proofing" stands. Unfortunately, fire destroyed his research plots in the Warner Mountains of northeastern California before results were achieved. Sartwell (1971) continued this work 15 years later and together with Stevens (Sartwell and Stevens 1975) and Dolph (Sartwell and Dolph 1976) established a threshold value of 34 m^2 per ha (150 ft^2 per acre) of basal area above which stands east of the Cascades in Oregon and Washington became susceptible to bark beetle attack. This value has since become well accepted in practice there, as well as, in California.

In California, and especially on the productive sites on the westslope of the Sierra Nevada and Cascade Range, bark beetle-stand density relationships are less well-known. In 1953, Clements was the first to recognize the relationship between stand density and mountain pine beetle (*Dendroctonus ponderosae* Hopkins) mortality. Most entomological investigations, however, have been concerned with the western pine beetle (*D. brevicomis* LeConte) in large, mature trees, because of their high economic and aesthetic value. The influence of stand density on bark beetle mortality of young, even-aged stands of ponderosa pine on the westside is less well-known. Information that does exist is anecdotal because no formal studies have been undertaken.

Sartwell's work suggests that bark beetles are ubiquitous regulators of stand density in young, even-aged stands of ponderosa pine. If this is true, does the Self-Thinning Rule apply? And can a bark-beetle-limited Stand Density Index (SDI) (Reineke 1933) be defined? Also, a question remains as to whether Sartwell's threshold value of 34 m^2 per ha (150 ft^2 per acre) of basal area applies to California and especially to the productive westside sites. The size-density relationship for even-aged ponderosa pine is described and this relationship is compared east and west of the Sierra Nevada and southern Cascade Range crest. Long-term stand development and subsequent

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bark beetle mortality in two levels-of-growing-stock studies are presented as examples.

BARK BEETLES AND THE SELF-THINNING RULE

The Self-Thinning Rule, also known as the –3/2 Power Rule, was proposed some 30 years ago as a universal size-density relationship that applies equally well to fish in a pond and trees in a stand (Yoda et al. 1963). Sixty years ago, Reineke (1933) introduced the rule for forest stands, naming it Stand Density Index. It is calculated as

$$\text{SDI} = N^{(\log N + 1.77 \,*\, \log D - 1.77)}$$

in which

log = logarithm to the base 10
N = number of trees per acre
D = average stand diameter at breast height in inches.

Reineke proposed a slope for the maximum density line of –1.605. A slope of –1.77, however, has been found to be a better fit for ponderosa pine data sets both in California (Oliver and Powers 1978) and in central Oregon and Washington (DeMars and Barrett 1987). This slope fits this data set, as well. Stand Density Index is displayed with size on the "X" axis and density on the "Y" axis, hence the slope of –1.77. The Self-Thinning Rule is traditionally, displayed with the axes reversed, as in Figure 1.

SDI has a distinct advantage over basal area as a measure of stand density because it is not significantly affected by age and site quality. If a constant SDI indicates the same site occupancy across a range of stand diameters, and site occupancy is a true measure of bark beetle susceptibility; then, a single SDI value would indicate a threshold of susceptibility without reference to mean diameter, site quality, or age. No direct conversion from SDI to basal area per ha is possible, however, because many combinations of mean stand diameter and number of trees will produce identical SDIs but different basal areas.

Size-density trajectories were plotted for 155 long-term permanent plots in both plantations and natural stands throughout northern California (fig. 1A). Twenty-three percent of the plots suffered bark beetle mortality. A size-density relationship is demonstrated with a bark-beetle-limiting SDI 365. This value is considerably below the maximum SDI of 500 used in Region 5 or 429 used in Region 6 for the Forest Vegetation Simulators (Stage 1973) in their respective areas (Personal communication with Gary E. Dixon, USDA Forest Service, Timber Management Service Center, Ft. Collins, CO, April 25, 1995). The SDI values used by the Forest Vegetation Simulators are maximum values, intrinsic to the species, and caused by competition-induced mortality. Occasionally and for short periods, some stands may reach such high levels before bark beetles attack.

It could be argued that a SDI of 365 is the result of increased bark beetle activity during the recent drought. Though this is reasonable, it is refuted by the fact that SDI 365 is identical to the SDI value derived by DeMars and Barrett (1987) from a least squares fit of the natural stand data Meyer (1938) used to construct his normal yield tables.

My contention that bark beetles and ponderosa pine stand development are inexorably linked seems to be supported by the Meyer's basal area-age relationship. Basal area of most other species rises continuously, albeit progressively more slowly, throughout the range of ages presented. In contrast, Meyer's figure 4 shows basal area building up rapidly and then plateauing sharply at age 60 which is about the age when maximum stand density is reached. This is the age at which Sartwell (1971) claims mountain pine beetle outbreaks begin. Actual stand data would, of course, trace a sawtooth pattern after age 60 as episodes of beetle kills reduce the basal area and growth of surviving trees subsequently builds back the basal area.

Stands that approach SDI 365 usually suffer large losses from bark beetle epidemics—losses that equal or exceed periodic growth. However, less dense stands often experience low levels of mortality from endemic populations. Figure 2 suggests that beetle kills from endemic populations can begin when stands reach SDI 230. This stand density could be characterized as the beginning of a "zone of imminent bark beetle mortality." It should be noted, also, that bark beetle epidemics often continue to reduce stand density to levels far
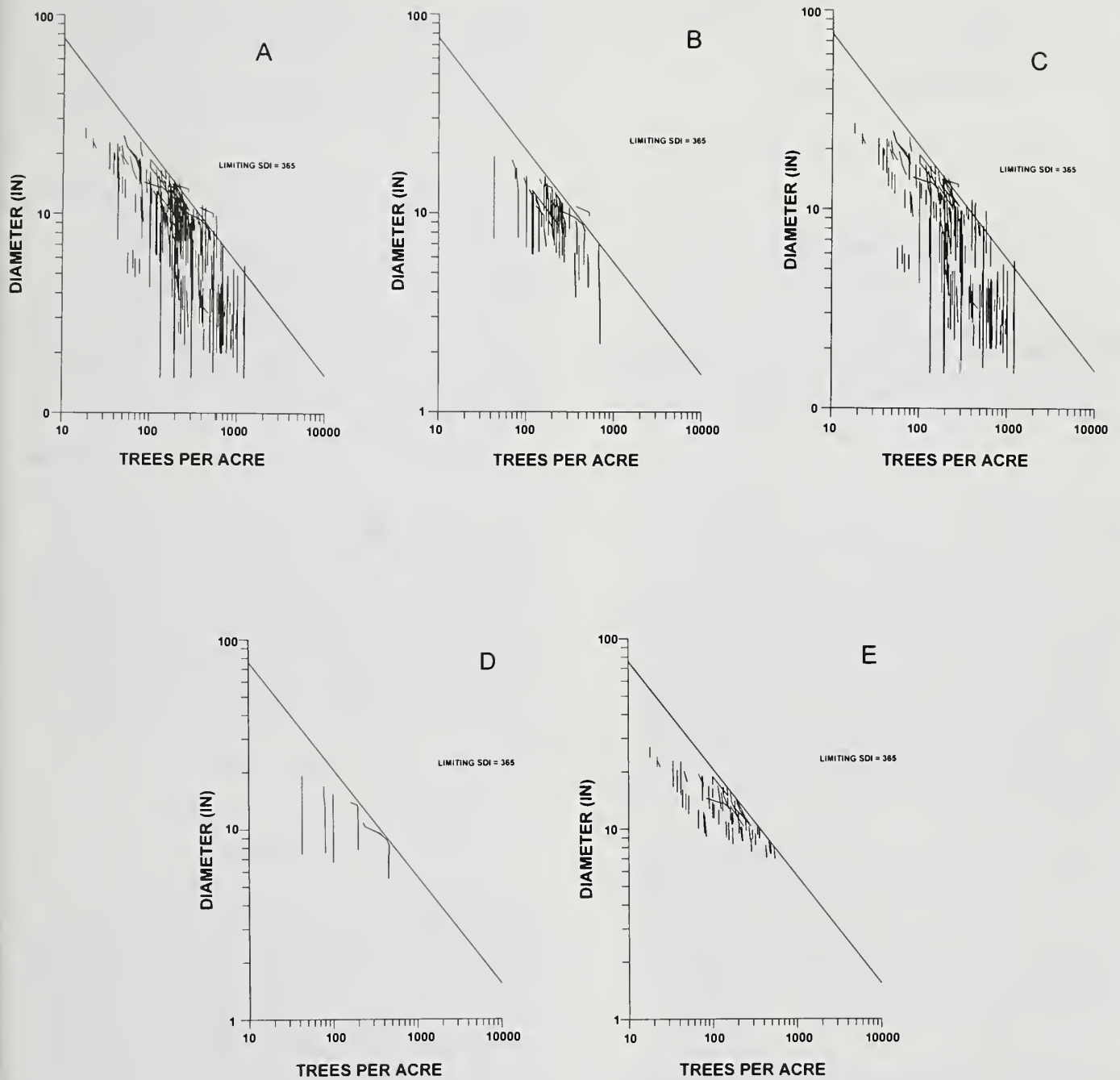
Figure 1.—Size-density trajectories plotted on log-log scales for (A) 155 permanent plots throughout northern California, (B) east and (C) west of the Sierra Nevada and Cascade Range, and levels-of-growing-stock studies at (D) Sugar Hill on the eastside and (E) Elliot Ranch on the westside.
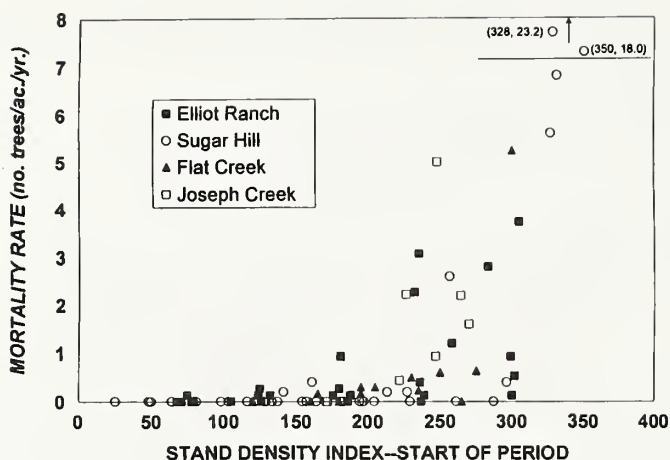
Figure 2.—The relationship of stand density to rate of mortality form *Dendroctonus* bark beetles did not differ between even-aged ponderosa pine stands east and west of the Sierra Nevada and Cascade Range. Flat Creek data from Cochran and Barrett (1993).

below the density that triggered the epidemic and well into this zone of imminent mortality.

The size-density trajectories shown in figure 1 often break off sharply when trees die, rather than forming a gently curving asymptote. In bark beetle epidemics, many trees are killed in a season, large as well as small. Because beetle kills do not cause an increase in average diameter of the residual trees, as when death is concentrated in the subordinate crown classes, the size-density trajectory tends to form a 90° angle.

