PROCEEDINGS OF THE 41st ANNUAL WESTERN INTERNATIONAL FOREST DISEASE WORK CONFERENCE

Boise, Idaho
September, 1993

Proceedings of the 41st Annual Western International Forest Disease Work Conference

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San Francisco, California

ME

Proceedings of the Forty-First Western International Forest Disease Work Conference

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Will Littke, Ph.D.

Project Leader Forest Pest Management Research
Weyerhaeuser Company, Centralia, WA

As the WIFDWC chairman for 1993, I would like to welcome you to Boise, Idaho for the 41st WIFDWC conference. I have participated in some 17 such meetings and look forward to the presentations and discussions to follow. I must remind the attendees that the key ingredient to a successful conference is participation and communication. I urge you to take full advantage of the next few days to seek out individuals to clarify or expand in your specific research or interest area.

This WIFDWC follows the passing of Frank Hawksworth and Bill Bloomberg two individuals whom have made significant contributions to our organization and to the field of forest pathology. We will miss them and their fellowship but their contributions to science and our organization will be long remembered. A moment of silence is called for in tribute to their memory ----.

Some 148 years ago (this week), my ancestors camped outside Ft. Boise on their way along the Oregon Trail. In their diaries are accounts of the majestic beauty and diversity of the region, and the challenges that lay before them. In much the same light, we have a similar situation today.

Some of the specific challenges which face us include;

(1) Understanding ecosystem management and translating pest management prescriptions into the ecosystems management perspective. The new Forest Plan outlined by politicians in Washington D.C. offers forest pathologists an opportunity to contribute in the decision making process, in ways which require that we view "pests" in a new light. "Pests" are now known as "agents of change". Our approach to forest management will involve changes in prescriptions such as; longer rotations, uneven age management, multiple entries, mixed species management and so on. These changes can not help to create new and different opportunities for pathology research.

(2) Dealing with the future loss of soil fumigants such as Methyl Bromide. Much of the regeneration stock planted in the U.S. is grown under MB based crop systems. The loss of this chemical will challenge us to better understand the interaction of soil pathogens and seedling growth.
and;

(3) Development of a global perspective on forestry has resulted in demand for forest products from "off-shore" sites. Imports of wood products from Russia, New Zealand, Chile, and Brazil have been mentioned as possibilities. Some have described this development as a ticking bomb!, while others see reduced risk if commodities are properly handled, inspected, and appropriate treatments are applied.

The following presentations and discussions will touch on these topics and surely lead to stimulating debate. Our forum for this meeting is the Greater Boise area and nearby forests. This is the perfect setting for our meeting and for the discussions ranging from urban forests to forest ecosystem planning.

I declare the 41st WIFDWC meeting officially open and would like to conclude by thanking the local arrangements committee and program committee for what will surely be a great meeting.

IN MEMORY

Frank Hawksworth
1926-1993

Frank G. Hawksworth, 66, a 35 year resident of Fort Collins, died Friday, January 8, 1993, at Poudre Valley Hospital. He was a pioneer member of WIFWDC. He greatly influenced the character and evolution of our organization, and we will miss his guidance and counsel. Our meetings will not be the same without his warmth and wisdom.

Frank was born on April 30, 1926, in Fresno, California, the son of William and Elsie Hawksworth. He received a B.S. in Forestry from the University of Idaho in 1949, and M.S. (1952) and PH.D. (1958) degrees from Yale.

Dr. Hawksworth, a highly respected and admired scientist, retired from the U.S. Forest Service's Rocky Mountain Forest and Range Experiment Station in 1990 with 43 years of federal service. He authored over 200 scientific publications on forest diseases. He was the world's authority on dwarf mistletoes, the most damaging parasites in forests of western North America. His research on mistletoes enabled him to travel, conduct research and cooperate on projects with scientists and managers throughout the world. His work on these pests did not stop with the publication of scientific information. He maintained constant contact with foresters, scientists, and practitioners at all levels of government, industry, university, and private practice to assist them with on-the-ground management problems. His kindness, concern for others, and quality work were especially appreciated by Mexican foresters, who affectionately knew him as "Dr. Frank". Frank's unique combination of brilliance, humility, and endless wit earned him a special place in the hearts of forest scientists and managers internationally.

Dr. Hawksworth was a member of the Society of American Foresters, International Union of Forest Research Organizations, International Council on Parasitic Seed Plants, Western International Forest Disease Work Conference, and Sigma Xi. He received Superior Service and Technology Transfer Awards from the U.S. Department of Agriculture, and the Outstanding Forestry Research Award from the Society of American Foresters.

Frank's commitment to the science of forest pathology did not stop with retirement. He maintained an office at the Research Station and volunteered over 1000 hours of his time each year since retirement. He also completed drafts of two books and the 40 year history of the Western International Forest Disease Work Conference. Frank's love of his science was an inspiration to the numerous students and colleagues who were fortunate enough to have known and worked with him. Many forest pathologists will remember how, when they were students or youthful unknowns, Frank listened to their ideas with patience, encouragement and genuine interest. His enthusiasm for science carried over into other aspects of his life as he was an active birder with a personal sighting list of over 500 species, an avid postcard collector, and an all-around family man. He set an exceptional example for us all.

Frank Hawksworth's Career – Excerpts from Buchanon's History of Forest Pathology of the West

"Frank G. Hawksworth first went to work for the division of Forest Pathology in late 1949 at Albuquerque, New Mexico for Dr. Lake S. Gill who immediately set him to work researching dwarf mistletoe problems in the Grand Canyon area. Frank previously had a "checkered" career in blister rust in the California Sierra during the summers and had worked as a summer assistant on the University of Idaho pole blight research crew in 1948. After graduating in 1949 he was rehired by the University on a more permanent basis to continue on that project. In the Fall of that year however, Dr. Buchanan, recognizing his potential as a researcher, recommended him to Dr. Gill. Fortunately for both of them, Lake was able to hire Frank immediately because one of his technicians, Pete Millenbaugh, had just decided there was a better future in the Post Office Department as a local letter carrier. Hawksworth and Hinds thus became Lake's two technical aides."

"In making idle conversations with some of his Department of Interior compatriots one day, Frank allowed as how a good man could make a round trip trek across the Grand Canyon between daylight and dark of the same day. Having vowed he thought it could be done, Frank felt obliged to prove his point. So, early in the morning on Thanksgiving Day, 1950, he set out for the South Rim, walked to the canyon bottom, thence up to the North Rim. He then turned right around and made the trip in reverse. This involved a vertical descent and ascent of about 13,000 feet. The 45-mile trip took him 18 hours and to date there is no evidence his record has ever been broken."

"Frank only worked a couple of years on dwarf mistletoe problems among the Mescaleros Apaches when he took off for one year to earn his Master's degree at Yale University. Then the Army pulled his number out of a bowl in 1954, but kept him only briefly before they released him because of his chronic asthmatic condition. Frank really didn't get a chance to settle down to his mistletoe work even then for in 1956 it was back to Yale again for residence requirements for his Ph.D."

"When he returned this time, he found himself stationed at Fort Collins, Colorado to where headquarters had been changed upon consolidation of the Southwestern and Rocky Mountain Stations. Stu Andrews was still laboratory leader at Albuquerque since Dr. Gill had been moved to Fort Collins as Division Chief in 1954. ...Frank was then moved up the line and has served as the equivalent or as project leader ever since. With all of these interruptions, reorganizations, and moving about, he has made a lasting contribution already to dwarf mistletoe knowledge. He has done some fascinating, interesting and important research based largely on imagination, initiative, and ingenuity not just of himself but especially with the aid of one of his fine assistants, Tommy Hinds...."

Others Who Will Be Greatly Missed

Bill Bloomberg, Ben Howard, and James Kimmey

TOWARD ECOSYSTEM MANAGEMENT

Dave Holland

Group Leader of Forest Pest Management in R-4

CHALLENGES WE FACE...WHAT'S DIFFERENT?

Shifting from an agricultural production view to an ecological systems view...outputs to process and functions.

Managing for multiple-use to managing for biodiversity.

Scale - Focusing on landscapes, not administrative boundaries. Looking at the "whole" first, and then the pieces.

Shifting from "Science Knows Best" to science recognizes problems that people solve.

Improving monitoring, analysis and feedback - Learning.

Forming networks of expertise.

Bringing quality data to the table...and sharing it.

Doing shared leadership, not informing and educating.

OUR CURRENT SYSTEM...

Creates conflicts rather than resolves it.

Encourages competing ideas rather than agreement on common objectives.

Retains traditional practices which may be damaging to ecosystems.

Proactive in creating goods and services, but reactive for ecosystem and species needs.

Inefficient, seeking remedy through politics and judicial processes.

OUR FUTURE SYSTEM...

Ecologically sound management programs, policies, and practices.

Management by geographical area across administrative boundaries.

Shared information systems and networking among organizations, interest groups, and political critics.

Shared leadership and deliberated outcomes among all interests.

WHAT CAN YOU DO AS A SCIENTIST?

As we have discussed, implementing ecosystem management means we take a broad view first, then focus on the project level so that we see our actions in the context of scale. As specialists, we need to understand the role of diseases and insects across landscapes through time. What role as disturbance agents do they have in creating patterns across landscapes? What type of information can we provide to help understand the role of insects and diseases?

We need to clearly describe the historic vegetative patterns and current conditions created by disease and insect activity to predict future vegetative conditions. This means we must work collaboratively, toward understanding and applying our knowledge on forest pests. Are you working collaboratively with others to identify knowledge gaps, and designing applications and research activities that attempt to apply knowledge and seek needed understanding? Or are you competing for limited funds with limited resources, and not sharing the credit?...The change needed is from INDEPENDENCE to INTERDEPENDENCE!

Most critical in the process of adaptive management is the LEARNING activity. That is, monitoring to learn from our assumptions is critical to this process. We must continually monitor, learn from our monitoring, incorporate new knowledge, and refine our goals to reflect this new knowledge. Our efforts must be collaborative, this means we, as humans, work together...academia/applications, scientists/politicians, entomologists/pathologists, federal agencies/state agencies, public interest groups/public land managers...etc.

We will be operating in a new work environment where administrative boundaries have no real meaning, so we must involve all partners in seeking understanding, and implementing our actions. You are going to be asked to derive measures of ecosystem health and integrity...or how do you measure ecosystem resiliency? Are aerial detection maps, and biological evaluations of pest occurrence enough to understand pest dynamics? Is disease and insect suppression helping to understand the role of these disturbance agents?...What about dwarf mistletoe and root disease suppression? Are we making good use of limited funds or do we need to rethink the focus of our programs? Are we all working toward sustaining the quality of lives through a better understanding of the role of pathogens in our ecosystems? Should we be focusing our talents on predictive models and monitoring criteria that will enhance understanding of the dynamics of pests as disturbance influences?

How can we be most effectively organized to provide managers and others with the service they need to incorporate forest disease and insect information into planning activities? What kind of skills do we need to discover and implement our understanding of pests and their role in ecosystems? What information gaps exist? All these questions are on the table and we are going to be increasingly called upon to discuss these. We cannot just go collect more information and have folks wait while we seek the definitive answer. We must put together our best judgement, monitor our assumptions, and learn.

We are all part of this grand experiment in resource management of PLAN - ACT - LEARN. WE will play an important role in helping to understand process and patterns on our landscapes as related to insect and disease occurrence. As you participate in discussions over the next several days, try to think about how the information you are presenting or listening to fits toward understanding Function, Composition, and Structure of ecosystems. Are we moving toward an ecological approach to management...where we value the whole, and our need to be interdependent; or are we continuing to collect data for data's sake, and work independently on competing interests?

ROOT ANATOMY: STRUCTURAL FEATURES RELEVANT TO FOREST DISEASE

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Although the root systems of woody plants are not subject to as much environmental variability as the shoots, they are nevertheless complex systems that must respond and adapt to numerous biotic and abiotic challenges. There is a considerable and rapidly increasing literature related to the root system functions of water and nutrient uptake, storage and anchorage. The purpose of this paper is to review how aspects of root anatomy and morphology may be important in relation to forest disease.