Because plots are located both east and west of the Sierra Nevada and Cascade Range crest, differences in limiting SDI can be examined between these regions (fig. 1B and C). It appears that limiting SDI for eastside stands maybe a little lower than that for westside stands, but more data are needed to be certain real differences exist.

EXAMPLES FROM LEVELS-OF-GROWING-STOCK STUDIES

Bark beetle-stand density interactions in two levels-of-growing-stock studies, one east and the other west of the Sierra Nevada and southern Cascade Range crest, suggest reasons why differences in limiting SDI between east and west sides may be minor.

Sugar Hill

Four growing stock levels are under test in the extensive plantations at Sugar Hill in the Warner Mountains east of the southern Cascade Range crest (Oliver 1979a). (Incidently, Sugar Hill is near where Eaton (1941) attempted his pioneering study 50 years ago.) The site index of 29 m (95 ft) at 100 years (Barrett 1978) is better than average for the area. Trees were planted to a 2.4- by 2.4 m (8- by 8-ft) spacing in spring 1932. Early survival and growth were good for those days. By 1959, when the study began, the plantation was 28 years old, 15.2 cm (6 in.) in diameter at breast height (dbh) and 5.5 m (18 ft) tall. The four unreplicated plots were thinned to a wide range of SDIs—25, 50, and 128 and the unthinned control of 157. Plots have not been rethinned in the intervening 36 years.

At Sugar Hill stand density in the unthinned plot built steadily to SDI 327 at which time the mountain pine beetle began killing large numbers of trees (fig. 1D). The killing began at age 48 and has continued to the present, killing half the trees and reducing SDI to 264. Killing began 10 years later in the plot thinned to SDI 128, when that plot reached SDI 331. Beetles in this plot have killed 23 percent of the trees, reducing SDI to 291. Similar patterns were found in a nearby natural stand at Joseph Creek and in a plantation at Flat Creek in central Oregon (Cochran and Barrett 1993) (fig. 2).

Elliot Ranch

Five growing stock levels are under test in the Elliot Ranch Plantation on the west slope of the Sierra Nevada (Oliver 1979b). This plantation has a site index of 35 m (115 ft) at 50 years (Powers and Oliver 1978). Trees were planted to a 1.8- by 2.4-m (6- by 8-ft) spacing in spring 1950. By age 20, when the study began, SDI averaged 307 and occasionally exceeded 350. The average tree was 17.8 cm (7.0 in.) dbh and 10 m (33 ft) tall. Each of three plots were thinned to SDIs of 71, 122, 174, 227, and 286. Plots have been rethinned three times in the intervening 25 years.

The western pine beetle and occasionally the red turpentine beetle (*D. valens* LeConte) are at work in the Elliot Ranch Plantation. Again, stocking level

had a profound influence on mortality, but surprisingly, the threshold of bark beetle susceptibility seems no higher than at Sugar Hill. Plots with SDIs above 230 suffered low or endemic levels of bark beetle mortality—97 SDI units lower than at Sugar Hill. Epidemic levels, however, were reached when stand densities reached an SDI of 300—similar to the pattern found at Sugar Hill (fig. 2).

What could account for this startling result? Startling because the site index at Elliot Ranch is twice that of Sugar Hill, and the general belief is that good sites will support a greater stand density than will poor sites. Bark beetle species differences and/or climate may be involved. Three generations of the western pine beetle are often produced during the warm summers on the westside of the Sierra Nevada. In contrast, only one generation is usually produced by the mountain pine beetle during the cooler, shorter summers in the Warner Mountains.

The most important factor, however, may be the repeated presence of volatile resins which attract bark beetles. Western pine beetle populations have been high, historically, in the Elliot Ranch area. Also, the plots have been rethinned three times, each time releasing these resins. Indeed, a few trees were killed by beetles after each thinning—a common phenomenon.

Stem breakage from winter storms is a major source of volatile resins and is a major cause of mortality at Elliot Ranch. Stem breakage and bark beetle mortality would seem to be linked. Most stems broke in the lower crown, leaving a few whorls of living branches—sufficient only to sustain life for a few years. These weakened stems were an ideal substrate for bark beetles and probably sustained a high population which attacked undamaged trees. And, of course, the exposed wood in the break released volatile resins. Like beetle kills, snow breakage was confined almost exclusively to the higher stand densities—SDIs of more than 194. Snow breakage was particularly severe in the winter of 1981–82. Plots with the highest stand density, SDI 303, suffered the most damage. Twenty-eight percent of the trees lost portions of their boles. The proportion of damaged trees fell to 19 percent for plots with SDI 244 and to 7 percent for SDI 194. More lightly stocked plots received virtually no damage. The Sugar Hill plots suffered no stem breakage from winter storms. Indeed, such damage is virtually unknown in northeastern California.

CONCLUSIONS

Several conclusions seem evident from these observations.

a) Sartwell's threshold of 34 m² per ha (150 ft² per acre) of basal area above which density stands are susceptible to attack by bark beetles appears to be a reasonable average value for California. The eastside plots at Sugar Hill reached a SDI of 329, without disturbance, but then suffered catastrophic losses. The basal area per ha equivalent to SDI 329 is 39 m² of basal area per ha for 820 trees per ha, 24.6 cm in average diameter (332 trees per acre, 9.7 in. in average diameter). The westside plots at Elliot Ranch, in contrast, was continually disturbed, either by cutting or storm damage, reaching a SDI of 245 before bark beetles began killing trees. The basal area per ha equivalent to SDI 245 at Elliot Ranch is 31 m² of basal area per ha for 415 trees per ha, 31.3 cm in average diameter (168 trees per acre, 12.3 in. in average diameter). Losses at Elliot Ranch reached epidemic levels, however, at a stand density similar to that found at Sugar Hill—SDI 309. The basal area per ha equivalent to SDI 309 is 40 m² of basal area per ha for 632 trees per ha, 29.0 cm in average diameter (256 trees per acre, 11.4 in. in average diameter).

b) Self-thinning in even-aged ponderosa pine stands does seem to be ruled by *Dendroctonus* bark beetles. The Self-Thinning Rule usually thought to describe suppression-induced mortality applies equally well to bark-beetle-induced mortality. This outcome is not so surprising when one considers that the root cause of both mortality factors is competition for a fixed amount of site resources. The limiting SDI for ponderosa pine stands in northern California as defined by *Dendroctonus* bark beetles is 365. SDI 230 defines a threshold for a zone of imminent bark beetle mortality within which endemic

populations kill a few trees but net growth is still positive.

c) Bark-beetle-limiting SDI differs little between eastside and westside stands of ponderosa pine. Even though SDI is reported to be insensitive to site quality, the similarity in limiting SDI between the distinctly different eastside and westside growing conditions is surprising. Two mortality agents are more active on the westside and seem to cancel productivity differences. Western pine beetle populations are more explosive on the westside because more generations are produced in a single season. And stem breakage from winter storms, a regular density-related feature of westside stands, is virtually absent in eastside stands.

ACKNOWLEDGMENTS

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Using Silviculture to Improve Health in Northeastern Conifer and Eastern Hardwood Forests

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Abstract.—The traditional role of silviculture was to manipulate forest vegetation to provide wood and related forest products for humanity's benefit over a long period. Silviculturists soon noticed that such manipulation influenced other components of the ecosystem. In particular, insects and diseases responded dramatically to silvicultural practices—both positively and negatively. The use of silviculture to improve the health of northeastern conifers is most used in spruce-fir forests for spruce budworm, white pine and mixed white pine-oak forests for white pine blister rust and white pine weevil, and jack pine forests for jack pine budworm. Major pests that can be treated silviculturally in eastern hardwood forest types include beech bark disease in northern hardwoods, gypsy moth and oak decline in oak-hickory types, and defoliators in several types. The long-term role of silvicultural treatments in maximizing forest health needs to be evaluated for its influence on other ecosystem components.

INTRODUCTION

Forests are dynamic and ever changing biological systems. For thousands of years they have been growing, developing, maturing, dying, and being replenished to start the process anew. Natural catastrophic events, fires, insects, and diseases eliminate and recycle the old, and prepare the way for the new. The traditional role of silviculture was to protect forests from these natural events and manipulate forest vegetation to provide wood and related forest products for humanity's benefit over a long period. Silviculturists soon noticed that these changes in vegetation had influenced other components of the ecosystem. Sometimes these influences produced desirable effects, so silvicultural practices for forest values other than wood were developed. But some influences produced less desirable effects, resulting in problems associated with other biotic and abiotic factors. In particular, insects and diseases responded both positively and negatively to silvicultural practices.

There are many definitions of forest health currently being debated. At this point in the program, the last thing you want to hear is another definition. All of them are similar with respect to the maintenance and integrity of the forest ecosystem. While forest health is a broad area that encompasses many ecosystem components, I will focus only on the insect and disease-related components of northeastern conifer and eastern hardwood forests, and the use of silvicultural treatments to improve forest health. Properly timed stand treatments provide a balance by slowing or accelerating the pace of natural succession and by reducing susceptibility, vulnerability, hazard, and risk from insects and diseases.

Definitions

Susceptibility

Susceptibility is defined as tree or stand biological/ecological conditions that result in some probability of insect attack, disease infection, or a buildup of fire fuel loads. Susceptibility can reflect conditions such as composition, stand structure,

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developmental stage, site factors like soil type, soil depth, aspect, and climatic factors such as rainfall/drought stress, and frosts. Susceptibility is a continuum, it ranges from susceptible to resistant to immune (high, moderate, and low probability).

Vulnerability

Vulnerability is defined as tree or stand damage resulting from successful attack, infection, or hot fire. By this definition, damage equals mortality, species, nutrient, and habitat loss, reduced aesthetics, compositional change, structural change, and many other indicators of forest health or decline.

Hazard

Hazard is defined as the probability that susceptibility or vulnerability will affect management objectives for the affected area. It is easy to identify situations in which both susceptibility and vulnerability are high but hazard is low. As a result, change due to the disturbance is acceptable and perhaps even desirable.

Risk

Risk is defined as the imminence or probability of arrival, outbreak phase of population cycle, infection phase of population cycle, or climatic conditions conducive to successful attack, infection, or hot fire. For example, an area might be highly susceptible/vulnerable and have high hazard from gypsy moth defoliation, but have low risk because gypsy moth has not yet invaded the area.

Role of Silviculture in Forest Health

As mentioned earlier, using silviculture to manage vegetation to influence other components of ecosystems in addition to producing commercial timber products is an integral part of influencing forest health. The subset of components related to insects and diseases is addressed here. Most of our experience in this area is in managing insects and diseases as pests. Although many insects and diseases perform valuable ecosystem processes, we

know little about how to influence these situations to increase ecosystem benefits (Muzika and Gottschalk 1995). Silviculture can alter both susceptibility and vulnerability as these are biological/ecological features. Hazard is a management-related component, so it can be affected only by changing management objectives or changing susceptibility/vulnerability. Risk, a temporal feature, also is less likely to be influenced by silviculture, though it is possible to influence some risk factors (e.g. length of population phase) by changing susceptibility and vulnerability.

Altering Susceptibility to Insects and Diseases

There are three basic philosophies for altering susceptibility: 1) maximizing stand growth and vigor, 2) manipulating insect/disease habitat, or 3) increasing forest diversity. Many insects and diseases have evolved in a role of killing weakened trees and removing them from the system. When conditions are such that many weakened, low-vigor, slow growing trees are present, stands can be made healthier by treatments that increase the vigor and growth of trees and stands, making them more resistant and less vulnerable. Manipulation of insect/disease habitat includes treatments like changing the composition, structure, or age class of the stand to make it less susceptible by reducing the size of contiguous areas to limit outbreaks.

Altering Vulnerability to Insects and Diseases

Similarly, there are three philosophies for altering vulnerability: 1) maximizing tree growth and vigor, 2) removing high-risk trees and stands, or 3)manipulating the habitat of secondary organisms. Vigorous, fast-growing trees usually are better able to survive attack or infection or successfully resist it, so treatments that increase growth and vigor usually will reduce vulnerability. Where high-risk, vulnerable trees and stands are present, the best treatment is to remove those stand conditions through regeneration or other silvicultural treatments. Many insects and diseases act as secondary mortality agents attacking trees weakened by other insects, diseases, or other stressors.

When conditions favoring the habitat of secondary organisms are reduced, vulnerability also is reduced.

NORTHEASTERN CONIFERS

Northeastern conifers are not a specific entity but a wide-ranging mixture of forest types ranging from the extensive spruce-fir forests of northern New England and the Lake States to scattered pine stands interspersed with hardwood stands, to mixed conifer-hardwood stands that include the following types and species: red pine (*Pinus resinosa*), jack pine (*P. banksiana*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), northern white-cedar (*Thuja occidentalis*), spruce-fir (balsam fir (*Abies balsamea*), red spruce (*P. rubens*), white spruce (*P. glauca*)), eastern white pine (*Pinus strobus*), hemlock (*Tsuga canadensis*), and pitch pine (*P. rigida*). Various insect and disease organisms infest these stands, but most of them have relatively minor local impacts and are host-specific as to the species they attack. The use of silviculture to improve forest health is most used in spruce-fir forests for eastern spruce budworm (*Choristoneura fumiferana*), white pine and mixed white pine-oak forests for white pine blister rust (*Cronartium ribicola*) and white pine weevil (*Pissodes strobi*), and jack pine forests for jack pine budworm (*Choristoneura pinus pinus*). Dwarf mistletoe (*Arceuthobium pusillum*), while not usually serious or widespread, also can be treated effectively by silviculture (Ostry and Nichols 1979).

Eastern Spruce Budworm

The spruce budworm prefers to feed on balsam fir, but white, red, and black spruce are suitable hosts. Heavy feeding sometimes occurs on hemlock, with lesser feeding on pines and larches. Defoliation of needles and mining of buds by the budworm on millions of acres of spruce-fir forest in the Northeast has resulted in heavy mortality and growth loss. Natural outbreaks occur in mature and over mature stands, especially those containing large numbers of balsam fir. Shelterwood cuts are highly effective in reducing budworm impacts. Such cuts will increase the amount of spruce and reduce the amount of bal-

sam fir in the regenerated stand, reducing susceptibility (Blum and MacLean 1985, Frank 1986). Shelterwoods also favor birds that prey on spruce budworms. Shortening rotations (45 to 70 years for spruce-fir) by clearcutting both mature and overmature stands also will reduce susceptibility (Blum and MacLean 1984). The silvicultural management of spruce budworm has even been the subject of a philosophical/psychological study (Miller and Rusnock 1993).

White Pine Weevil

The white pine weevil prefers eastern white pine and jack pine but also attacks Norway spruce, and Scots, pitch, and red pine. Adults and larvae feed on the previous-year's leader and kill all of the branches above the feeding site. One or more lateral shoots may replace the leader, resulting in a crooked or forked stem and small, bushy trees. Open-grown plantations of white and jack pine are highly susceptible, especially in the northeastern and central portions of white pine's range. Silvicultural treatments for reducing damage by white pine weevil are some of the best ways to improve forest health. Regenerating white pine under 30- to 50-percent shade (or tree cover) by shelterwood cutting will reduce weevil attacks on the leaders and branches of these trees (Lancaster 1984, Stiell and Berry 1985). Once the white pines are 12 to 25 feet tall, the shelterwood can be removed. The weevil will then attack the trees, but the damage will be above the first log of the tree, greatly reducing the economic impact of the weevil. However, shelterwoods will not reduce damage by white pine weevil in jack pine because that specie does not regenerate under a shelterwood canopy.

White Pine Blister Rust

White pine blister rust is a disease that begins in needles, spreads to the branches and stems, and eventually kills the tree via trunk infections. The disease has eliminated white pine from some portions of its range and restricts planting on certain sites within that range. Practices to reduce white pine blister rust include not planting white pine on high-hazard sites (off site), planting resistant seedlings, and pruning infected branches to

prevent the tree from being killed and the disease from spreading to other trees (Lancaster 1984, Robbins 1984).

Jack Pine Budworm

The jack pine budworm, closely related to the spruce budworm, prefers to feed on jack pine but also feeds on small red, Scots, and white pine trees in the understory. Defoliation of needles and mining of buds by this budworm results in top-killed and stagheaded jack pine trees, though mortality is rare in larger trees. Mortality can be heavy in younger understory pine trees (poles, saplings, and seedlings) that are defoliated beneath a jack pine overstory. The jack pine budworm currently is the most serious conifer insect pest in the Lake States. Heavily infested areas of jack pine budworm should be regenerated to salvage losses and prevent infection of the new stand. Prescribed burning of regeneration areas also will reduce infection of new stands and encourage dense regeneration to minimize tree loss (McCullough and Kulman 1991a). Removing top-killed and stagheaded trees by thinning can reduce the economic impact of jack pine budworm (McCullough and Kulman 1991b).

EASTERN HARDWOODS

The eastern hardwood forest is a mixture of many species and forest types, including oak-hickory (numerous oaks (*Quercus* sp.), hickories (*Carya* sp.), other hardwoods, some conifers), bottomland hardwoods (cottonwood (*Populus deltoides*), willows (*Salix* sp.), sycamore (*Platanus occidentalis*), gums (*Nyssa* sp.), silver maple (*Acer saccharinum*), several oaks), oak-pine (many species from oak-hickory, various pines), northern hardwoods (sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), black cherry (*Prunus serotina*), red maple (*Acer rubrum*)), and aspen-birch (bigtooth (*Populus grandidentata*) and quaking aspens (*P. tremuloides*), paper (*Betula papyrifera*) and gray (*B. populifolia*) birches). Many insects and diseases attack the more than 200 species in the eastern hardwood forest, though most of these pests cause minor, local impacts. The major pests that can be

treated silviculturally include the beech bark disease complex in northern hardwoods, gypsy moth (*Lymantria dispar*) and oak decline in oak-hickory types, and other defoliators in several types.

Beech Bark Disease Complex

Beech bark disease is an introduced insect-fungus complex that kills or injures American beech. Two scale insects (*Cryptococcus fagisuga* and *Xylococculus betulae*) pierce the bark of beech and then feed. The fungi (*Nectria coccinea* var. *faginata*) then infects the bark through feeding wounds. The tree walls off the damaged area, creating defects and slow growth. Many trees are killed as the bark becomes girdled. In 1987, beech bark disease was the second most important disease in New York in terms of volume loss. Some individual beech trees show genetic resistance to scale infestation. This resistance can be utilized in silvicultural treatments by favoring resistant trees and clones and those with smooth bark. Infected, large, overmature, and rough-barked trees can be removed by thinning, and single-tree and group-selection cutting (Burns and Houston 1987). Diseased trees and sprouts should be herbicided during regeneration cuts (Ostrofsky and McCormack 1986). Increased species diversity can reduce the effects of beech bark disease in pure stands.

Oak Decline

Dieback and decline are complex diseases triggered by biotic or abiotic stress factors, e.g., drought and defoliation (Houston 1981, 1987). One of the most significant is oak decline across the southern and central United States (Oak and others 1991, Starkey and others 1989). Terminal branches of trees dieback and trees often became stagheaded. Affected tree mortality usually is the result of stressed trees being attacked by secondary organisms (Wargo and Shaw 1985). Since oak decline is related to increased physiological maturity, stands should be regenerated when the site index/age ratio is less than 1.0 to maintain vigorous trees (Oak and others 1991). It is advisable to remove declining trees by thinning and group-selection cuts. Maintaining tree growth and vigor

through periodic thinning may be important as many susceptible trees showed growth reductions 30 to 40 years before oak decline symptoms (Tainter and others 1990).

Gypsy Moth

An introduced pest, the gypsy moth is a defoliator of leaves of more than 500 species, but it especially favors oaks. When half-grown, larvae eat many hardwoods and conifers except for the ashes, yellow-poplar, black walnut, and some other species. Defoliation occurs in May and June and usually is followed by a new growth of leaves in July. This refoliation process weakens the tree considerably, allowing other insects and disease agents to attack and kill it. Mortality ranges from very light to complete and is increased by drought stress. The nuisance of gypsy moth larvae also poses problems in recreation areas, rural housing areas, and small cities and towns. The gypsy moth continues to expand its range in the United States and eventually will be present over much of the eastern hardwood area. Only several of the silvicultural treatments designed to minimize gypsy moth effects are discussed here (Gottschalk 1987, 1993).

Presalvage thinning

Presalvage thinning is designed to reduce damage by removing highly vulnerable (high hazard) trees before they are defoliated and die; its primary objective is to reduce stand vulnerability. Secondary objectives are to increase stand and tree vigor (and crown condition), remove structural features or refuges for gypsy moth larvae and pupae, and promote habitat for predators and parasites. In stands with more than 50 percent of the basal area in gypsy moth-preferred species, normal thinning prescriptions will not reduce the preferred species sufficiently to significantly alter stand susceptibility. Instead, presalvage thinning emphasizes reducing vulnerability. Presalvage thinning must be implemented 1 to 3 years before defoliation because the stand needs time to recover from the stress and disturbance caused by this treatment. Priorities for marking trees to be removed are

(highest to lowest): 1) oaks with poor crowns, 2) non-oak species with poor crowns, 3) oaks with fair crowns, and 4) non-oak species with fair crowns. These priorities are integrated with the normal marking priorities of maintaining the desired residual stand density, removing unacceptable growing-stock trees before better quality trees (also could include species priorities), and achieving the desired stand structure. Additional measures can be taken to enhance predator and parasite habitat, for example, removing trees with abundant structural features or refuges for larvae, leaving snags, leaving cavity or den trees, and creating brush piles. In heavily overstocked stands with few good crowns, light thinnings to develop and build crowns are favored over a heavy thinning.