From a morphologists perspective shoot and roots are similar with respect to the following characteristics: they are both axial structures; they both may undergo primary (herbaceous) and secondary (woody) growth; they have similar basic tissue types; and they both are capable of branching. They differ in the fact that roots have no appendages equivalent to leaves.

It is logical to begin an examination of the properties of roots and root systems by a discussion of branching patterns. Typically they are classified as fibrous or taproot systems. Fibrous systems are most common in herbaceous plants (especially grasses) and the roots are often adventitous (stem-borne) in origin. The roots of woody plants are usually thought of as developing from a taproot which was the radicle of the embryo. However it is important to remember that the size, length and longevity of the taproot is extremely variable between species and under different growing conditions. For example, phenotypic plasticity of plants growing in sun and shade is evident in the morphology and anatomy of both the root and shoot systems. In shade, root growth is typically limited by photosynthate availability as you would expect. However, some species respond differently to the same parameters and may for example be developmentaly constrained such that their response may not seem adaptive. Ecologists and physiologist recognize two patterns or "strategies" of root system development that are related mainly to resource capture. These are sometimes referred to as intensive and extensive. The former produces a high density of roots in a limited volume and the latter attempts to explore more territory with a smaller or equal investment of root biomass. Nutrient density and patchiness, water availability and soil physical properties affect the patterns. Thoughtful discussion and more importantly a method for quantifying a number of relevant root system parameters is provided by Fitter (1987). It would seem that the ability to accurately describe and perhaps even quantify overall root system morphology would be useful in the study of both disease infection processes and examining the consequences of root disease.

Root growth and development are typically described as being zonal, with distinct regions of cell division, cell elongation and cell maturation. However more recent quantitative studies have shown that these processes are not confined to zones with discrete boundaries and that at a particular transverse level different tissue may be dominated by very different processes (Rost, Jones, and Evans,1989). For example cell division may cease first in the provascular tissue so those cells may on average be longer than adjacent cortical cells, even though the total elongation of the root had to be uniform at that cross-sectional level. An understanding of when and where the various tissues of the root become mature and eventually senesce is critical in determining the course of disease infection and spread. For example one might need to know: are the root hairs mature; what stage of endodermis exists; is there an exodermis; is the cortex present or necrotic (Esau, 1977). In woody roots it would be valuable to know: the extent of periderm formation; the level of cambium activity and the condition of the secondary xylem and phloem.

Although most pathologists will have a general understanding of root development and anatomy, it is important to realize that most of the textbook generalizations may or may not accurately describe the root system encountered in the field. Therefore it is important to learn to recognize the cell and tissue types of the host plant and how they may change in response to pathogen attack. Details of cellular anatomy such as: the extent of suberization of the exodermis, endodermis and cork; or the size of pit membrane pores, may also be critical to an understanding of infection mechanisms and the causes of certain symptoms. For example is dysfunction of the xylem caused by the presence of the pathogen, a product of the pathogen, or normal or pathogen-induced resin , gum or tylose formation.

The study of forest diseases presents many complex and interesting biological problems. It seems to me that interdisciplinary research teams composed of broadly trained pathologists but including anatomists, physiologists, microbiologists, entomologists, etc. , might come up with new perspectives and testable hypotheses. Don't be afraid to approach your non-pathologist colleagues. If you pose an interesting biological problem to them they may be happy to bring their own unique perspective to its solution.

NOTE: In the question period following my talk a question about the occurence of heartwood in roots was raised. According to Hillis (1987), heartwood has been documented in several species, but only near the stem. Where it exists it has the same cytology and physiology as stem heartwood. This reference gives reagents for heartwood detection. Zimmerman (1983) states that if , as commonly stated, water loss is the first step in heartwood formation, then roots may have less heartwood because stress is lower and water loss due to cavitation is less common. My search of the AGRICOLA database for root+ heartwood turned up only one citation (Ranjani and

Krishnamurthy, 1988). It claims the first observation of tyloses in root wood (*Cassia fistula* L.).

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PHYSIOLOGY OF ROOTS: WATER RELATIONS IN CONIFERS

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Reviewing the physiology of roots in twenty mintues is a broad assignment. In order to make this session more useful I shall focus on the water relations in roots and will limit my comments to conifers. Hardwoods are interesting also but the occurrence of vessels in hardwoods complicates the hydraulic considerations. We will first consider the whole plant because we must consider roots in their context if we are to understand how roots function and the consequences of their failure to function.

Xylem water potential

The pressure chamber apparatus, or pressure bomb, has made it possible to assess the xylem water potential in woody plants (Scholander et.al., 1965). One of the first lessons we learn when we measure water potential is that it seems to be always changing. It changes from hour-to-hour during the day, sometimes rather rapidly, as shown in figure one. Although these data are taken from the shoot, the roots are subjected to very similar xylem water potentials. From a relatively low tension on the water column in the morning before dawn the tension increases rapidly as soon as light falls on the foliage. This increase continues as the heat load from the sun increases, causing increased water loss through the stomata, until late morning or mid-day. At that time the stomata may close, reducing the rate of water loss and therefore causing no additional tension on the water column. As the heat load is reduced later in the afternoon, transpiration is reduced and uptake of water in the roots exceeds demand from the shoot so that tension in the water column is reduced. As uptake during the night continues, the tension is further reduced until the following morning when the cycle starts all over again. As soil moisture is depleated, the roots are less able to take up water and the minimum tension from day to day increases. Under very droughty conditions the stomata may not open, resulting in a rather flat diurnal curve. The important lesson here for us is that water potential in both the shoot and root changes continually, from hour-to-hour and from day-to-day.

The evaporative force at the interface between xylem water and the atmosphere provides the driving force for water movement through the plant. As water moves along this path from the soil through the plant and into the atmosphere it encounters resistance to movement. Resistance in the root is considerably lower than the resistance in the stomata, and may well be lower than resistance in the shoot. Hydraulic conductivity, or the ability of water to move through the xylem, is considerably higher in the root lower shoot than in the upper shoot (Tyree and Ewers, 1991). Considering the cross sectional areas of roots and shoots, roots in at least some species seem to have more capacity to conduct water than shoots. I.e., there is an excess capacity for water movement in roots. If some of the roots were to become incapacitated by mechanical injury or disease, the remaining roots would have sufficient hydraulic capacity to supply the water needs of the shoot given sufficient soil moisture.

Roots can fail for a number of reasons: low soil moisture, insufficient oxygen available to the roots, xylem cells plugged by hyphae, or xylem cells containing air instead of water (embolisms). When we look at a forest we may see shoots which appear to be suffering from drought, but we usually cannot identify the cause of root failure. When roots are unable for any reason to supply the demand for water in the shoot, the water potential in the xylem decreases (i.e., the tension in the water column increases). For the shoot, the consequence of massive root hydraulic failure is extreme tension on the water column causing breaks in the column in tracheids (cavitation) followed by the tracheids filling with air (embolism), and eventually death by drought (Sperry and Tyree, 1990). Figure 2 shows a droughted Western hemlock seedling which has lost several lower branches because of excessive tension on the water column.

Xylem cavitation

When cavitation (breaking of the water column) occurs in a cell (tracheids in the case of conifers), a sound is produced. The frequency of that sound spans part of the audible range as well as ultrasonic frequency. These acoustic events caused by cavitating cells can be detected by a sensitive microphone using ultrasonic frequencies (Sperry and Tyree, 1988). Audible frequencies cannot be used because of excessive interference. The drought stress monitor is a commercially available instrument which can detect, record, and process acoustic emmissions from cavitating cells. Figure 3 shows a microphone attached to a Western hemlock seedling to monitor cavitation.

Cell architecture plays an important role in determining the susceptibility of a cell to cavitate. We will deal with tracheids here but in hardwoods, vessels play a dominate role. Tracheids have bordered pits through which water flows from cell to cell. These pit pairs contain a torus in the center which is attached by a network of cellulose strands. For air to enter a water-filled tracheid, the meniscus must pass through this very fine network. Only at very high tensions on the water column can a meniscus be forced through such a small opening. When a cell cavitates and becomes embolized, the tori between cells may close and seal off the cavitated cell from its neighbors. The broken water column can take an alternate route through other cells. Tracheid diameter may play an important role in recovery of a cell from an embolism. Spring wood has larger diameter tracheids while summer wood has tracheids with smaller diameters. Tracheids with larger diameter tend to have larger bordered pits and be more susceptible to cavitation than tracheids with smaller diameters (Zimmerman, 1983). Similarly, larger tracheids may recover from an embolism more slowly than smaller tracheids (Borghetti et al., 1991).

We intentionally exposed freshly planted Western hemlock seedlings to drought, then monitored their water relations. The shoots maintained their ability to conduct water but the water potential became very low (high tension on the water column) and did not recover as would be expected of seedlings which survive (McCreary and Zaerr, 1987). Several of these plants died and most lost a few lower branches even though soil moisture was plentiful. Figure 4 shows the acoustic emmissions recorded in a hemlock seedling which died of drought in the laboratory. When we monitored the acoustic emmissions in four of our outplanted seedlings we found that one of them was cavitating daily (as the water potential became more negative) but the other three were not (figure 5). The one which cavitated died subsequently but the others survived. In this case cavitation in tracheids of both shoots and roots could have brought about the death of these seedlings. Although we do not know the cause of failure of the roots to take up sufficient water, we do know that cavitation in the tracheids brought about the death of some of the hemlock seedlings.

Figure 6 shows the course of acoustic events (roughly proportional to cavitation events) which occurred in a Western hemlock seedling as it died of drought. As more and more of the hydraulic pathway is broken by cavitation and embolism, increasing demand is placed on the remaining portion of the pathway, causing further increased tension which induces further cavitation and so on. This so-called "runaway" cavitation continues until a point is reached when most of the pathway is blocked and fewer cells are available to cavitate (Tyree and Sperry, 1988). Eventually the entire xylem pathway is blocked and no more cavitations are detected. The plant reached a point at which it probably would not recover even if placed in a favorable environment at about the time of maximum acoustic events. For plants growing in the field, the point of no return is probably reached well before the time of maximum acoustic events.

Vulnerability curves

The susceptibility of various species to cavitate and lose hydraulic conductivity can be compared by constructing and comparing vulnerability curves (Tyree and Sperry, 1989). These curves are constructed by measuring the loss in hydraulic conductivity caused by emboli at various xylem water potentials. Thus, one can compare the xylem water potentials at which half of the hydraulic conductivity is lost in two species and get an idea of the relative resistance to cavitation between the two species. Figure 7 shows a vulnurability curve for Western hemlock. These curves can be obtained by exposing plants to a known xylem water potential and then either measuring the rate of flow of a liquid through a stem section or measuring the proportion of conducting elements in a stem cross section by the dye method (Logullo and Salleo, 1991).

Measuring roots

In 1992 we had opportunity to measure the hydraulic conductivity of roots of Douglas-fir and grand fir trees obtained from excavations used to plot presence of root disease. These roots showed a range of disease symptoms ranging from no symptoms to obviously colonized. An adjacent segment of the roots we measured was cultured to verify the presence or absence of disease. The roots were selected as they were exposed by washing away the soil, sealed in a plastic bag and stored in a cooler until the hydraulic conductivity could be measured later the same day or the following morning. We used a simple liquid perfusion method to obtain the volume of liquid forced through a segment in one minute. Following that measurement we passed a solution of saffranin dye through the segment to provide a visual indication of the hydraulic pathway through the segment. The segments were then dried and measured to calculate the hydraulic conductivity.

Figure 8 shows one of the results of this experiment (Baker et al, 1993). Root segments which showed no symptoms of disease generally had a high hydraulic conductivity but segments which showed symptoms of disease had lower hydraulic conductivity. Figure 9 indicates that the various classes of disease symptoms had different hydraulic conductivities. Of special interest is that segments with certain apparent symptoms of disease had hydraulic conductivities similar to that of segments showing no symptoms.

Segments which had been stained with safranin showed the hydraulic pathway in the segments. Figure 10, for example, indicates that only a small central core was not conducting. The segment in figure 11, however, shows that part of certain annual rings became non-conducting. It is possible that these non-conducting portions were embolized because of excessive water stress, although at this point such a statement is only speculation. Figure 12 is interesting because it shows that only the very latest wood to be laid down was conducting; all older xylem was non-conducting. Such a root may be barely alive, but it contributes very little to the water needs of the tree.

This paper has reviewed briefly some of the basic elements of water movement and use in forest trees and how disease might intefere with water movement. The measurements of hydraulic conductivity on root segments outlined above is a clear indication that root diseases interfere with the movement of water in infected roots. The extent of how a given disease or symptom is related to interruption of water movement in roots is not clear, however. The challenge before us is to understand how root disease affects the physiology of roots and how the disease can be managed to reduce those effects.

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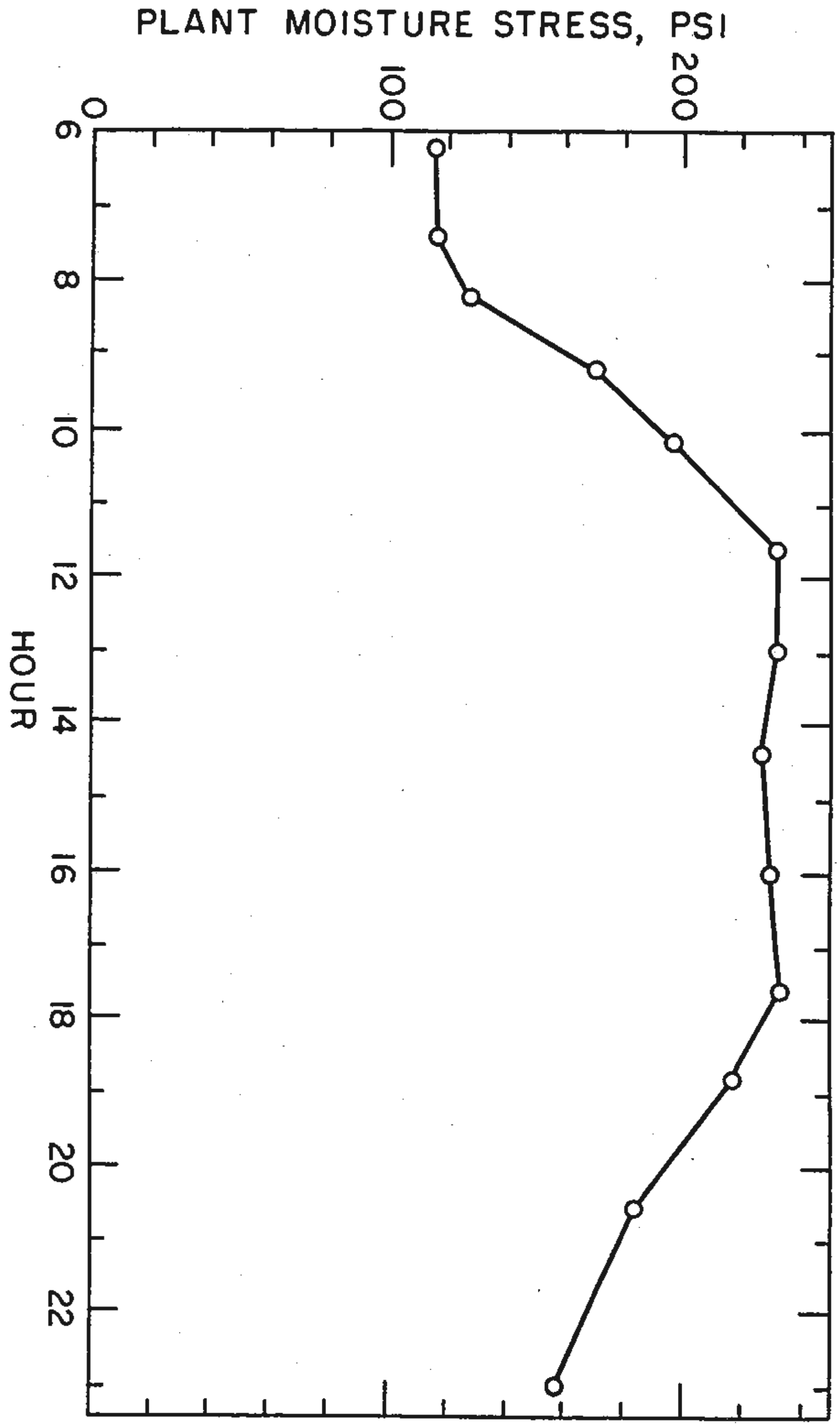

Figure 1. A typical diurnal curve of plant moisture stress for a young Douglas-fir tree. Note the delay in recovery as the solar radiation is reduced in the afternoon.

Figure 2. A Western hemlock seedling which has been partially killed by drought. Note that some branches died completely while other branches appeared undamaged. This pattern of damage is typical of drought damage in some species.

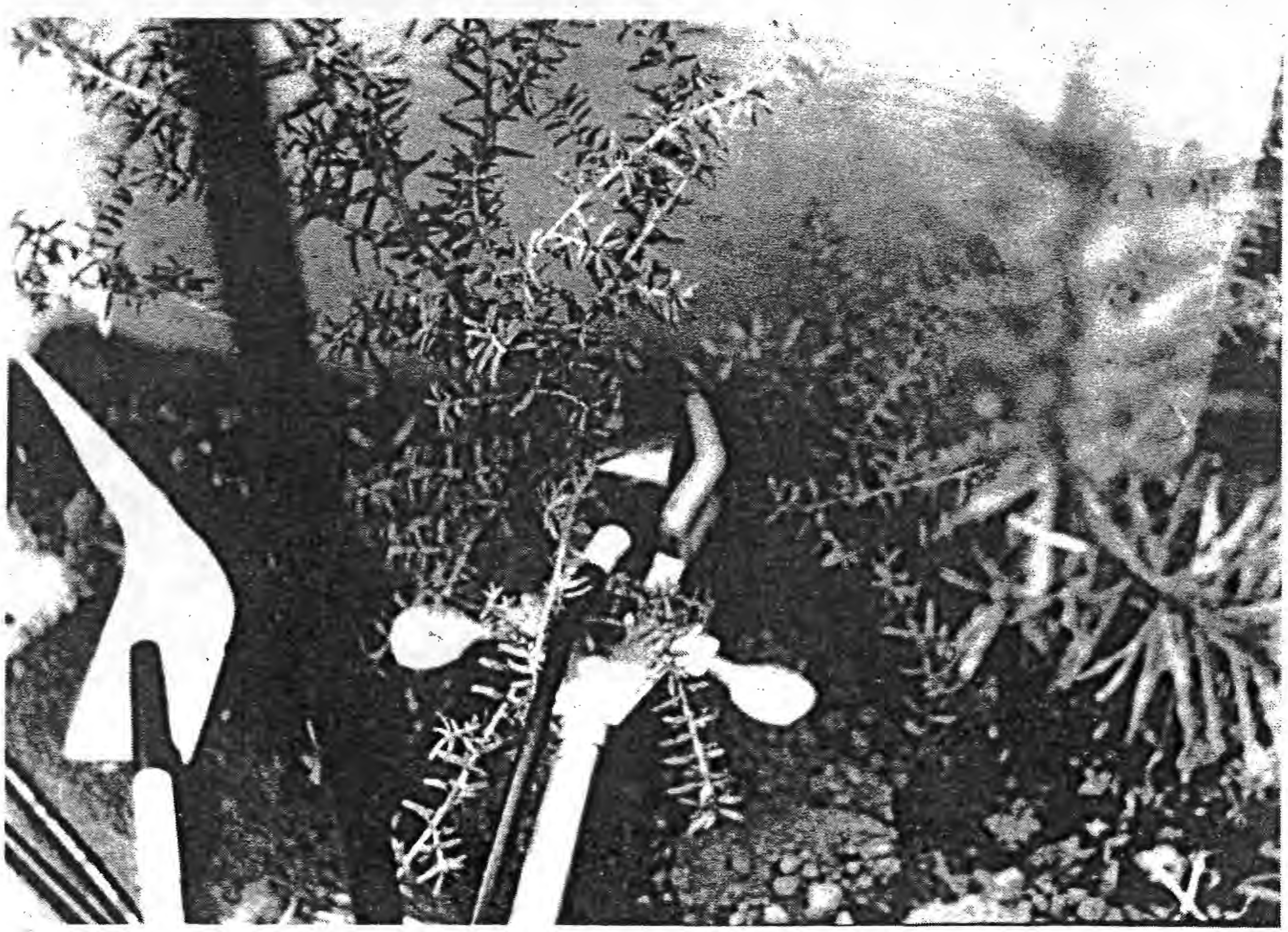

Figure 3. Ultrasonic microphone attached to a seedling of Western hemlock to monitor acoustic events (cavitation) in the seedling as it is droughted.

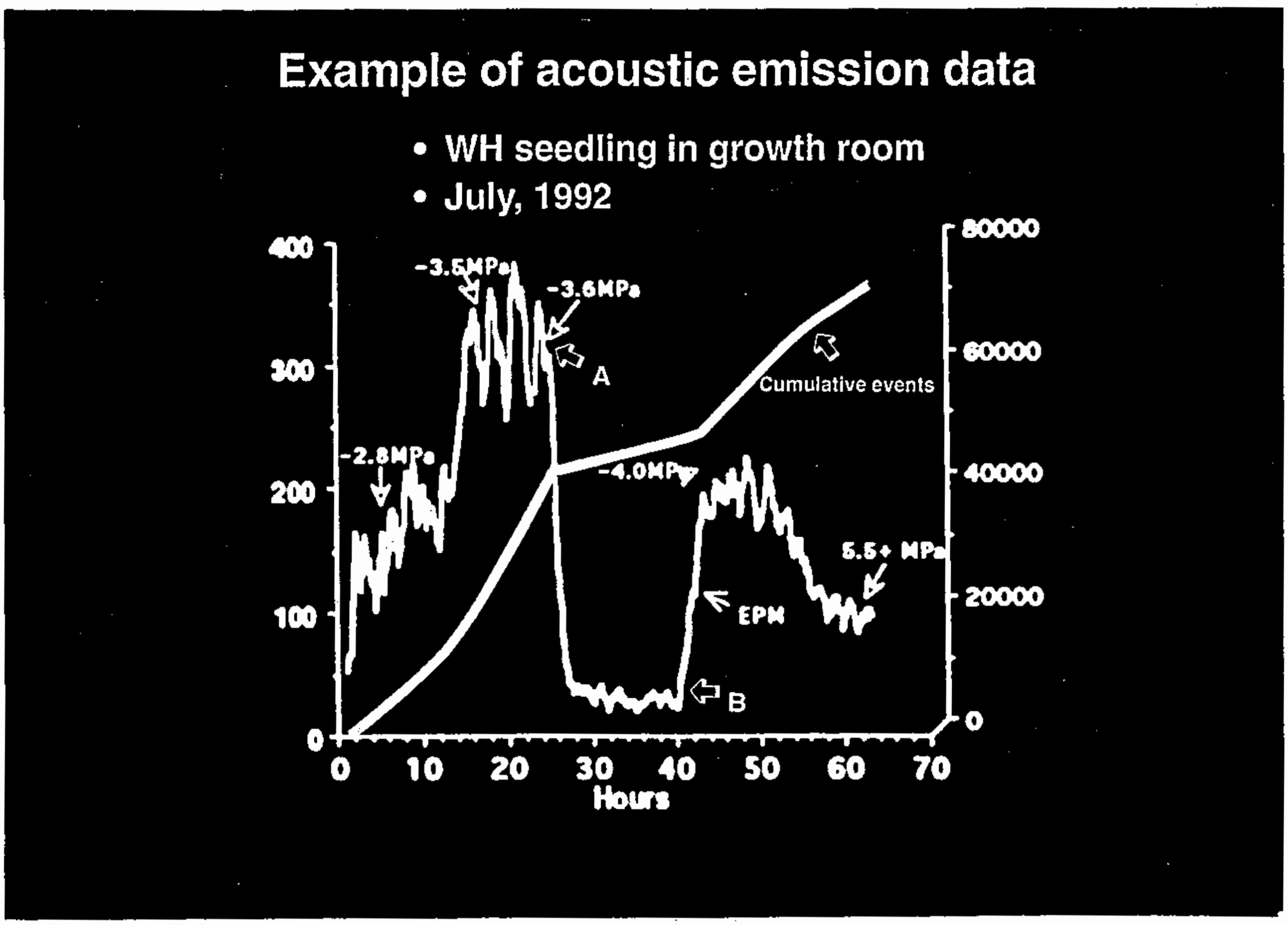

Figure 4. Typical course of acoustic emmissions (cavitation) in a Western hemlock seedling under conditions of drought.