A recent demonstration stand in West Virginia received a presalvage thinning. Estimated stand susceptibility and vulnerability before and after treatment were:

	Before treatment	After treatment
Susceptibility	High	High
Vulnerability	Moderate	Low

This treatment accomplished the objective of reducing vulnerability of the stand, but did not change its susceptibility (Atkins 1989).

Sanitation thinning

Sanitation thinning is designed to prevent the spread and establishment of damaging organisms. Its primary objective is to reduce stand susceptibility. Sanitation thinning eliminates trees that are current or prospective sources of infestation. With gypsy moth, this process entails removing preferred food species, as well as structural features or refuges, and promoting habitat for predators and parasites. Secondary objectives are to increase stand and tree vigor and remove high-hazard trees. These treatments also need to be done 1 to 3 years before defoliation. Stands that can be considered for sanitation thinning are similar to those for presalvage thinning. The major difference is that these stands have less than 50 percent of the basal area in preferred species. As a result, it is possible to reduce this percentage sufficiently to alter stand

susceptibility. There is some evidence that a minimum of 15 to 20 percent basal area of preferred food species is required for a sufficiently large gypsy moth population to develop to the stage where it can survive on nonpreferred hosts. Reducing the percentage of preferred food species to 15 to 20 percent or less should make the stand less susceptible to defoliation. Priorities for marking trees to be removed are (highest to lowest): 1) preferred food species, 2) trees with abundant structural features or refuges for larvae, 3) trees with poor crowns, and 4) trees with fair crowns.

Recently, a second demonstration stand received a sanitation thinning treatment (Atkins 1989). Estimated stand susceptibility and vulnerability before and after treatment were:

	Before treatment	After treatment
Susceptibility	Moderate	Low
Vulnerability	High	High

This treatment reduced the susceptibility of the stand, but not its vulnerability.

Salvage thinning

With salvage thinning, the economic value from the dead trees is salvaged and the remaining live trees are thinned to reduce susceptibility and vulnerability. Stands that qualify for salvage thinning have greater than C-level density of acceptable growing stock, are more than 10 years from maturity, and have more than 60 percent stand density in live trees. They are sufficiently well stocked to be managed to maturity. These thinnings will improve stand vigor, growth, and quality, and could make the salvage cut economically feasible by supplementing the volume of dead trees with green trees. Priorities for marking trees to be removed are (highest to lowest): 1) dead trees, 2) oaks with poor crowns that are likely to die, 3) other species with poor crowns that are likely to die, and 4) trees with fair crowns. These priorities are integrated with the normal ones of maintaining the desired residual stand density, removing unacceptable growing stock trees before better quality trees, and achieving the desired stand structure. It may be desirable to leave several

dead trees per acre as snags, cavity, or den trees, and to remove trees with structural features or refuges for larvae.

In recent demonstration salvage thinning in West Virginia, estimated stand susceptibility and vulnerability before and after treatment were:

	Before treatment	After treatment
Susceptibility	Moderate	Moderate
Vulnerability	Moderate	Low

In addition to reducing the future estimated vulnerability of this stand, dead trees (7 percent of the stand) were economically salvaged, mature trees were thinned, poor-crowned trees as a result of the defoliation were thinned, and the landowner received more income for this treatment than a local logger had offered to liquidate the entire stand (Atkins 1989).

Salvage cutting

The objective in stands that qualify for salvage cutting is to economically salvage dead and dying trees. These stands are similar in acceptable growing-stock density and stand maturity to those in the preceding prescription, but have less than 60-percent density in live trees. In this situation, no thinning of live trees is necessary since these stands already are below the optimum residual density. They also have more than 30-percent mortality, which means there is sufficient volume and value of dead trees for a salvage cut (depending on local market conditions). Marking priorities are simple—only dead and dying trees should be cut and removed because all of the live trees are needed to carry the stand to maturity (or to the next thinning). Trees with poor crowns that will not recover are considered the same as dead trees. These dying trees are removed and not counted toward the acceptable growing-stock density. If desired, several dead trees per acre can be left as snags.

Salvage shelterwood

The primary objectives of salvage shelterwood are to salvage economic value from dead trees and

develop adequate advanced regeneration by shelterwood cutting. It may be necessary to cut some live trees for the shelterwood in addition to salvaging dead trees. These stands do not have sufficient live trees (less than C-level stocking) to manage them further and they should be regenerated. The lack of adequate advanced regeneration requires the shelterwood treatment to develop it. This is the most common treatment in many areas following initial gypsy moth infestation.

ADVANTAGES OF SILVICULTURAL TREATMENTS

The use of silvicultural treatments to increase forest health has a number of advantages. The treatments usually are inexpensive as they can be done at no net cost or net income. They treat the cause of the problem (unhealthy stands) instead of the symptom (insect and disease outbreaks). They create healthy, mixed forests which usually can withstand problems associated with insects and diseases. The manager can treat highest priority areas first, i.e., high-hazard stands that will provide the greatest return on investment. And the treatments are ecologically preferable to chemical controls for most insects and diseases.

DISADVANTAGES OF SILVICULTURAL TREATMENTS

Of course, silvicultural treatments are not without disadvantages. Only a limited area can be treated each year due to the time and labor required to set up and treat an area. As a result, a long period (minimum of one rotation length) is needed for maximum effect in treating insect and disease habitat. Few, if any, of these treatments will prevent outbreaks of many insects and diseases; they will only reduce their effects when outbreaks occur, or increase the time between outbreaks. Despite our inability to accurately predict insect and disease problems, silvicultural treatments are most effective when installed several years before forest health problems develop. Finally, silvicultural treatments cannot be used in certain areas where cutting is not allowed, for example, wilderness areas.

SUMMARY

The most effective approach for reducing insect and disease-caused damage to forest ecosystems is to apply treatments that will reduce the frequency of outbreak occurrence and minimize the severity of outbreaks. Preventive silvicultural treatments are a practical and long-lasting means for achieving this goal (Gottschalk 1987). High-hazard stands can be manipulated to reduce susceptibility and vulnerability, vulnerable individual trees can be removed, and low-risk stands can be tended to maintain vigor and rapid growth. Managers who want to improve or maintain forest health are encouraged to consider of the positive and negative effects (Muzika and Gottschalk 1995) of insects and diseases on forest ecosystems, and to apply silvicultural treatments when such strategies are compatible with other management goals.

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Implementing Forest Ecosystem Health Projects on the Ground

Cathy Barbouletos and Lynette Z. Morelan[1]

Abstract.—Understanding the functions and processes of ecosystems is critical before implementing forest ecosystem health projects on the landscape. Silvicultural treatments such as thinning, prescribed fire, and reforestation can simulate disturbance regimes and landscape patterns that have regulated forest ecosystems for centuries. As land managers we need to understand these processes, including historical disturbance regimes and then determine where on the landscape the forests are at high risk to uncharacteristic disturbances. By using our knowledge of ecosystem processes we are developing site specific management actions such as the Deadwood Ecosystem project. Management activities from the Deadwood EM project will provide for sustainable ecosystems in the future because these activities simulate disturbance regimes and landscape patterns of the past. Monitoring, adaptive management, and the human dimension must become key components of ecosystem management if we are to fulfill our role as land stewards and leaders in conservation biology.

INTRODUCTION

Insects in epidemic outbreaks and large catastrophic fires sweeping over the landscapes; these are symptoms of a forest health crisis. What are the causes underlying the symptoms? What steps are needed to address these symptoms and the cause? Where on the landscape are forests at the greatest risk? To implement forest ecosystem health on the ground we need to answer these questions.

In 1988, insect activity began to show sharp increases. The Forest responded by treating the symptom (dead trees) with salvage harvesting and hoping for rain. The insect activity continued and large intense fires became the normal summer occurrence (fig. 1). There was something else occurring on the landscape that treating the symptoms was not going to cure. In 1991, after more than 400,000 trees had been killed by insects (a four fold increase) (USDA Forest Pest Management,

1992), the Boise Forest initiated a Forest Health Strategy.

THE STRATEGY

The three part strategy focused on 1) Salvaging dead or dying trees to recover the economic value and provide minor forest health benefits (fuel reduction, fund reforestation); 2) thinning green stands using silviculture and prescribed fire to reduce tree densities and to increase the use of prescribed fire on the landscape to treat fuel buildup; and 3) collecting and sharing information on forest health (Morelan, et al. 1994). It became evident right from the start that forest health is more than "trees." The Forest shifted to Forest Ecosystem Health as recommended by a group of interested citizens, organizations, agencies, and partners during a policy analysis of the Forest Health Strategy.

The Boise NF now had a strategy for implementing forest ecosystem health. But, salvage was a short term activity to treat the symptoms not the cause. To provide for future ecological functioning

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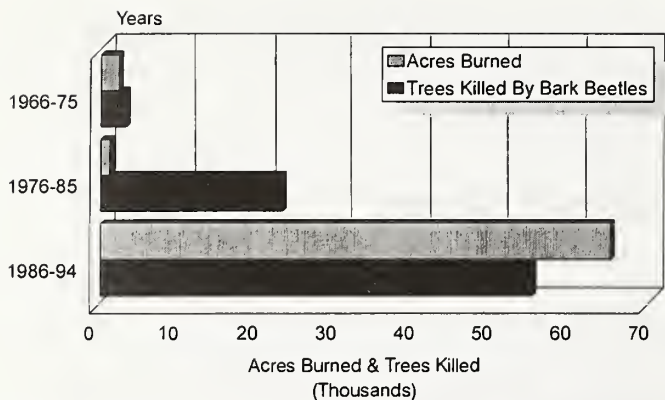
Figure 1.—Average Annual Acres Burned and Trees Killed. Boise National Forest 1966–1994.

Figure 2.—Tree Densities and Species Composition in the Boise Basin.

of the landscape, the forest has begun concentrating on what remains on the site NOT what is removed. Long term measures such as thinning from below, prescribed fire, and adjustment of species composition are needed to restore resilience to the ponderosa pine dominated landscapes of the intermountain west and provide for wildlife habitat, aquatic systems, and recreational values. Also critical in our forest ecosystem health strategy is and has been collecting and sharing information. Information on fire frequency, intensity and severity demonstrated that changed fire regimes were an underlying caused to the forest ecosystem health symptoms. Studies into the historical range of variability (HRV) demonstrate that current species composition and stand density are significantly different than before settlement and current conditions present a risk to maintaining wildlife diversity (Erickson & Towell, 1994). Research information (Sloan, 1994) shows the tremendous increase in Douglas-fir trees and the subsequent mortality when the drought began in the dry Douglas-fir habitat types in the Boise Basin (fig. 2).

As silviculturists and land managers we need to understand the disturbance regimes that regulate ecosystems and cycle materials (nutrients). We must recognize that a one size approach to management does not fit all, management options in the ponderosa pine forest cover types may not be appropriate in the spruce-fir or cedar-hemlock types. Gathering and sharing information on disturbance regimes for all forest cover types will move us toward ecosystem management at the landscape level.

THE TREATMENTS

Where frequent low intensity (non-lethal) ground fires were the historical norm, the Boise Forest is experiencing uncharacteristic high intensity (lethal) fires across the landscape. Management options can reduce the risk and help sustain ecosystems.