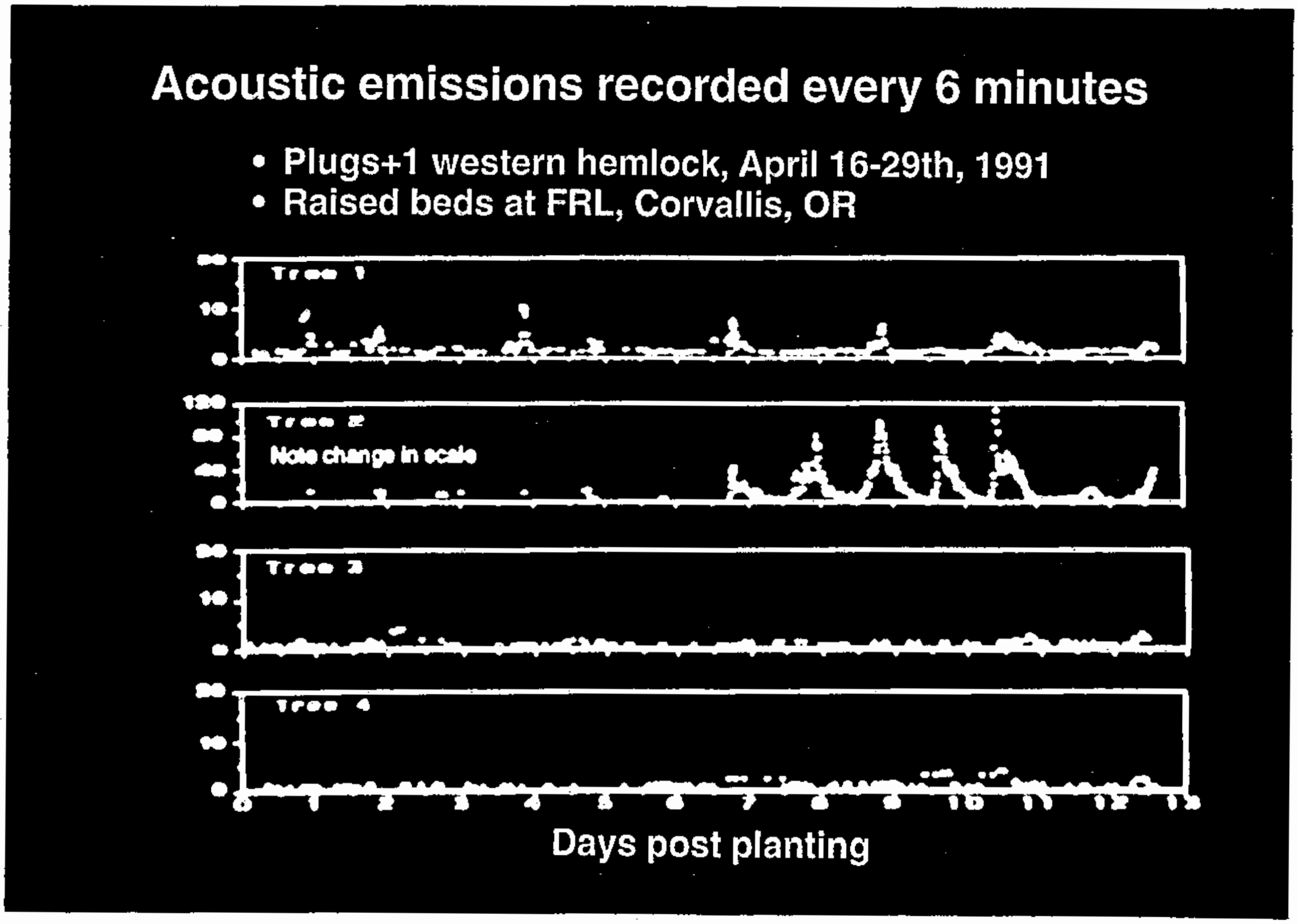

Figure 5. Acoustic emmissions (AE) in four seedlings of Western hemlock growing in the field. The seedling which was cavitating (indicated by the incidence of AE) died subsequently but the other three did not.

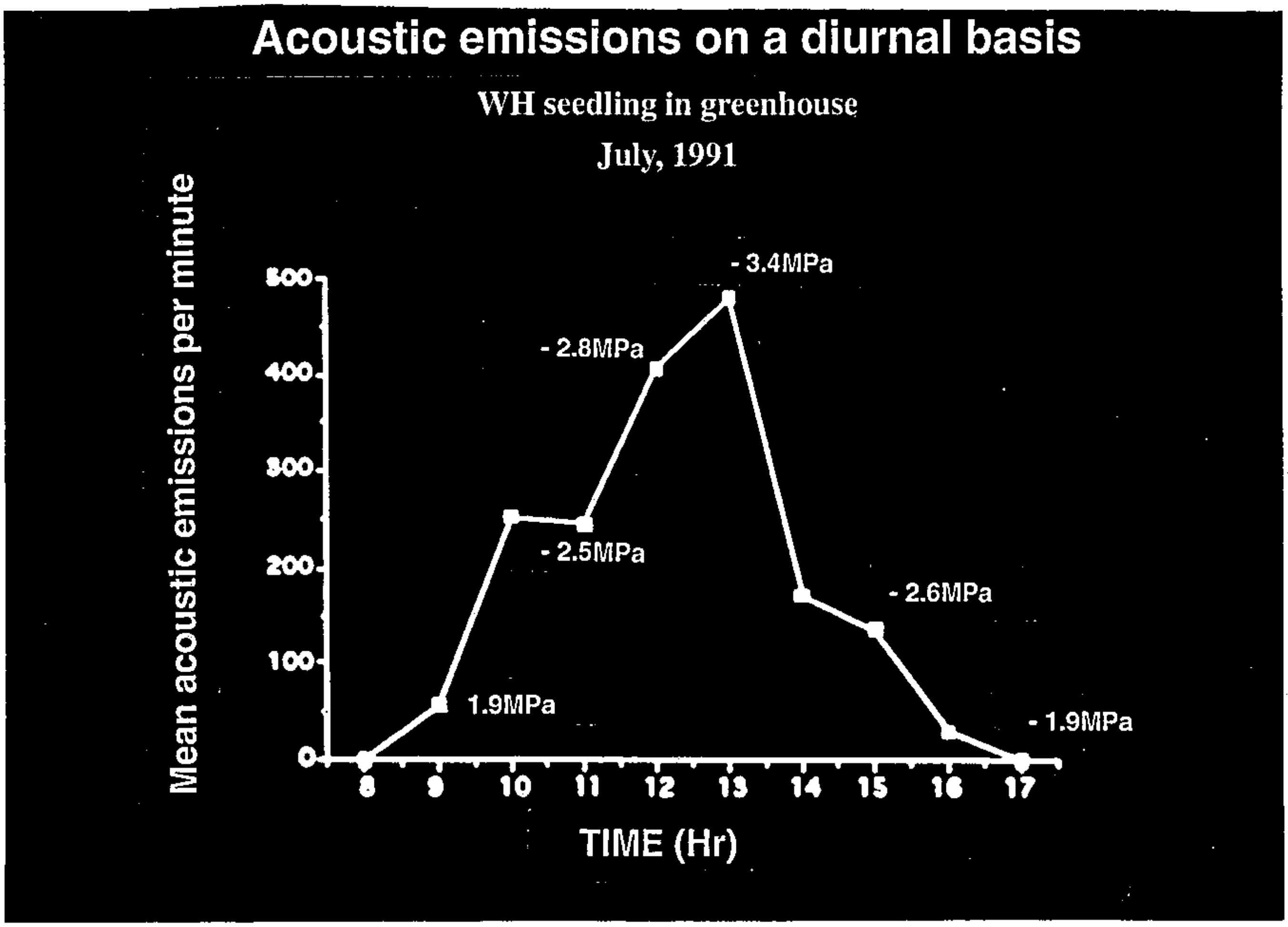

Figure 6. Acoustic emmissions of a Western hemlock seedling as it dies of drought. The seedling is beyond the point of possible recovery by the time the emmissions reach a maximum.

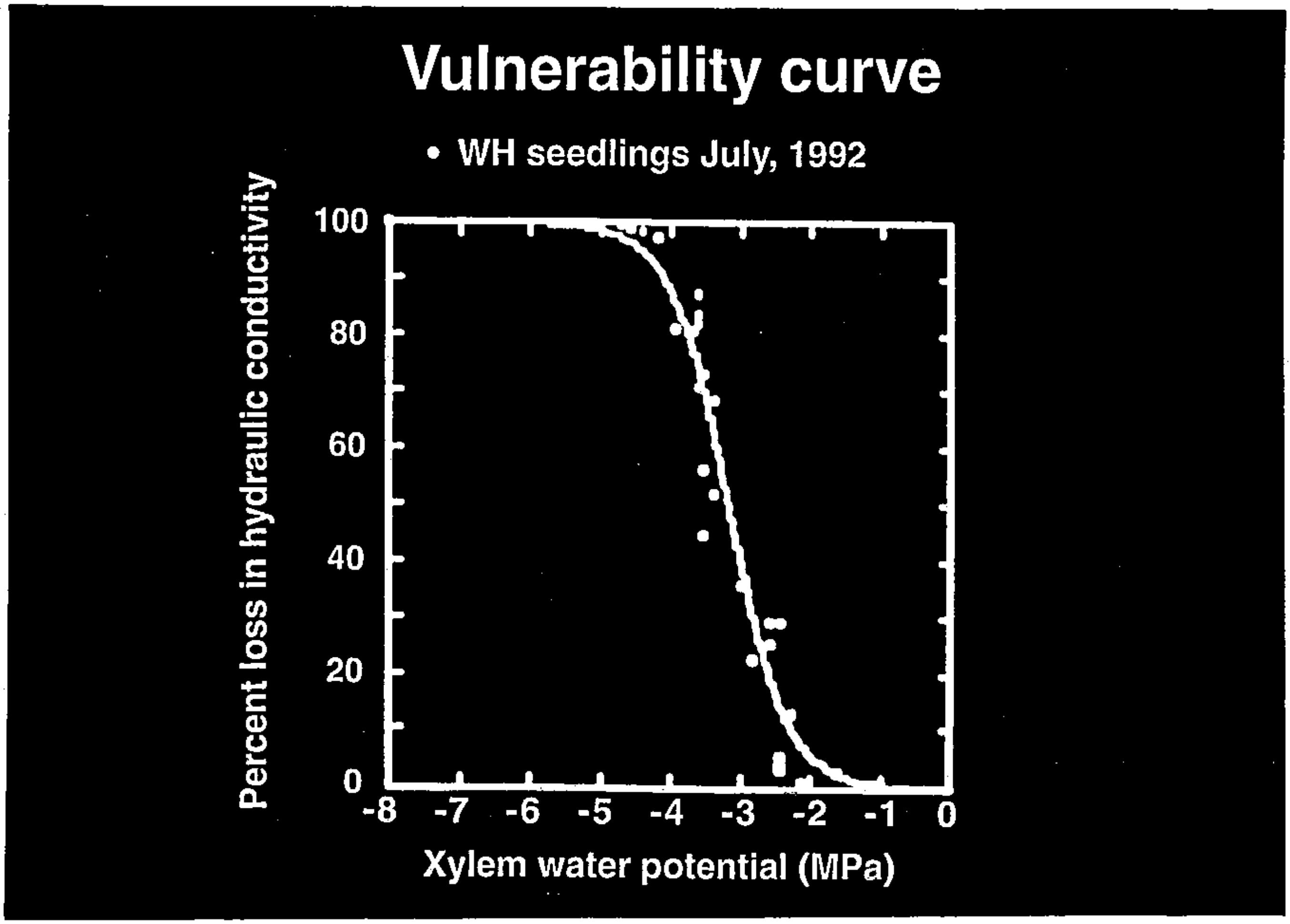

Figure 7. Vulnerability curve for Western hemlock. The mid-slope of this curve is rather steep compared to curves for Douglas-fir or pine, suggesting that western hemlock is likely to be more sensitive to drought than the other species.