During the Foothills fire of 1992, the Tiger Creek drainage displayed that thinning and prescribed fire when used together can significantly affect wildfire behavior. The Tiger Creek area was commercially thinned and shelterwood harvested in the late 80s and early 90s. A fuels treatment prescribed burn was completed in March of 1992. During the August foothills wildfire, flames came racing over the ridge into the upper end of Tiger Creek burning intensely (lethal). When the fire reached the thinned/prescribed burned area, it dropped to the ground and became a low-intensity (non-lethal) ground fire and suppression crews were able to stop the spread of the Foothills fire on that flank. Other areas such as the Sheep Creek drainage continued to burn as a high intensity (lethal) fire.

The Cottonwood prescribed fire was initiated in May of 1994, a maintenance burn in an area that was prescribed burned in the early 1980s. Originally planned for a few hundred acres, the size was increased to a landscape-based prescribed fire

(1,000 acres). The Star Gulch fire of August 1994 moved quickly and intensely south and east heading towards the Cottonwood Creek drainage. The Star Gulch fire came roaring over the ridge burning down slope as a high severity (lethal) fire until it came to the Cottonwood prescribed fire area (just on the other side of a 14' wide road). When the Star Gulch fire entered the prescribed fire area, it reburned the area as a low-intensity (non-lethal) ground fire and once it exited the prescribed burned area it regained intensity and became a lethal fire again as it continued east and south.

Cottonwood and Tiger Creek areas displayed that treatments can reduce the risk of uncharacteristic fires burning across the landscape. But, the Boise Forest still needed to know where to implement these effective tools and how much of the landscape was at risk to uncharacteristic high intensity wildfires. A mid-scale (forest level) hazard and risk assessment was initiated.

THE HAZARD/RISK ASSESSMENT

Information related to watersheds and sub-watersheds was used to develop the Boise National Forest Hazard/Risk Assessment (Boise NF, 1995). This assessment is fire-based because wildfires burning outside HRV can directly affect more resources than most other disturbances (insects, disease, floods, windstorms, etc.). This assessment will estimate where high-intensity (lethal) wildfires burning outside HRV (uncharacteristic wildfires) will result in high levels of erosion, increased risk of extinction of important fish species, and will change late-successional habitat needed by old growth and other wildlife species.

Satellite imagery was used to determine forest cover types where ponderosa pine is or once was a major seral species and to assess current density compared to historical information. Moderated and high hazard subwatersheds are those where 25 percent or more of the area contains forest cover types where ponderosa pine is or was a major seral species and is moderate or dense (> 30 percent crown closure). Other submodels evaluate where lightning and human-caused fires have historically started since 1956. Subwatersheds which contained sections (640 acres) where more than 4 fires were

noted are identified as moderate or high hazard. Erosion potential was used to evaluate sediment yield using landtypes and landtype associations. Subwatershed with potential sediment yields greater than 36 tons/square mile/year were rated moderate or high hazard. Wildlife persistence examines where large, extensive areas of late-successional forested habitat occurs that are uncharacteristic (outside HRV) and very susceptible to high intensity (lethal) wildfires. And fisheries persistence evaluates the risk of extinction over the next 100 years for indicator species such as Chinook salmon and bull trout, based on factors such as availability of "refuge" habitat, population size, growth and survival.

The hazard and risk assessment will be a tool for District personnel as they prioritize areas to further examine for potential ecosystem restoration projects, similar to the Deadwood Ecosystem project.

THE DEADWOOD ECOSYSTEM PROJECT AND LANDSCAPE ASSESSMENT

The Deadwood project is an integrated, systematic, interdisciplinary approach to ecosystem management on a broad, landscape scale. The Forest Supervisor and the District Ranger have challenged the Interdisciplinary Team to expand and validate ecosystem concepts and ideas using a holistic landscape approach, to assess ecosystem complexity, biological legacies, viability of the landscape to retain ecological values, comparison of historic-to-existing conditions, and resilience to environmental stresses. The concepts of analysis scales, ecological units, land system inventories, potential natural vegetation, fire regimes, historical range of variability, disturbance regimes, and hazard and risk from insects, disease, fire, and inherent erosion were incorporated into the project.

The Deadwood Landscape analysis area is the Deadwood River drainage, approximately 153,000 acres. The Deadwood River system is part of the Upper Columbia River Basis assessment and EIS. Linkages between these higher scale assessments and project scale assessments will be looked at as part of the Deadwood Landscape analysis process.

The Forest Vegetation Simulator (FVS [formerly Prognosis]) is used to determine current and future

structural stages (early successional, late successional, etc.) on the landscape. These stages are then mapped using GIS (Arc-info), producing a "picture" of how the landscape could change over time. This is used to display ecosystem sustainability. Hazard and risk assessments linked to these structural stages (current and future) are also mapable through the GIS system.

These structural stages and hazard and risk assessments are further linked to fire regime (fire group) which is determined by using Potential Natural Vegetation (Habitat types). With the linkages of fire regime, potential vegetation, structure, and hazard, the district can determine where prescribed fire should be used, where certain silvicultural treatments with prescribed fire should occur and where restorative treatments are needed to incorporate integrated Pest management opportunities over the entire landscape.

By viewing the changes that could occur over time on the landscape and knowing the current and historical conditions (figs. 3 and 4), it will be easier to assess the changing landscape effects on wildlife habitat, Threatened and Endangered species, sensitive plants, water quality, fish habitat, recreation, and societal values (including economics and jobs).

Proposed Actions will consider all 153,000 areas in the drainage over the next 10 years where treatments are necessary. The proposed actions range from no treatment to prescribed burning, thinning young stands (precommercial thinning), commercial thinning, selection harvests, and regeneration harvests (shelterwood and limited patch clear cutting). All areas of the Deadwood project will have a hazard and risk assessment completed as part of the analysis. Looking at the current vegetation, as well as at future vegetation

Legend

■ Closed Forest

▦ Open Forest

☐ Non-Forest

Lowman RD-GIS 08/22/94 WEF

Figure 3.—Historical Landscape Patterns, Pre-1850.

Legend

■ Closed Forest

▦ Open Forest

☐ Non-Forest

Lowman RD-GIS 08/22/94 WEF

Figure 4.—Existing Landscape Patterns, 1994.

(simulated using growth models) and the hazard and risks associated with the landscape.

The Deadwood Ecosystem project and landscape assessment will also contain extensive monitoring so that adjustments to future treatments will be based on the knowledge we gain from current treatment a process known as adaptive management.

ADAPTIVE MANAGEMENT

Implementing Forest Ecosystem health doesn't end with assessments, proposed actions, or management activities. We need to assure that appropriate monitoring is completed, learn from the monitoring, and then adapt future management activities based on what we've learned. The success of forest ecosystem health will depend on how successful we are at implementing and the information we've gained with our customers. Ecosystem management as we know is more than ecological functionings, it also has a human dimension (economic and social).

THE HUMAN DIMENSION

As more people recreate on national forest land, build home on private lands adjacent to national forests, continue to use wood products, and enjoy the amenity values of fish and wildlife, we must continue to collect and most importantly, share information about forest ecosystems. Without public support the most ecologically sound, the highest resilient, or the lowest risk management option for sustaining ecosystem may not be implemented. We have the tools, we can implement them on the ground to provide for sustainable ecosystems, but private citizens, interest groups, and government employees must work together to provide sustainable healthy ecosystem for future generations.

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Atypical Forest Products, Processes, and Uses: A Developing Component of National Forest Management

Mike Higgs, John Sebelius, and Mike Miller[1]

Abstract.—The Silvicultural practices prescribed under an ecosystem management regimen will alter the volume and character of National Forests' marketable raw material base. This alteration will affect forest-dependent communities that have traditionally relied upon these resources for their economic and social well being. Community based atypical forest products, processes and uses, such as landscape timbers, mushrooms, rustic furniture, seasonal greens, etc. add value to the smaller, more diverse and/or less traditional raw materials these silvicultural practices will provide. As it implements ecosystem management driven silvicultural prescriptions, the USDA Forest Service should recognize the importance community-based enterprise has in complementing high volume commodity focused industries.

PREFACE

This paper is the result of collaborative efforts between National Forest Systems' Timber Management Staff and State and Private Forestry's Cooperative Forestry Staff. This partnership is built on the overlap of resource management issues affecting both public and private lands, and, in particular, shared commitments to forest-dependent communities. Sustainable development, ecosystem health/restoration, and forest products link the programs, partners, and objectives of these two staffs.

INTRODUCTION

It was not so long ago that terms like multiple use and sustained yield basically captured the principal concepts involved in the management of national forests. Timber, wildlife, recreation, water and air were identified as these lands' typical products.

Today, management of National Forests is to focus upon entire ecosystems. Sustainability is now to address landscapes as well as harvest levels. Silvicultural prescriptions are to be driven by entire biotic communities as well as commercial species.

Ecosystem-driven management significantly expands the role of silviculture. And therefore, ecosystem-wide resource manipulation prescriptions have expanded influence on forest-dependent communities, through the resources these communities rely on for their social and economic health and welfare.

The purpose of this paper is to reinforce some of the elements affecting forest dependent-communities, and emphasize the role atypical forest products, process and uses will play in the relationship ecosystem-driven silviculture will have with those communities.

THE ROLE OF TIMBER HARVESTS IN NATIONAL FOREST MANAGEMENT

Classic market theory connects consumer demand with raw material supply through entrepreneurs. National Forest timber serves the nation's

demand for wood products, via a corporate investor in industrial-scale production of wood commodities. Typical products include pulp and paper, panel products, dimension and grade lumber. Despite shifts in consumer preference, processing technology and resource character, National Forest timber continues to fill this role through its timber sales program.

Commercial timber harvests not only contribute to the nation's wood and fiber supply, they provide a fundamental tool in the management of forest based resources. A timber harvest provides the opportunity to manipulate a large range of forest resource components. And when commercially viable, these activities have an additional advantage of generating government revenue.

Markets are the key. Timber stand manipulation does not always generate harvest plans that call for felling trees in demand by local industry. The difference between commercial and non-commercial timber felling depends not solely on the intent of the resource manager, but on the nature of the local timber processing industry and the characteristics of its market demand. Dog hair lodgepole on the Bighorn NF, would be whole-tree pulp chips on the Bankhead National Forest (NF). Scrub oak on the Apalachicola NF, would be firewood on the Allegheny NF. Decadent aspen on the Cache NF, would be panel flake-bolts on the Chippewa NF.

TURMOIL IN THE MARKETPLACE

Recent events reducing the availability of National Forest Systems (NFS) timber to the market have created serious difficulties for both the supply and the demand side of the resource management/ wood products production equation. Inside the Forest Service, entire program staffs, as well as individual positions, have been eliminated. In the private sector, many traditional wood products processors have gone out of business. Forest-dependent communities are suffering. Jobs, tax bases, community services—all intimately keyed to the availability of commercial timber—are declining.

On the resource side, resource manipulation options through commercial timber harvests decline with the loss of each mill. And once shut-down, or worse yet, sold for scrap, these mills are very difficult

to re-establish. The capital required to build and maintain an industrial-scale wood products processing enterprise is a serious barriers to corporate investors. Processors surviving current reductions in the availability of National Forest Timber are scrambling to maintain production and economies.

The loss of each timber processer translates into a loss of opportunity to manipulate the forest resource in a manner that allows for a financial return to both a forest and any of its dependent communities. More importantly however, it increases the potential for escalation in non-reimburse felling and removal costs associated with timber stand manipulation.

With the expanding adoption of ecosystem management, the issues of restoration, salvage and health will energize the near-term stimuli for timber stand manipulations. Such objectives will, in many cases, call for fellings and disposals of a timber mix (volumes, species/mixes, sizes and qualities) very much unlike materials that historically have been targeted in commercial timber sales.

This adoption will generate a second serious impact on commercial timber sales programs. Those mills surviving the volume reductions described above, may not be capable of adapting to this dramatic change in raw material mix. Existing local processing technologies, capacities, geometries, qualities, existing secondary markets, etc., could all translate to expanded barriers to a successful timber sales program.

Each National Forest will face its own local circumstances. Those fortunate, will be able add to ecosystem manipulation volumes into their existing commercial timber sales programs. Those unfortunate, have already lost their industrial wood processing base and will face felling and removal costs with little hope for a commercial timber sale. Most forests, those in between, will face the challenge of matching the character of this material to the constraints of existing markets and local processing technologies.

ATYPICAL PRODUCTS, PROCESSES, AND USES—A POTENTIAL ASSET TO EM

For large-scale wood product industries, reduced timber volumes or variation in sizes, quality and

species can create a serious mismatch with existing processing technologies. Typically, large volumes of predictable uniformity are crucial. Daily truckloads of Hem-fir studs, yellow-pine plywood, or pallet cants are the key to many processers' efficiencies and survival.

Ecosystem management will call for a significant alteration in the role of forest manipulation. Attention will include focus on smaller components of the ecosystem. Any one of these components could rise enough in importance to direct the manipulation of traditional timber species, generate its own manipulation prescription, influence existing, and/or create new markets.

SPECIAL FOREST PRODUCTS

For example, National Forest focus on ecosystem components will expand the typically limited interface that exists between what USDA Ag Info Bulletin 666 refers to as Special Forest Products, and the elements addressed in most forest plans. This publication, *Income Opportunities in Special Forest Products* lists sixteen unique classifications of forest produced materials atypical to the list of traditional forest products, i.e., timber, water, air, wildlife, recreation, etc., most plans address. These sixteen classifications include:

- Forest Botanicals as Flavorings, Medicinals, and Pharmaceuticals
- Chips, Shavings, Excelsior, Sawdust, Bark and Pine Straw
- Recreation and Wildlife Enterprises
- Cooking Wood, Smoke Wood and Flavor Wood
- Greenery, Transplants and Floral Enterprises
- Weaving and Dying Materials
- Berries and Wild Fruit
- Decorative Wood
- Speciality Wood Products
- Cones and Seeds
- Honey
- Nuts
- Mushrooms
- Syrups
- Charcoal

And each in turn, includes hundreds of individual products, from beverages to bird houses.

COMMUNITY BASED ENTERPRISE

This focus on the smaller components of an ecosystem's forest base could also generate smaller per-sale volumes, based upon fewer removals per acre. The same focus could generate a broader range of species and/or stem sizes, and include include larger per-sale-volumes of lesser valued species. Ecosystem driven sale specifications could call for the removal of shrubs, vines, etc., as collateral activities of the timber harvest. All of these factors could significantly reduce the market based value associated with typical forest products.

While these changes may be complications for a panel producer, there is a small but growing segment of wood processors who are learning to deal with its consequences. As specialists in niche markets rather than commodity production, small scale enterprise can thrive on the variety inherent in these complications. There are community based businesses, focusing on a variety of products from on non-homogeneous resource currently find success through specialized products. Rustic furniture, bark filtration systems, horticultural and landscape posts/stakes/boards/trim, poles, fencing, utility structures, pallets, crating, hobby wood, crafts, packaging, etc., all are practical products currently matching community and non-homogeneous timber to consumer demand. Processing and marketing flexibility is the key to these small enterprises raw material adaptation and success.

VALUED ADDED

Each of the above specialized products can in turn generate a range of value added support enterprises. The logging, sawing/shaping, drying, blanking, assembly, packaging and shipping, required in the production of the products listed above, often involves many of the same skills associated with large commodity industries. Where forest dependent communities have lost their major industrial base, the skills of the local work force are often fully capable of developing support

enterprises for the niche product manufacturers mentioned above.

USES

This emphasis on resource extraction should not mask an important ecosystem feature. Manufacturing, marketing and consumption all come to mind when the term "use" is employed. Even hobby or family-gathered products such as mushrooms or seasonal greenery usually involve harvest and removal, even if only in small amounts.

There is, however, another element that needs to be recognized. For lack of a better term, "uses" is employed to address a special type of access to a particular component of an ecosystem's character. Many unique personal and/or cultural experiences and traditions are intimately dependent upon interaction with nature. This interaction does not involve consumption in the commercial sense. Some, such as the tradition of burning an herb, or gathering of basketgrass, the digging of a medicinal bark, may involve "collecting" materials. Others—the coming together at a special place, ceremonies in groups or as individuals, personal spiritual experiences—only involve a setting.

Attention is due these activities. They involve a critical component of the ecosystem—its people. And they require attention in the management of the biological as well as, site-specific cultural components of an ecosystem.

SUMMARY

Ecosystem management is clearly a new era for the Forest Service. Its science is changing many of our standard practices. Coincidently, forest based communities are also undergoing significant change. In many places, smaller community-based forest enterprises are a growing component of their economic and social future.

As members of our forest based communities and practitioners of ecosystem management, the Forest Service needs to capitalize upon opportunities to serve these collateral roles. Efforts by timber dependent communities to remain viable will be affected by specific practices mandated by ecosystem management. The entire Forest Service, and those directing resource manipulation through fellings and removals, should be on the look-out for mutual benefits when the science of ecosystem management allow practices that can benefit local communities.

It is unlikely that the economic stability forest dependent communities enjoyed over the last 25 years can be fully restored. However, ecosystem managed harvests recognizing both commodity and atypical forest products, process and uses, can ease the transition of some of these communities to a new level of economic stability.

Closing Remarks: A Visit to Dr. Stout's and Dr. Murphy's Forest Health Clinic

Russell T. Graham and Theresa B. Jain[1]

Two years ago I attended a camp with fellow silviculturists in central North Carolina. Camp Kanuga provided all kinds of fun activities. We described ecosystems and designed silvicultural systems for a variety of objectives; and as our camp scribe (Phil Aune) noted, the central camp theme evolved into ecosystem management. I am not sure exactly how or what happened but Phil Aune, Andy Youngblood, Nelson Loftus, and I rudely woke the sleeping giant of ecosystem management. However, as often happens in these circumstances, only one individual gets blamed for the deed. After Camp Kanuga, Phil went back to Redding, Andy to Bend, and Nelson to Washington, DC. I was the unfortunate silviculturist caught with my hands in the cookie jar so-to-speak, and was sentenced to a minimum of 18 months in Walla Walla, WA with the Interior Columbia Basin Ecosystem Management Project (Graham and others 1994b).

Twelve months into my sentence as Deputy Science Team Leader the frustrations, meetings, and stress started taking their toll. My sponsor, Terrie Jain noticed that the stress was affecting my psyche and suggested when my sentence in Walla Walla is complete, I might attend a rehabilitation clinic. She said a clinic would help me readjust to society and help me reaffirm my roots in silviculture. Therefore, we decided to investigate clinics that I might attend after finishing my sentence in Walla Walla.

Since I could only be AWOL a minimum of one week the search was limited to clinics in the West. The Jimmie Heuga Clinic in Colorado was considered but it specializes in helping people with multiple sclerosis and at this point I needed something to help my mental state. Also the Betty Ford Clinic showed potential, but unfortunately celebrities like Liz Taylor usually overwhelm the participants. Terrie and I were looking for a clinic staffed by general practitioners, rather than specialists, one that could integrate many issues, develop good prescriptions no matter the objectives, and be respected in the ecological and forestry communities.

Fortunately, Terrie grew up in a small community north of Santa Fe, NM, and remembered a clinic high in the mountains of south central New Mexico at Mescalero. Terrie investigated this clinic and found it good at integration and staffed by competent resource professionals who prescribed treatments for a wide range of objectives and health conditions. The forest health clinic was led by two general and well respected practitioners, Dr. Stout and Dr. Murphy. To determine if this clinic would benefit my mental and physical health, Terrie and I planned a visit during the week of May 8, 1995.

I knew little about Mescalero, NM, except that it was near Ruidoso, the site of some of the richest horse races in the world and it was located at 8,000 feet elevation in the mixed conifer and ponderosa pine forests. Since it had forests, horse racing, and a nice hotel it appeared perfect for a forest health clinic.

Terrie acquired some information about the clinic we were visiting. I tried to read while Terrie drove, but it was almost impossible because she drove very fast; seems several cars with flashing lights were wishing us a good trip. According to the information, the clinic directors are general practitioners in both the mental and physical health of forests. They are silviculturists. Since the late 1800's silviculturists have been meeting the desires of land owners, managers, and society by prescribing forest treatments to produce a wide variety of forest conditions. As silviculturists, Dr.

Stout and Dr. Murphy are two of a long line of silviculturists mentored by individuals such as Davis, Smith, Gisborne, Wellner, Marquis, Leopold, Hawley, and Baker (Baker 1934, Hawley 1937, Smith 1962).

As silviculturists they were trained in a wide variety of related disciplines including wildlife, soils, economics, timber management, autecology, synecology, fire ecology, landscape ecology, sociology, and silvics. Not only are Dr. Stout and Dr. Murphy well trained, but they are also leaders in continuing education. Since the early 1970's they have developed and presented continuing education to a wide variety of resource professionals. These programs include continuing education in forest ecology and silviculture (CEFES), the Silviculture Institute, and continuing education in ecosystem management (CEEM). These programs have supplied education to a wide variety of resource professionals throughout the United States and are models used for other educational programs.

With this excellent educational background, Dr. Stout and Dr. Murphy understand that ecosystems are communities of organisms working together with their environments as integrated units. They are places where all plants, animals, soils, water, climate, people, and processes of life interact as a whole. These ecosystems may be small, such as a rotting log, or large, such as a continent or the biosphere. The smaller ecosystems are subsets of the large ecosystems, that is, a pond is a subset of a watershed, which is a subset of a landscape, and so forth (Salwasser and others 1993).

All ecosystems have flows of things—organisms, energy, water, air, and nutrients—moving among them and all ecosystems change over time and space. Therefore, it is not possible to draw a line around an ecosystem and mandate that it stay the same or stay in place for all time. Managing ecosystems means working with the processes that cause them to vary and to change (Salwasser and others 1993).