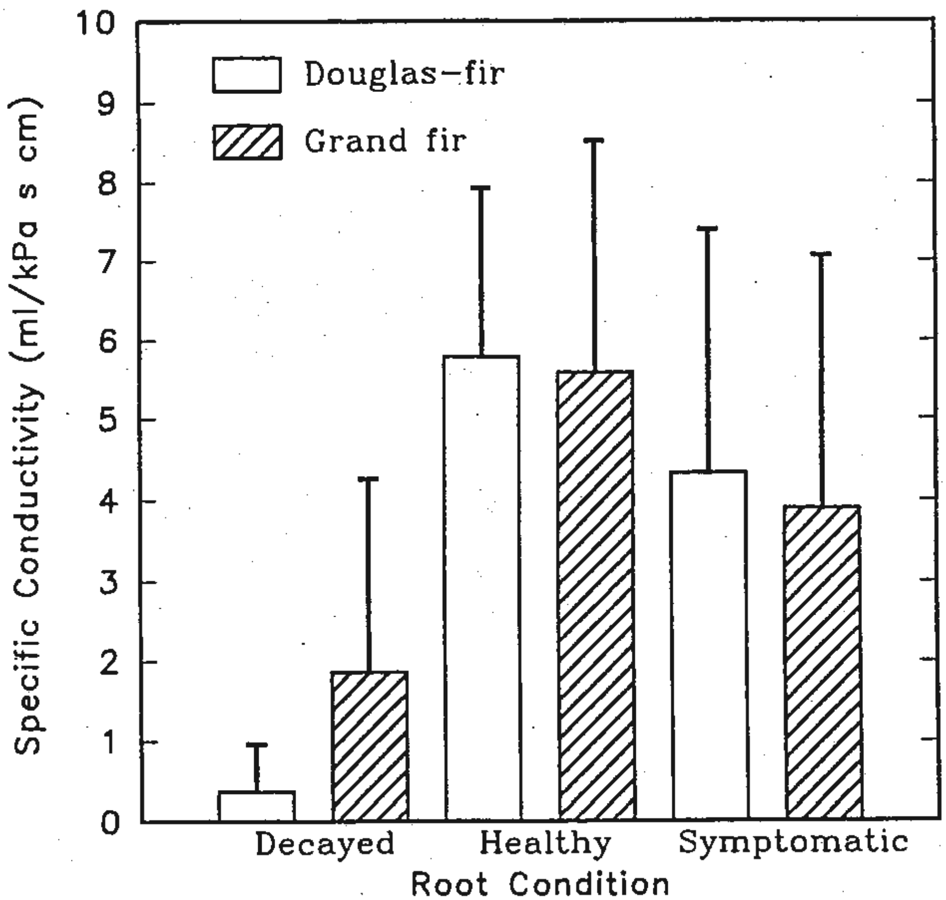

Figure 8. Hydraulic conductivity of Douglas-fir and grand fir roots for three classes of root disease severity.

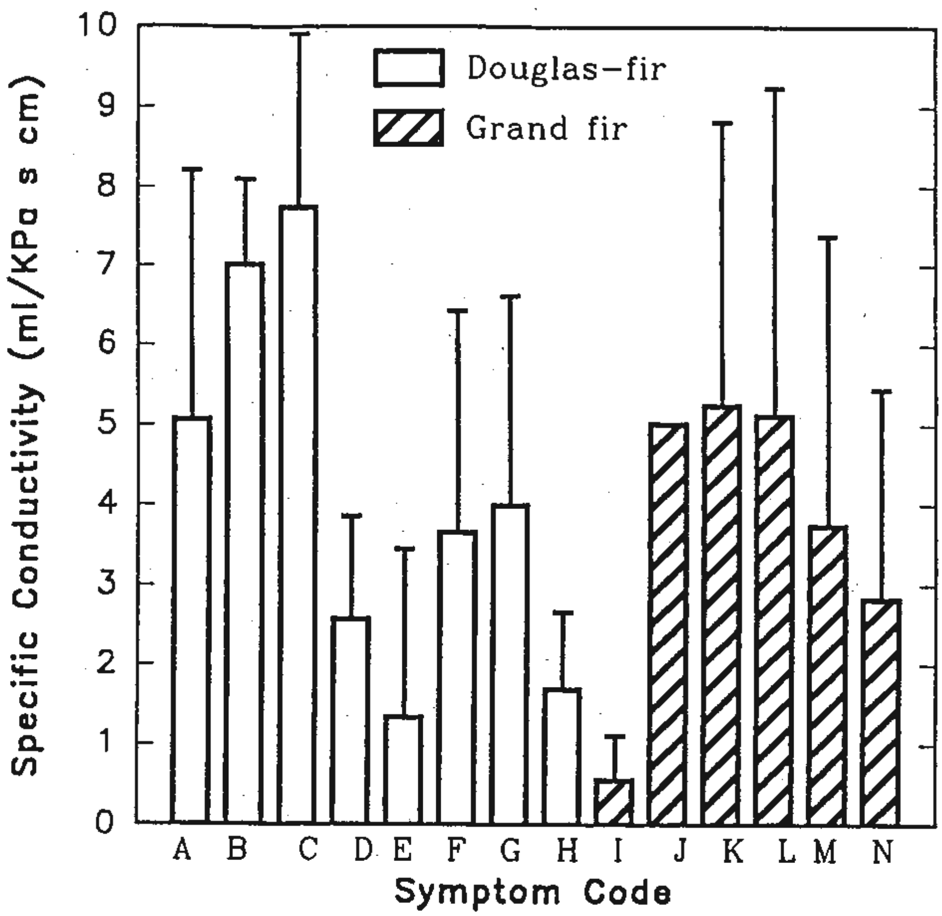

Figure 9. Hydraulic conductivity of Douglas-fir and grand fir roots associated with different symptoms of root disease. Note that certain symptoms of disease is not associated with reduced hydraulic conductivity.

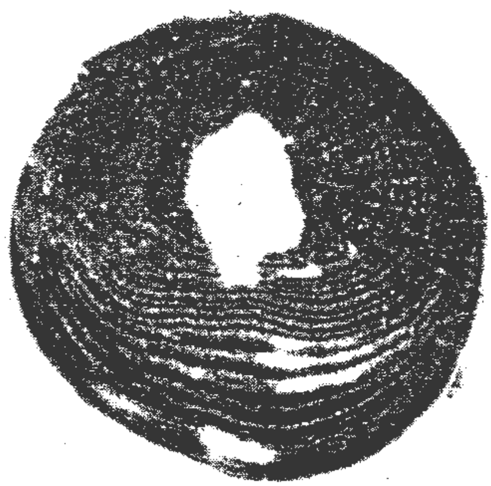

Figure 10. Example of a root segment (cross section) stained with safranin to show the conducting pathway of water. The stained portions (dark) are areas in which water was conducted.

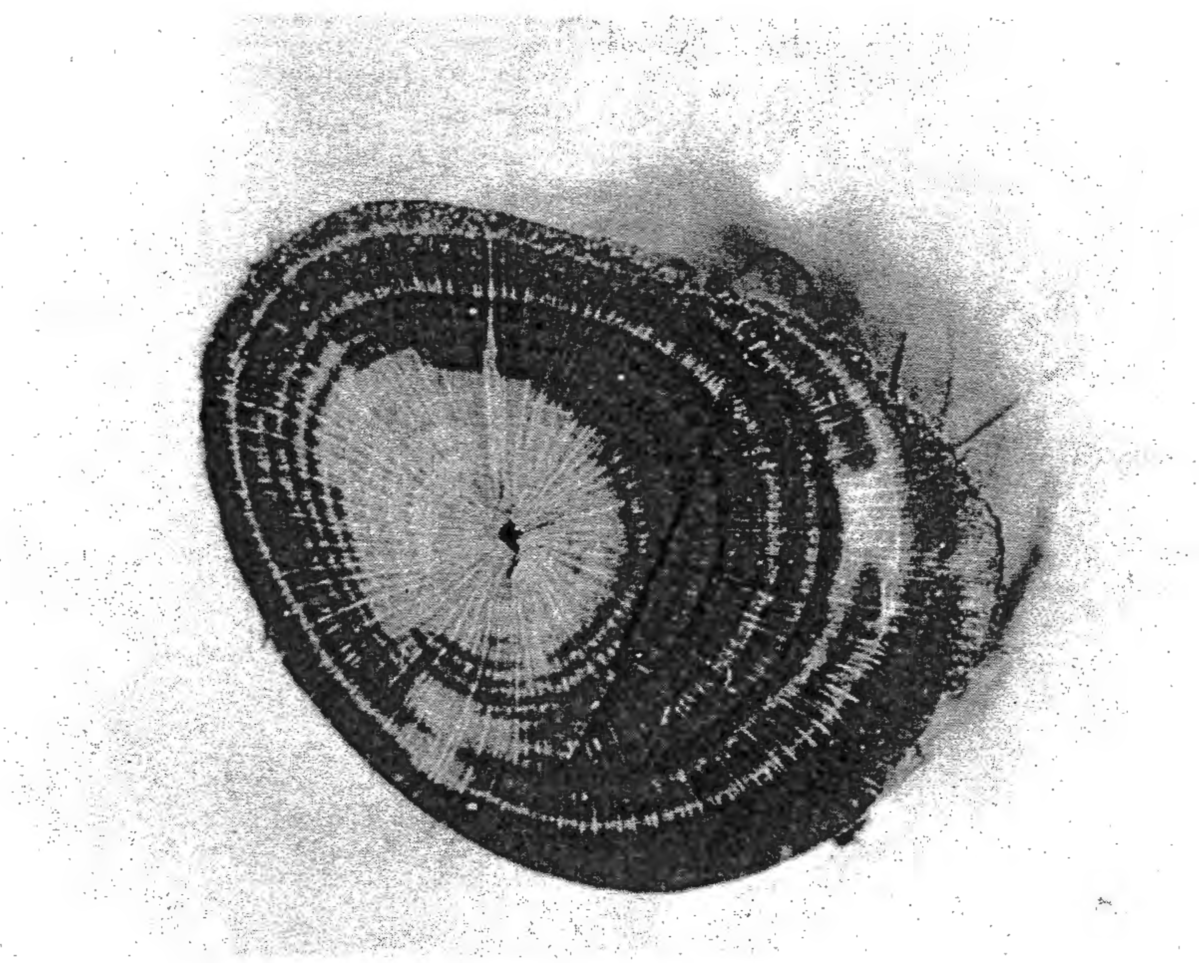

Figure 11. Example of a root segment (cross section) stained with safranin to show the conducting pathway of water. The stained portions (dark) are areas through which water was conducted. Note that tracheids in some of the annual rings did not conduct water.

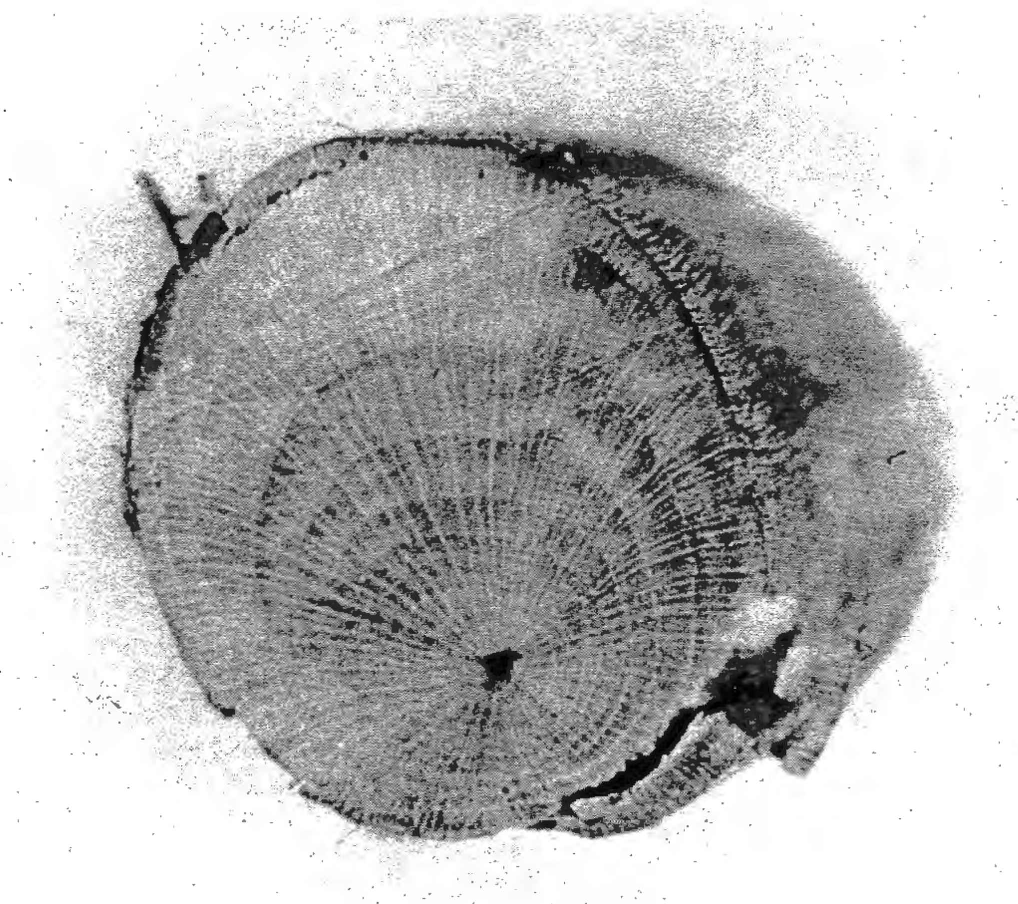

Figure 12. Example of a root segment (cross section) stained with safranin to show the conducting pathway of water. Only the newly-formed wood (the stained portion) conducted water. The non-stained central core was non-conducting because of root disease.

ROOT PATHOLOGY - AN OVERVIEW OF SEVEN ROOT DISEASE FUNGI AFFECTING CONIFERS IN THE FORESTS OF WESTERN NORTH AMERICA

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Introduction

The preceding three speakers on this Panel on Roots and Root Disease have given us a very good review of various aspects of living root systems including their anatomy, physiology, and fine root functions.

It is now by responsibility to bring the discussion full circle by describing how living root systems can be challenged and many eventually killed by one or more of the root disease fungi occurring in the forests of western North America.

To save time here today, and for your future reference, I have tabulated (Table 1) information on the most common and economically important of these root disease fungi. They are, in alphabetical order: *Armillaria ostoyae* (Romagn.) Herink, *Heterobasidion annosum* (Fr.:Fr.) Bref., *Inonotus tomentosus* (Fr.:Fr.) S. Teng, *Leptographium wageneri* (W.B. Kendrick) M.J. Wingfield, *Phaeolus schweinitzii* (Fr.:Fr.) Pat., *Phellinus weirii* (Murr.) Gilbn., and *Phytophthora lateralis* Tucker and Milbraith.

For the task of comparing and contrasting these seven fungi, they can be classified in several ways. For example, five out of the seven (i.e. *A. ostoyae*, *H. annosum*, *I. tomentosus*, *Phaeolus schweinitzii*, and *Phellinus weirii*) are members of the Basidiomycetes - a diverse class of fungi which includes rusts, wood decayers and root rotters. *Phytophthora lateralis* is an Oomycete and belongs to a genus with an appropriately descriptive name - *Phytophthora* meaning 'plant destroyer'. *Leptographium wageneri* is a Hyphomycete and is the only member of the group which does not cause wood decay.

These seven fungi may also be classified according to their relationships with the root systems they infect (Garrett 1970, Wilcox 1983). For example, *Phytophthora lateralis* can be considered an unspecialized root parasite. Generally speaking, these are parasites which vigorously macerate and kill plant tissues and do not have an extended life inside roots. Their effects on root morphology and anatomy are subsequently short-lived.

Armillaria ostoyae, *Heterobasidion annosum*, *Phaeolus schweinitzii* and *Phellinus weirii* may all be categorized as specialized ectotrophic root-infecting fungi. These are parasites which reside in roots for extended periods of time and may ultimately kill their hosts. The effects which these parasites have on host root morphology and anatomy may be profound.

Finally, *Leptographium wageneri* stands alone among the group of seven as the only parasite which can be categorized as a tissue-specific pathogen: it is restricted almost entirely to hosts' xylem tracheids.

Now for some comments which generally apply to all seven of these root disease fungi. Each fungus can infect the roots of a wide range and age of hosts; each may reduce tree growth and volume by killing roots and by decreasing water and nutrient uptake and each may eventually cause mortality by predisposing hosts to blowdown or insect attack. All of these root disease fungi cause similar crown symptoms which include chlorotic foliage, reduced terminal growth, thinning of crown foliage, and crops of numerous, but abnormally small, cones.

Table 1. Information on seven root disease fungi affecting conifers in the forests of western North America (N. A.)

Root Disease Fungus Common Name(s)	Distribution; Endemic to N.A.?	Hosts	General Mode of Pathogenesis on Roots	Rate of Spread	Survival in Stump Roots / Dead Host Tissues	Site Factors Affecting Incidence
Armillaria ostoyae Armillaria Root Disease	Europe, Japan and North America. Endemic to North America.	*A. ostoyae* has numerous hosts. Conifer hosts include Douglas-fir, true firs, spruce, pines, hemlock and cedar. Hardwood hosts include red alder.	•*A. ostoyae* is transferred from inoculum source (e.g. stump roots or living, infected host) to new host or food base (e.g. stem of thinned tree) by root contact or by way of rhizomorphs growing through soil. •Mycelial fans invade outer bark of host roots, eventually penetrating to cambium; fans then grow in bark and cambium to root collar where stem may be girdled and host killed. •Occasionally, infected trees die as a result of blowdown after failure of decayed structural roots.	The fungus spreads up to 30 cm/year in living hosts; up to 100 cm/year in cut stumps.	*A. ostoyae* may survive for decades in decaying wood (conifer and hardwood) in soil; is infective for a shorter time - perhaps 10 to 20 years, depending on host species.	*A. ostoyae* occurs over a wide range of sites and soil types; specific factors affecting incidence not well reported.
Heterobasidion annosum Annosum Root Rot	Most temperate regions of northern hemisphere where conifer forests grow. Endemic to North America, occurring throughout USA including Alaska, and in British Columbia and Southern Ontario.	*H. annosum* has numerous hosts, however it is an important pathogen only on gymnosperm hosts which include: cedar, cypress, Douglas-fir, hemlock, juniper, larch, pine, redwood, spruce, and yew. Angiosperm hosts include: alder, birch, cherry, dogwood, laurel, maple, poplar, and willow.	•Infection may be initiated by mycelium transferred by root contact or by basidiospores dispersed by air and water which land and germinate on susceptible tissues such as wounds or freshly cut stump surfaces. •Depending on mode of infection and host, the fungus may eventually girdle and kill suscept, be confined as butt rot, or decay structural roots of suscept such that it is blown down.	In roots, the fungus spreads at average rates of 50 to 200 cm/year. Parasitic growth is slow while saprophytic growth is relatively fast.	As long as *H. annosum* is the first 'one' into a food base, it is an able competitor and may persist for many years; its longevity is greatest in cool regions and in large stumps. Where stumps decay rapidly (e.g. southern USA), inoculum dies more quickly.	*H. annosum* occurs over a wide range of sites and soil types; in eastern USA the disease is most severe on deep, well-drained sandy/ loamy sites. Soils with a high content of clay or organic matter or poor internal drainage are not conducive to the disease.
Inonotus tomentosus Tomentosus Root Rot; Red Root and Butt Rot	Canada, United States and Eurasia. Endemic to North America.	Conifer hosts include spruce, western red cedar, Douglas-fir, true firs, lodgepole pine, eastern and western hemlock. Has been found on red alder and birch in British Columbia.	•*I. tomentosus* is transferred from inoculum source to new host by root contacts and likely also by basidiospores. •Penetration of roots occurs along small feeder roots, at small root junctions, or for small roots, directly through bark; for infection to occur through root contact, mycelium must be ectotrophic. •For roots <4 to 5 cm in diameter mycelium grows ectotrophically; for roots >4 to 5 cm in diameter mycelium grows in heartwood longitudinally until the tree dies, then expands radially to bark. •Infected trees may eventually die or be blown over because of decayed wood in major roots or butt.	1 to 10 cm/ year on spruce in Canada.	May persist for 15-20 years after death of spruce (in Canada)	In Canada, occurs on a variety of sites but is most common and severe in spruce growing on acidic (i.e. pH. 4-5), relatively infertile soils with low water-holding capacity or where shallow soil overlies rock or hardpan. In mixed conifer stands in Idaho, it is most common in stands at elevations >1500m. *I. tomentosus* is well adapted to moderate versus low, soil temperatures.
Leptographium wageneri Black Stain Root Disease	In North America, occurs from New Mexico to southern California to Colorado and Montana, and in British Columbia. Endemic to North America.	There are at least 3 host specialized strains of *L. wageneri*: first occurs on Jeffrey, lodgepole and ponderosa pines; second occurs on pinyon pines; third occurs on Douglas-fir. Hardwoods are not affected.	•*L. wageneri* may be transferred from inoculum source (e.g. stump roots or living, infected host) to new host by root grafts and contacts, by hyphae growing through soil for a few centimetres, or by insect vectors. •Fungus apparently cannot penetrate bark tissues - it requires a wound or natural opening to xylem tissues to infect host. •Following infection the fungus rapidly colonizes only host xylem tracheids, moving toward the root collar and lower bole. •Tree mortality is caused by loss of vascular tissue function and/or insect attack on disease-stressed trees.	Growth rate in Douglas-fir roots averages 220 cm/year.	Fungus reported to survive in stump roots or dead stems for only a few months to a maximum of perhaps 4 years.	Severity of the disease is affected by a variety of stand and site factors including site quality, soil moisture and temperature, host tree density, topography and site disturbance. Stand history and site disturbance appear to play a major role in incidence and severity of the disease - e.g. Black Stain is well established along roads and on sites greatly disturbed by harvesting practices.