Dr. Stout and Dr. Murphy recognize that their patients (ecosystems) are difficult to define, the doctors understand that often ecosystems are defined by the issues. Natural resource management issues such as protecting habitat for anadro-mous fish, grizzly bear, spotted owl, or maintaining community stability can be used to define ecosystem boundaries and components. The doctors know their patients contain a variety of structures, processes, and functions all interacting among each other. In addition, the doctors are comfortable working with a variety of temporal and spatial scales, knowing that time and space are key components of their patients.

Terrie and I soon discovered that Dr. Murphy and Dr. Stout and their immediate staffs do not work in a vacuum. They confer with a network of associates and specialists from throughout the United States and Mexico. During the week in which we visited the clinic there were more than 170 specialists and associates visiting the clinic (fig. 1). Associates from New Mexico were the most supportive, but surprisingly many came from Washington, DC, and a team from Mexico was present. With this network, the patients receive the utmost professional and most advanced diagnosis, prognosis, and integrative prescriptions.

After being introduced to the staff and associates of the clinic, Terrie and I were invited into the waiting room. The waiting room was quite a sight. It was full of ecosystems all expressing different health concerns. Southeastern Alaska with its glaciers and islands occupied one of the large easy chairs. The middle of the waiting room was occupied by both the mixed conifer forests of the inland west and the forests of the Appalachians. These patients were constantly changing and moving,

Figure 1.—The number of associates from throughout the United Sates and Mexico who attended the Forest Health Clinic from May 8 through May 11, 1995.
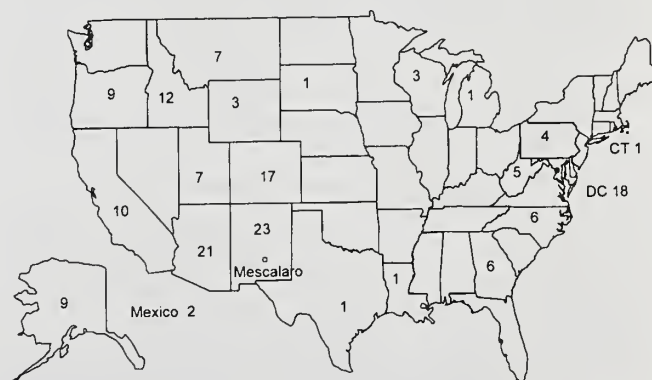
arguing over who got to sit at the kid's play table in the waiting room. One of the smaller patients (ecosystems come in all shapes and sizes) was the North Kaibab led by its top-level consumer the northern goshawk. Moreover, the line outside the waiting room was increasing as we watched. It appears there are no limits to ecosystems displaying health problems. We asked the doctors if it would be possible to visit an examining room while they examined their patients. Being open, integrating silviculturists they were more than agreeable.

The first patient we observed the doctors examining was the mixed conifer forests of the inland west. This ecosystem was led by the ponderosa pine, western white pine, and western larch patriarchs. The ponderosa pine was a majestic tree, tall and straight, with yellow bark. At it's base was the evidence of many surface fires occurring early in it's life, but no evidence of fire during the last 50 years.

Along side of the ponderosa pine was the state tree of Idaho, the western white pine. It also was a majestic tree but had some discolored needles. In fact, much of its top was dead due to white pine blister rust, an introduced disease. The western larch stood tall and proud, for the most part the tree was healthy, however it had a few remnants of small needle-eating insects (larch casebearer). Unfortunately, although seemingly healthy, the species has problems reproducing. Because western larch flowers early in the spring, frosts often damage the flowers making regeneration difficult.

In addition to the patriarchs in the exam room, there were several other vegetative components ranging from grasses and shrubs like cheat grass and sagebrush to pinegrass and alder. As Terrie and I watched, the exam room filled because of the prolific regeneration of Douglas-fir, white fir, and grand fir. These species were constantly being eaten by spruce budworm, tussock moth, *Armillaria* and other killing and stressing agents. In addition, because fire had been excluded, these trees were filling in all of the open spaces between patriarchs, thus changing the ecosystem structure. Because of these conditions and recent droughts large portions of this ecosystem were blackened by large forest replacing fires.

Many other components also filled the examining room. Juniper, pion pine, grizzly bears, spotted owls, goshawks and suites of other plant and animal species occupied various niches in the ecosystem. The social and economic components were characterized by small towns like Priest River, ID to metropolitan areas like Salt Lake City, UT.

The diverse communities and intervening areas were populated by a host of humans ranging from Native Americans, to movie stars, to loggers, to ranchers, to retirees, and a multitude of others. These people expressed a multitude of demands ranging from the production of commodities (timber and forage) to the protection of spiritual and special places.

As with all good exams, the doctors quizzed the patient as to their employment history. Initially, from 10,000 years to 500 years ago, the forest ecosystems of the inland west worked for the human inhabitants. During this time they provided food, water, sacred places, medicine, and fiber for Native Americans. From 500 years to 100 years ago human populations increased primarily from European settlers and their offspring. To keep this employer happy, the inland forests had to work harder to supply food, water, and fiber. Since then and especially the last 25 years, the inland forests have been putting in overtime, trying to supply a disparate list of goods and services for the ever-changing objectives of the employer, the public. Inland forests tried to produce abundant fiber, abundant water, abundant wildlife, and abundant scenery. Unfortunately, these objectives often conflicted, adding additional stress on the patient. As the doctors examined the patient, aggressive regeneration of Douglas-fir, white fir, grand fir, ponderosa pine, western hemlock, and western redcedar continued to increase the biomass and carbon loading of the ecosystem.

During the exam Dr. Stout, noticed some entries from a previous exam. The note highlighted some of the problems facing western forest management. It went on to state "that the picture that has been drawn thus far can hardly be called satisfactory; over cutting of pines and undercutting of other species, an unbalanced drain upon forests. Confusion is added by the fact that the public and local, state, and federal governments have not come to an agreement on the problem, the approach, and the division of responsibility."

Dr. Stout continued reading the note: "There is no shortage of solutions. The problem is to select the one which least disrupts the existing scheme of things and invites public support necessary to transform it into an action program. It is critical to recognize that the course which is best from a purely local stand point may not serve the best national interest." Surprisingly, Dr. Stout noted that this entry was not made when the patient last visited, but rather it was made by Drs. Hutchison and Winters when they were leading the clinic (Hutchison and Winters 1942). Due to excellent diagnostic work at the clinic, silviculturists 50 years ago, recognized health problems in western forests. But, like many patients, and in this case because of the patient's employer, the ecosystem did not change its work, reproducing, smoking (fire), or consumptive habits and it's health continued to deteriorate.

Because of it's employers consumptive demands, the foremost treatment being applied to forest ecosystems of the west was the attempt to exclude wildfires. In addition, large volumes of high quality fiber, primarily the ecosystem's patriarchs, were harvested. Intermediate treatments (thinnings, cleanings, and weedings) were conducted to increase or maintain fiber production. Regeneration was prescribed to establish important tree species that contributed to primarily fiber production. In general the treatment history emphasized forest protection and commodity production for the human inhabitants of the ecosystem.

After interviewing the patient Dr. Stout and Dr. Murphy addressed the general health of the patient. They both had sound suggestions, but there is no definitive definition of forest health on which they could rely. It seems that the complexity of ecosystems and diversity of issues accentuated the different views of forest health. These views range from "another reason for doing business as usual," to a utilitarian view point, to keeping all processes and components in good working order, to sustaining ecosystem complexity while providing for human needs (see Sampson and Adams 1994). In addition, it was strongly recognized that all of these viewpoints are temporally and spatially dependent. Fortunately, Dr. Stout and Dr. Murphy being adept silviculturists do not ascribe to any one single definition of forest health. Rather they ascribe to producing forest conditions that can address a wide variety of issues and maintain forest management options for future generations. In accomplishing this task the doctors attempt to teach and communicate to their employers (society) the necessity of understanding the consequences of management actions on forest ecosystems.

Terrie and I were excited about all of the new tools available to Dr. Stout and Dr. Murphy. Visualization, GIS, and computer simulation were available to the doctors for diagnosing forest ecosystems and prescribing treatments. Although these tools offer many possibilities and are important, the doctors know that the practice of silviculture also relies on many time-tested tools. Those developed by Haig and others (1941) for managing western white pine or by Pearson (1950) for managing ponderosa pine are as valuable today as the day that they were developed. All of these tools can be used in both coarse and fine filter ecosystem analyses to address a multitude of issues and concerns. The concept of a coarse filter assumes that if habitats are conserved more than 90% of the elements of the habitat would also be conserved (Hunter and others 1988). In contrast, a fine filter would address individual elements (species) that need special treatment or protection.

As Terrie and I observed the actions in the examining room we were constantly amazed at how the doctors used the wide range of tools available. One of the most interesting was the mental health shed with it's half moon cut-out on the door behind the main clinic building. Terrie and I did not fully understand the use of this tool, however, many of the associates present at the clinic, felt the mental health shed was a vital part of their continued success (fig. 2).

Other tools available to the doctors included recommendations for managing coarse woody debris and conceptual models of addressing ecological functions (Graham and others 1994a, Kaufman and others 1994). As the exam continued the doctors summarized the information using indicator variables and reference conditions. These summary diagnostic tables enabled the doctors to address the trends that were occurring in the ecosystem.

An important instrument available to the doctors was the availability of genetic information and

Figure 2.—The mental health shed located behind the main clinic building.

genetically improved planting stock for use in managing forest ecosystems. Safe seed transfer rules for regenerating forests were available, genetically improved rust resistant western white pine was also a valuable tool often used by the doctors. The doctors understood how important the genetic resource was in managing inland forests.

Terrie and I were very impressed with how Dr. Murphy and Dr. Stout developed silvicultural systems, a planned program of forest treatments through the life of a forest. The doctors pointed out that although many silvicultural systems were initially devised for producing timber crops they can be modified to produce forest conditions that meet a variety of management objectives. The doctors have provided prescriptions that produce desired forest structures, maintain forest processes, and maintain forest functions (i.e. maintain forest health). These prescriptions can also produce a variety of forest products and amenities (Reynolds and others 1992).

Maintaining forest health of mixed conifer forests of the inland West is a huge task for both biophysical and social reasons. One such challenge is addressing the many myths about resource conditions. There is a concern that although public opinion may not be right, it may prevail. Also, many people incorrectly assume that ancient forests covered North America, and that Native

Americans did not alter the landscape. Dr. Stout and Dr. Murphy suggested that silviculturists must educate the public, so they too will understand the complexity of ecosystems and the issues concerning future management of these forests.

It was extremely refreshing to witness the many significant examples of implementing projects for improving forest health. An example from the Idaho Panhandle National Forests included projects that successfully minimized root disease and introduced rust-resistant western white pine. Likewise, the Bitterroot National Forest success-fully introduced fire into ponderosa pine / Dou-glas-fir forests. The Kaibab Forest implemented projects for sustaining northern goshawk habitat. Likewise, the production of and the continual development of blister rust resistant western white pine and its millions of seedlings planted were a major success.