Root Disease Fungus Common Name(s)	Distribution; Endemic to N.A.?	Hosts	General Mode of Pathogenesis on Roots	Rate of Spread	Survival in Stump Roots / Dead Host Tissues	Site Factors Affecting Incidence
Phaeolus schweinitzii Brown Root and Butt Rot; Brown Cubical Rot.	Occurs throughout forested regions of North America and also widespread in Eurasia. Endemic to North America	The fungus commonly causes damage in Douglas-fir, true firs, larches, eastern and western white pines; it is likely that all conifers are susceptible to some extent.	•Most infection by *P. schweinitzii* is probably initiated by basidiospores which are capable of establishing persistent infestation of soil; there is little evidence for root-to-root mycelial growth. •Fungus may enter through wounds in aerial parts of trees but more common mode is invasion of suscepts roots. •Mycelia penetrate to wood tissues and eventually cause a radially extensive brown cubical decay which often involves most of the cross-section of suscepts lower bole (butt).	Not reported.	Literature is sparse on this subject, however in Great Britain, stumps of a 40 year old felled Sitka spruce were found to provide food bases for the fungus for at least 17 years, but main flush of basidiospore production by basidiocarps was within an initial 7 year period.	Site factors influencing infection poorly understood.
Phellinus weirii Laminated Root Rot	Japan, Manchuria, and western North America from northern California to southwestern British Columbia and eastward to northern Idaho. Endemic to North America.	Two 'strains' of fungus recognized: principle strain of most economic importance affects Douglas-fir, true firs, western and mountain hemlock, lodgepole and western white pines, and spruce; second strain causes butt rot in western red cedar.	•*P. weirii* is transferred from inoculum source (e.g. stump roots or living, infected host) to new host by root contact. •Ectotrophic mycelium invades bark tissue of host roots, eventually penetrating to the cambium. •Ectotrophic mycelium may spread proximally and distally from infection point(s) - up to 200 cm ahead of decay (i.e. endotrophic mycelium). •Ectotrophic mycelium often spreads to root collar and down other major laterals - tree may be girdled and killed, but more often is blown down because of decay in major structural roots.	Ectotrophic mycelium spreads at 20 to 40 cm/year.	Viable mycelium has been found in stumps >50 years old but probability of infection by this mycelium is likely low; its infectivity is not known.	*P. weirii* is generally present over a range of sites and soil types and from sea level to alpine forests. It has been suggested that incidence of disease is at least partly dependent on timber type and soil moisture regime - drier sites have less disease.
Phytophthora lateralis Phytophthora Root Rot	In North America occurs over natural and planted range of Port Orford cedar from northern California to southern British Columbia Not endemic to North America - likely introduced; thought to be of Eurasian origin.	Principle host is Port Orford cedar.	•Fungus overwinters as chlamydospores or oospores in soil or dead tissues or as mycelium in dying tissues. •In spring, zoospores germinate from overwintering stages to infect tips of fine roots. •Mycelia penetrate to cambial region of larger roots and eventually to root collar and lower bole of infected tree; infected trees are always eventually killed.	In infected bark, average rate of mycelial growth is 5 cm/month in late autumn to early spring.	Chlamydospores and oospores can live many months, and possibly years, in organic fraction of soil. Fate of mycelia that invade structural root system and girdle tree at root collar is unknown, however a minimum of three years has been proposed as the longevity of this potential source of inoculum.	Disease is most abundant in wet soils and during wet weather. *P. lateralis* thrives at low soil temperatures prevalent during wet weather. Rate of disease development is fastest in cooler and wetter parts of the range. Disease appears not to be influenced by soil type.

The following sections are overviews of these seven root disease fungi: their modes of pathogenesis and their effects on host root systems.

Armillaria ostoyae

Armillaria ostoyae is the most common and pathogenic species of *Armillaria* occurring in western North America. Its principal hosts are living conifers including Douglas-fir, true firs, spruce, pines, hemlock, and cedar.

Armillaria ostoyae becomes established by infecting live trees and by colonizing stumps created during thinning or harvesting operations. The fungus spreads to new hosts by way of root contact or by way of rhizomorphs which can travel through the soil. There is no evidence to indicate that basidiospores can directly infect living roots, presumably because these spores posses an inadequate inoculum potential.

The site of infection on a host, whether it arises from root contact or rhizomorphs, plays an important role in the development of *Armillaria* root disease. For example, infections occurring at the root collar or on the tap root (if present) usually kill the host more rapidly than infections on lateral roots (Shaw 1980). In Douglas-fir, infections originating from root contacts on lateral roots spread distally and proximally from the point of infection and on reaching the root collar, spread to other lateral roots (Morrison 1981).

Root deformities, frequently associated with growing conifer seedlings in containers, are hypothesized to predispose planted spruce to *Armillaria* root disease caused by *A. ostoyae*. Livingston (1990) suggests that the downward growth of lateral roots induced by container walls is maintained when seedlings are planted out. As these laterals increase in diameter after planting they merge together to form an aggregate of "strangulated" root tissue which is both predisposed to *Armillaria* infection and in close contact with other roots for direct penetration by the fungus. This type of root growth contrasts that of a naturally seeded seedling which has unrestricted lateral growth that will not result in the formation of an aggregate of root tissue.

For conifer hosts affected by *A. ostoyae*, root infection by mycelial transfer begins when the outer bark of healthy roots comes in contact with infected roots and is subsequently invaded by mycelial fans. Bark tissues become necrotic in advance of these fans, likely as a result of both mechanical and enzymatic activities. When a mycelial fan reaches the bark-soil interface rhizomorphs may be initiated and begin to grow into the soil (Morrison 1972).

A. ostoyae forms dichotomously branched rhizomorphs which grow only a few centimeters from the food base. The growing tip of a rhizomorph is white; with increasing distance from the tip it becomes red, brown, and then black. The growing tip is also hollow; but within 2 cm, becomes filled with hyphae in a mucilaginous matrix (Redfern 1973). A rhizomorph initially becomes attached to a host root by hardening this mucilage. On suscepts with smooth bark, lateral branch rhizomorphs then develop to provide better attachment to host roots. These branches eventually begin to penetrate cork cells by mechanical force then, through combined chemical and mechanical means, they spread laterally and radially into bark tissues (Thomas 1934, Day 1927, Morrison et al. 1992). For suscepts with scaly bark, the rhizomorphs run tangentially under bark scales, eventually penetrating them and developing infection wedges beneath.

Armillaria can degrade suberin (via a suberase) and this may be involved in bark penetration (Swift 1965, Zimmerman and Seemüller 1984). *Armillaria* also produces phenol oxidases which can overcome host defense reactions during the infection process. The discoloration, especially browning or greying of tissues commonly observed in conifers with incipient decay caused by *Armillaria*, may be accredited to the activity of these enzymes. There is little information which details the roles of any of these compounds in the pathogenic process.

Whether infection by *A. ostoyae* originates from root contact or rhizomorphs, the fungus eventually penetrates to the host's cambium and spreads laterally in all directions. Ectotrophic growth of mycelial fans in the outer bark of host roots may precede growth in the cambium. The degree of ectotrophic growth likely varies with host and perhaps with soil conditions. For example, in Scots pine (Redfern 1978), mycelium of *A. ostoyae* was just 2 cm ahead of established infection proximal to the infection point. *Armillaria* will generally grow much more rapidly toward the tip of a girdled root than toward the butt of a living tree.

Armillaria ostoyae does not need wounds or anatomical points of weakness to attack healthy, vigorously growing suscepts. However, root injuries caused by stones and wind-induced root movements, wounds made by insects and site preparation equipment, and rootlets killed by excessive moisture could all serve as infection courts for the fungus (Whitney 1961, Kile 1981, Basham 1988, Rizzo and Harrington 1988). In addition, a wide variety of both abiotic and biotic stress factors such as light, moisture, temperature, pollutants, insects and other diseases may stress host trees and predispose them to infection and colonization by *A. ostoyae*. It is not known whether stress-induced susceptibility is an important or necessary component of host infection by *A. ostoyae*.

Host responses to infection by *A. ostoyae* on roots and at the root collar include resin production (resinosis), and meristematic activity leading to cork and callus formation and frequently, adventitious roots. Resin production is most common in conifer genera that have resin canals (*Pseudotsuga, Picea, Larix,* and *Pinus*) or that form traumatic resin canals (*Tsuga* and *Abies*). Resinosis at the root collar or in the lower bole of affected trees is not usually evident until mycelial fans are near or have reached the root collar (Morrison et al. 1992). The formation of lesions at points of infection may serve to isolate these areas and prevent further spread by the fungus. For example, Tippett and Shigo (1981) describe a central column of decay caused by *Armillaria* in conifer roots being compartmentalized by a barrier zone of resin ducts and parenchyma or numerous resin ducts separated by tracheids. This strong host response is most common in conifers more than 20 years old. Decreased incidence of mortality by *A. ostoyae* often occurs with increasing plant age. This is particularly true for western larch which shows an increasing resistance until about age 25 at which time roots contacting inoculum are either not infected or infection is checked (Morrison et al. 1992).

Armillaria is classified as a white-rot fungus because it degrades the lignified components of cells, leaving the white cellulose and hemicelluloses somewhat intact. In conifers, wood with incipient decay is stained grey to brown with a water-soaked appearance. Advanced decay is yellow-brown and stringy; final decay is a very wet, stringy rot with pale yellow flecks. Zone lines (pseudosclerotial plates) are also common in woody tissues decayed by *Armillaria* species. These plates, composed of pigmented bladder hyphae, serve to isolate the fungus from unfavorable environmental conditions or other wood decay fungi. Their formation is likely induced by a number of mechanical and physical factors including fluctuating moisture content (Campbell 1934).

Heterobasidion annosum

Heterobasidion annosum is one of the most economically important pathogens causing root and butt rot of conifers in the temperate zones of the Northern Hemisphere. Damage to forest productivity in North America has been most severe in the intensively managed loblolly and slash pine plantations of the Southeast. In western North America western hemlock and true firs are the principal hosts affected by *H. annosum*.

Regardless of host and type of disease produced, spread of *H. annosum* occurs by basidiospores or by growth of ectotrophic mycelium across contacts between healthy and infected roots.

Rishbeth (1950, 1951a) demonstrated that airborne basidiospores of *H. annosum* can infect freshly cut stump surfaces and the fungus then rapidly colonizes the stump and its root system. For the first few weeks after felling, freshly cut stump surfaces are colonized by few fungi other than *H.*

annosum. After this time and as cambial death progresses, a variety of saprophytic organisms (e.g. *Peniophora gigantea* and *Trichoderma* spp.) compete for the host substrate; this may stop growth of *H. annosum*. Basidiospore infections allow the fungus to enter previously healthy stands (Hodges 1969).

A variety of inoculation trials (Rishbeth 1951a, Wallis 1961, Kuhlman 1969) suggest that conidia and basidiospores of *H. annosum* can directly infect stump roots and possibly even living trees. However, direct root infection by the fungus under natural conditions appears to be uncommon as evidenced by the few studies reporting its occurrence (Hendrix and Kuhlman 1964, Hodges 1968, cited by Hodges 1969).

Although conidia are relatively inconspicuous in nature (Rishbeth 1951a) they are quite capable of initiating infection (Kuhlman 1969). Conidia are thought to be dispersed by water and possibly by insects (Hodges 1969).

Taproots and vertical lateral roots of suscepts infected by *H. annosum* appear to be frequently more decayed than other roots (Jorgensen et al. 1939, cited by Hodges 1969, Hepting and Downs 1944, Day 1948). The greater soil depths and lower oxygen concentrations generally experienced by these roots relative to shallower laterals may predispose them to infection by *H. annosum*, be it by spores or root contact (Hodges 1969).

Some tree species, such as western hemlock, are very susceptible to infection by *H. annosum* through stem wounds (Rhoads and Wright 1946, Hunt and Krueger 1962) such as those occurring from harvesting activities. Pines are seldom infected in this manner, likely due to their ability to compartmentalize infected tissues through copious resin flow (Meredith 1959).

Although some studies suggest that *H. annosum* cannot penetrate intact bark but requires wounds or entry points such as lenticels (Hiley 1919 and Braun 1958, cited in Hodges 1969), most reports indicate that the fungus can infect intact bark (Olson 1941, Rishbeth 1951b, Wallis 1961, and others).

Regardless of how roots become infected by *H. annosum*, the fungus moves steadily to colonize them. In pines, small roots up to about 3.0 cm in diameter are invaded soon after bark is penetrated. Portions of such small roots not already colonized by the *H. annosum* are soon invaded by other microorganisms. On larger roots of pines, ectotrophic mycelium of the fungus may colonize the bark surface ahead of wood tissues. Rishbeth (1951b), for example, observed ectotrophic growth of *H. annosum* up to one meter beyond the point of infection. As with *P. weirii*, faster surface versus interior growth of mycelium provides *H. annosum* with opportunities for multiple infections and enables it to readily spread through a stand (Hodges 1969).

After invading the cambium and sapwood of a pine host, *H. annosum* progresses through roots to the root collar where it may girdle the tree and spread to other laterals. Pine hosts normally react to annosum infection with a secretion of oleoresin and the production of fungitoxic compounds such as pinosylvin (Rennerfelt and Nacht 1955, cited in Shain 1971) in heartwood tissues. In addition, pines apparently become less susceptible to annosum infection with age (Rishbeth 1951b).