So as the patient (ecosystem) exited the examina-tion room Terrie and I were impressed by the prescriptions the doctors had prepared and suc-cessfully implemented. Even with these successes it appeared that the forest health questions facing the inland forests will continue. Drs. Stout and Murphy will likely see the patient again and again.

The doctors were extremely efficient and multi-faceted. They not only worked with forest ecosys-tems of the West but were at home examining, diagnosing, and prescribing treatments for other forest ecosystems. Terrie and I watched as the doctors patiently and carefully lead the Appala-chian ecosystem into the examining room. This ecosystem was led by the sugar maple, loblolly pine, and eastern white pine patriarchs. In addition, to these leading tree species, there were several oaks attempting to take leadership roles. Since no single oak species could assume this commanding position they all demanded to be heard.

This disparate group of tree species was leading a highly complex and diverse ecosystem. The suite of tree species present was large but we recognized the long leaf pine, eastern hemlock, beech, cherry, and balsam fir. In addition, there was an extremely rich populations of dogwood, red maple, poison ivy, silver bell, sourwood, and many others. This diverse and often dense vegetation provided habitat for black bears, ticks, chiggers, raccoons,

opossums, deer, mosquitoes, black flies, and a host of other organisms. The introduced gypsy moth and blister rust were thriving while acid rain fell in many areas. The human inhabitants of this ecosystem lived in diverse communities ranging from Washington, DC, to Rosman, NC.

As in the West, the native Americans were the first employers of this ecosystem. For centuries the demands they made were simple and well within the limits of what the system could produce. Beginning in the 1600's European immigrants started asking the system to produce more and more goods and services for an expanding population. These business moguls, politicians, farmers, miners, loggers, and industry workers frequently changed their minds on how this ecosystem should be managed. During the last 25 years dominant management objectives included producing fiber, scenery, woodpeckers, turkeys, water, sacred places, and stable communities.

Even with this wide variety of management objectives the doctors enthusiastically started examining their patient. They used their full complement of diagnostic tools. Dr. Stout even dusted off a 1922 copy of Frothingham's works for managing hardwood mixtures. They are still as applicable today as the day they were prepared. When the doctors prepared their lab sheets they looked similar to those prepared for the western ecosystems. *Armillaria*, blister rust, budworm, pine beetle and introduced species were prominent on the list. In addition, those pesky deer, along with acid rain and gypsy moth, were causing many changes in the ecosystem.

The doctors and their network of specialists and associates located throughout the United States set about developing silvicultural systems and prescribing treatments to meet the wide variety of management objectives this ecosystem has. What Terrie and I did not see in the western ecosystems that was so obvious in the East, was the tremendous human populations making demands on the system. There were millions of people living in this ecosystem making the task of maintaining the system in a healthy state extremely difficult.

Even with these difficulties the doctors developed excellent silvicultrual systems and prescriptions. Prescriptions have been developed and

successfully implemented for mediating the effects of the southern pine beetle. Likewise, prescriptions have been prepared and implemented reducing the vulnerability of many parts of the ecosystem to attack by gypsy moth. Even though the oaks are such an important species in much of the ecosystem establishment is sometimes difficult. But, the doctors successfully developed shelterwood systems producing excellent regeneration. Also, the doctors have successfully linked silvicultural systems to the specific habitat for sensitive wildlife species.

To prevent staring at the land and serving the DG, the clinic hosts extensive field excursions. Terrie and I participated in two excursions while we visited the clinic. Excursions were designed to allow the doctors and associates the ability to view, touch, and experience ecosystems. A short-coming of the excursions was that the vegetation, geology, soils, climate, and other basic ecosystem attributes were not described. This type of information would have been very useful for viewing the good, bad, and indifferent. For the field excursions the clinic could only afford school buses compared to the comfortable motor coaches we had at Camp Kanuga. This is probably a sign-of-the-times indicating that declining budgets will make it difficult to keep the forest health clinic fully operational.

It was refreshing to experience the ecosystems of central New Mexico. We were able to witness small trees crowding out the dominant patriarchs and view how the human component of the ecosystem continued to place heavy demands on the system through domestic grazing, timber harvest, and recreation sites. We saw places where potential house replacing fires were likely in the future. We viewed sites where active management produced forest conditions less susceptible to stand replacing fires yet provided habitat for many wildlife species. These treatment prescriptions were designed to meet the management objectives of the Mescalero Tribe. We discussed how aspen could be maintained as a forest component enhancing forest health.

These field excursions emphasized portions of the ecosystem that need intensive care by the doctors and their staff. The portion of the ecosystem containing the Mexican spotted owl was being over-run by small trees. The fuel loadings were

high and the tree component appeared to be very susceptible to epidemics of disease and insects. The participants on the excursion recognized that fires will eventually alter this portion of the ecosystem threatening more than the Mexican spotted owl. These sites were in stark contrast to the ones actively managed by the Mescalero Tribe to minimize the effects of these ecosystem components. Moreover, we were told that only a very small portion (approximately 3%) of the tree component of the area could be treated to reduce the fire potential. These management constraints demonstratively disturbed Dr. Murphy. He concluded that this approach to managing forest ecosystems definitely would not produce healthy ecosystems. The only thing that restrained Dr. Murphy was the appearance of some exotic black, triangular shaped planes overhead. These took his mind off of the sad situation that he witnessed.

The clinic had characteristics similar to those of Camp Kanuga. An important part of the therapy applied at the clinic was the communal dining of the staff and associates. This allowed for the interaction of silviculturists and associates from all over the United States and parts of Mexico even though some of the food lacked freshness and warmth (pancakes). As part of the therapy, the entire group boarded the school busses and went to a gun fight and barbecue. This evening excursion included a fisherman, a yodeler, and a fiddler. The highlight of the evening was the presentation of awards to associates of the doctors for their outstanding contributions to timber management. Dick Bassett, Bobby Kitchens, Milo Larson, Wayne Shepperd, Dennis Murphy, Bill Oliver, Ralph Johnson, and John Fiske were presented with plaques. In addition to this evening excursion there was an opportunity every evening for the staff to intermingle and have some refreshments. These group therapy sessions seemed invaluable.

Since I only had a week furlough from Walla Walla and we began planning our departure and reflecting on the work of the clinic. The doctors' work will never be complete. There will always be a forest ecosystem in the waiting room and a line waiting admittance. But Dr. Stout's and Dr. Murphy's Forest Health clinic is well equipped to address the continuing issue of forest health because they are silviculturists. The clinic is proficient

in the art and science of managing forest ecosystems to meet management objectives over a variety of spatial and temporal scales. The doctors stressed the need for public acceptance of active management to achieve healthy ecosystems. The practice of silviculture is the foundation for timber production, new forestry, new perspectives, ecosystem management, forest health, or what-ever the future may bring.

Therefore, after my sentence in Walla Walla is complete I plan on spending a long time at Forest Health Clinics with my fellow silviculturists.

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Attendees of the
1995 National Silviculture Workshop

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Barbara Anderson, PAO
Bruce Baldwin, CF
* Joe Barnard, FFASR
* Jack Barry, FPM
* Ann Bartuska, FPM
* Bob Bridges, FIDR
Frank Burch, TM
Leah Clark, S&PF
Mark Delfs, TM
Dave Hessel, TM
* Mike Higgs, IF
Ralph Johnson, TM
Joe Lewis, FPM
** Nelson Loftus, FMR
* Doug MacCleery, TM
* Rob Mrowka, TM
Dennis Murphy, TM
* Jim Saveland, FFASR
* Richard Teck, TM
* Harold Thistle, MTDC
Dave Thomas, FPM
Les Whitmore, FMR

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Barry Bollenbacher, RO
* Susan Hagle, RO
Pete Laird, RO
* Mary Frances Mahalovich, RO
* Hal Salwasser, RO
* Cathy Stewart, Bitterroot NF

Region 2

* Bob Averill, RO
Dave Crawford, San Juan NF
Susan Gray, RO
Art Haines, Grand Mesa-Uncompahgre-
    Gunnison NF

Phil Krueger, Medicine Bow-Routt NF
Paul Langowski, Arapaho-Roosevelt NF
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Vera Pena, San Juan-Rio Grande NF
Bruce Short, San Juan-Rio Grande NF
Chris Thomas, Bighorn NF
Bob Thompson, Medicine Bow-Routt NF
Robert Vermillion, San Juan-Rio Grande NF

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Peg Crim, Lincoln NF
* Don DeLorenzo, Lincoln NF
Manny Diaz, Lincoln NF
Jim Ellenwood, Kaibab NF
John Hinz, Tonto NF
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Mickey Mauter, Lincoln NF
Guy Miller, Lincoln NF
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** John Shafer, RO
Rick Stahn, Coconino NF
Rogers Steed, Coconino NF
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Don Weaver, Gila NF
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Doug Austin, RO
Dave Bassler, Sawtooth NF
Greg Clark, Sawtooth NF
Tammy Clark, Sawtooth NF
Larry Deblander, RO
Valerie Deblander, RO
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* Melody Steele, Boise NF
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Julie Weatherby, RO
Dave Wilson, Ashley NF

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Pamela Campbell, Stanislaus NF
** John Fiske, RO
Jerry Jensen, RO
** Jane Laboa, Tahoe NF
Mike Landram, RO
Sheri Smith, Lassen NF

Region 6

* Tom Atzet, Siskiyou NF
* Jerry Beatty, RO
Don Connett, RO
Ken Denton, RO
** Victoria Rockwell, Wallowa-Whitman NF
Fred Zensen, RO

Region 8

Ed Brown, NF's in North Carolina
Jim Brown, RO
* Stephen Clarke, RO
Robert Kitchens, (Retired)
Jim Naylor, RO
Paul Schuller, NF's in North Carolina
Karl Stoneking, RO

Region 9

Monty Maldonado, RO
* Al Saberniak, Hiawatha NF
Bob White, Allegheny NF

Region 10

Jerry Boughton, RO
* Tim Garvey, Tongass-Chatham
Don Golnick, RO
Rick Hauver, Tongass-Ketchikan
Jim Russell, Tongass-Chatham
Bill Wilson, RO
Dick Zaborske, RO

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* Dave Koch
Gene Long
Gene Lonning
Hal Luedtke
Jere Mclemore
Merlin McDonald
James McRae
Rick Wells
Pete Wikoff
Jim Youtz

Tribal Representatives

Robert Billie, Navajo Nation
Charlie Murphy, Hualapai
Frankie Thompson, Navajo Nation
Tom Wahlquist, Hualapai
Craig Wilcox, San Carlos Apache

Other Attendees

* Christopher Baisan, University of Arizona-Tree Ring Lab
Garry Blackwell, New Mexico Forestry Division
* Lance Clark, American Forests
* Alfonso Dominquez, Republic of Mexico
Bill Duemling, New Mexico Forestry Division
* Oscar Estrada, Republic of Mexico
Barbara Luna, New Mexico Forestry Division
* Tom Kolb, Northern Arizona University

* Made presentation
** Served as moderator

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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