In roots of older spruces, firs, and other species susceptible to butt rot caused by *H. annosum*, relatively small roots are usually the first to be infected. Roots < 2 cm in diameter are entirely colonized while in larger roots the fungus is confined to the central xylem. From here the fungus progresses toward the root collar and lower bole where it may eventually invade the sapwood and cause death of the host or it may be confined as a butt rot. Trees with many decayed roots and/or extensive butt decay are susceptible to windthrow and wind breakage. The production of resin and inhibitory substances in response to *H. annosum* infection is apparently uncommon in these species (Hiley 1919, cited in Hodges 1969), although it has been demonstrated that, despite extensive heart rot, Norway spruce limits invasion of its sapwood by the accumulation of inhibitory substances such as phenols in an area between incipient decay and sapwood termed a 'reaction zone' (Shain 1971).

Heterobasidion annosum is a typical white rot fungus which is able to degrade and metabolize lignin, cellulose, and hemicelluloses. Depending upon the host affected, incipient decay is characterized by a yellow-brown to red-brown stain. Wood with advanced decay is weak and soft but never brittle and contains numerous elliptic to elongate pockets filled with black specks of dissolved host tissue. In species such as western hemlock final decay is often typified by a completely hollow butt.

Inonotus tomentosus

Inonotus tomentosus is the cause of the stand-opening disease of spruce and pine in the boreal forests of North America (Whitney 1962). This disease is characterized by variable-sized pockets of dead, dying, or fallen trees.

Inonotus tomentosus spreads from tree to tree primarily by root contacts, with infection normally occurring on small roots (< 4 cm in diameter) and where ectotrophic or intrabark mycelium of the fungus is present at the contact point (Whitney 1962, Merler 1984, Lewis et al. 1992). In these roots, the fungus penetrates directly into the bark and ectotrophic growth of the fungus often precedes stain and decay in root xylem, albeit to a limited degree (Lewis et al. 1992).

Lewis and others (1992) demonstrated that, in spruce, direct infection of host wood by *I. tomentosus* occurs through small feeder roots (< 1 cm in diameter) which provide a direct pathway to xylem tissues of roots > 4 cm in diameter. Heartwood of small roots was also infected through feeder roots after the fungus had penetrated and colonized a large section of bark and cambium.

Inonotus tomentosus is suspected to gain entry to roots and stems by a variety of other means. These include trunk scars or wounds (Hubert 1929, Whitney 1962) such as those caused by fire, basal cankers caused by rust (Boyce 1963), wounds caused by root-feeding weevils (Krebill 1962, cited by Myren and Patton 1971, Whitney 1962), and roots which have been stressed or weakened by unfavorable soil or environmental conditions (Christensen 1940, Whitney 1962, and others).

Infection of host roots and stems by basidiospores of *I. tomentosus* has also been suggested (Myren and Patton 1971, Lewis and Hansen 1991). Whitney (1966) reported that basidiospores of the fungus remained viable after storage at low temperatures and after several freezing and thawing cycles. This suggests that the spores could survive in soil and initiate infection in roots. Lewis and Hansen's (1991) report of several unique fungal genotypes of *Inonotus tomentosus* occurring in single disease centres in spruce stands provides further evidence that basidiospores play a role in spread of *I. tomentosus*.

The progression of *I. tomentosus* through host tissues is perhaps best documented for spruce and pine occurring in north-central British Columbia. Small spruce roots and, in general, all pine roots colonized by the fungus are usually girdled before internal decay 'takes off'. In larger roots of spruce hosts, stain and decay move proximally and distally through the heartwood, eventually reaching the root collar and lower bole of infected trees. These infection columns inside spruce roots are often surrounded by healthy sapwood (Lewis et al. 1992). In spruce hosts that die, longitudinal growth of the fungus ceases (Lewis and Hansen 1991) and the fungus grows radially to colonize sapwood, cambium and bark tissues. Colonization of spruce stumps by *I. tomentosus* often ceases after several years when it is countered by other fungi invading down the roots from the stump surface (Lewis and Hansen 1991). Stump roots of infected pine hosts rarely become fully colonized by *I. tomentosus*, likely because of the resinous nature of pine.

Host responses to infection by *I. tomentosus* include resinosis of stained wood in roots, necrotic lesions in cambium and wood of healthy roots in contact with infected stump roots, and sometimes, basal resinosis of infected trees (Lewis and Hansen 1991).

Decay caused by *I. tomentosus* is classified as a white pocket rot. Incipient decay is dark reddish brown. Wood with advanced decay is soft but not brittle and contains numerous small, elongate pockets which are filled with white fibers. Decayed wood visible in cross section of an infected stem is said to have a honeycomb appearance.

Leptographium wageneri

Leptographium wageneri causes black stain root disease of Douglas-fir and several pine species. It is found only in western North America. The disease is unique among the root diseases of conifers because it is caused by a wood-staining rather than wood-decaying, fungus. The fungus is unique because it is the only true vascular wilt pathogen of conifers (Cobb 1988).

Reports on modes of infection by *L. wageneri* are somewhat conflicting, likely as a result of differences associated with different hosts and environmental conditions. In Douglas-fir and ponderosa pine, at least, most local infections appear to be initiated in small roots (≤5 mm in diameter) which are in close proximity (≤15 cm) to, or in contact with, infected roots of living trees (Landis and Helburg 1976, Goheen and Hansen 1978). It has also been demonstrated that the fungus can grow through the soil for a few centimetres (Hicks et al. 1980).

That *Leptographium wageneri* has not been observed in any cell types except xylem tracheids and that it does not produce cellulolytic enzymes necessary for cell wall penetration (Smith 1967, Hessburg and Hansen 1987) suggests that the fungus requires infection courts to enter host roots. Root-dip inoculation studies with seedlings conducted by Hessburg (Hessburg and Hansen 1987) revealed many such sites of infection in Douglas-fir: penetration by the fungus often occurred through broken, fractured or dead roots, but also occurred at the base of emerging rootlets, where a path to xylem tissue was exposed. Natural openings such as these are also common on roots of mature trees and are likely important infection courts for the local spread of *L. wageneri* (Hansen et al. 1988). Intertree spread of the fungus may also occur through functional root grafts (Landis and Helburg 1976, Goheen and Hansen 1978). Spread of the fungus within diseased sites may also occur when insects and perhaps water, transport conidia from insect galleries in diseased or dead roots or from soil adjacent to roots.

Insects are known to play a role in the overland or long distance spread of *Leptographium wageneri*. For example, three root-inhabiting insects have been reported in association with black stain root disease in Oregon; *Hylastes nigrinus,* a root-feeding bark beetle, and two weevils, *Pissodes fasciatus* and *Steremnius carinatus* (Witcosky and Hansen 1985). Although not substantiated by any published literature, vectoring of the fungus to pinyon pine by two species of *Ips* has been suggested. The frequency of overland vectoring of *L. wageneri* by insects in ponderosa pine appears to be quite low (Cobb 1988). These insects colonize the declining roots of trees infected by *L. wageneri,* become contaminated with the fungus and are subsequently attracted to other trees that have been injured or otherwise predisposed to insect attack.

That insects, particularly bark beetles, are frequently the direct cause of death of trees already stressed by *L. wageneri* infection is generally well accepted. Much remains to be learned, however, about the mechanisms and significance of predisposition of trees to bark beetles by root pathogens such as *Leptographium wageneri.*

In each conifer host, once mycelia of *L. wageneri* have entered host roots, they are confined to mature sapwood xylem tracheids, growing from one to another through bordered pits. The fungus does not invade parenchymatous cells (Smith 1967). While the fungus rapidly colonizes vertically (or axially) in roots and up the stems of affected hosts, it also invades tracheids tangentially to gradually spread around the circumference of a root or stem. In ponderosa pine the fungus colonizes larger roots such that it reaches the outer xylem as it spreads toward the main stem. In Douglas-fir the fungus does not have this same tendency and so in this species, particularly in larger trees, the fungus may be several centimetres within the xylem at the root collar (Cobb 1988). Mycelial colonization of ray tracheids occurs but is limited (Hessburg and Hansen 1987).

The patterns of colonization by *L. wageneri* in host wood result in the characteristic bands of black, ink-like stain which, in cross-section, appear as arcs in one or more growth rings. This pattern of stain is in contrast to all other stains caused by blue-stain or similar fungi which tend to invade parenchyma cells and colonize radially to produce wedge-shaped stain patterns in sapwood. The 'black stain' caused by *L. wageneri* results from a combination of large, amber to brown branched hyphae of the parasite, a thick, amber sheath that surrounds each hyphae and sometimes fills tracheid lumen, and amber to brown discoloration of tracheid walls.

Host responses to infection by *L. wageneri* include resinosis of stained wood in roots and stems, necrotic lesions in cambia next to colonized wood (Hessburg and Hansen 1987), and sometimes basal resinosis of affected hosts (Morrison and Hunt 1988). Resin exudation varies with tree species and vigor, bark thickness and incidence of insect attack. Douglas-fir responds to infection by the fungus with the production of a gumlike substance which plugs tracheids (Hessburg and Hansen 1987).

Leptographium wageneri may eventually kill by extensive colonization of vascular tissue in the roots and stems of affected trees that limits water uptake and impedes translocation of xylem sap (Hessburg 1984).

Survival of the fungus in dead roots appears to be quite limited relative to some of the other root disease fungi; survival times of months to a maximum of about four years have been reported for *L. wageneri* (Smith 1967, Adams and Cobb 1986, Morrison and Hunt 1988).

Phaeolus schweinitzii

Phaeolus schweinitzii is one of the most common root and butt rot pathogens occurring throughout the forested regions of North America. The fungus may infect trees of any age but is more commonly associated with butt rot of mature trees.

Much of the information on the infection biology of *P. schweinitzii* comes from Great Britain. Most infections are probably initiated by basidiospores which are capable of establishing persistent infestations in forest soil (Barrett 1985). While the fungus does not grow freely as a soil saprophyte it can produce chlamydospores (Dewey et al. 1984). Root infections by *P. schweinitzii* apparently do not arise from root contacts between infected and healthy trees (Barrett and Greig 1984).

Phaeolus schweinitzii can enter trees through basal wounds (Boyce 1948, Harvey 1962) but more often enters host tissues via roots. The fungus can penetrate suberized and non-suberized rootlets (Wean 1937) and may also penetrate along the surface or at the base of, emerging lateral roots. Weakened or dead roots may also serve as infection courts for the fungus. Studies in Great Britain suggest that, on some sites, *P. schweinitzii* may be a secondary pathogen on roots after *Armillaria* spp. (Barrett 1970, Barrett and Greig 1984). In contrast, in Douglas-fir and grand fir in Idaho, *Armillaria* occurring at the root collars of trees was considered to be secondary to *P. schweinitzii* which was causing severe root decay (Dubreuil and Martin 1982).

Once it has encountered susceptible young roots, *P. schweinitzii* penetrates to their central core and colonizes proximally and radially toward the root collar of the infected host. Decay eventually involves most of the cross-section of the butt and, depending on the tree species affected, may extend from 3 to 30 m up the stem.

Incipient decay caused by *P. schweinitzii* appears as a yellow to reddish-brown stain. Infected wood loses strength quickly as the fungus decomposes cellulose. Wood in later stages of decay is brittle and breaks into large, reddish brown cubes (Foster and Wallis 1969). Trees infected with the fungus are subject to windthrow or wind breakage.

Phellinus weirii

Laminated root rot, caused by *Phellinus weirii*, is a serious root disease affecting several species of native conifers in western North America.

Phellinus weirii is transmitted to healthy roots from infected stump roots or from the infected roots of living trees by way of root contact (Wallis and Reynolds 1965). Types of root contact and their lengths do not appear to have a significant effect on transfer of the fungus. It has been demonstrated that root grafts account for a very low proportion of successful transfers (Wallis and Reynolds 1965, Reynolds and Bloomberg 1982).

A higher frequency of successful transfers of *P. weirii* mycelium by way of intratree versus intertree root contacts has been observed in Douglas-fir (Wallis and Reynolds 1965, Reynolds and Bloomberg 1982). The frequency of either type of root contact is likely determined by the morphology of individual root systems which is influenced by both site and stand factors including soil depth, stoniness, slope, tree dbh and stand density. Intratree root contacts may facilitate rapid deterioration of individual tree root systems and hasten tree death (Wallis and Reynolds 1965). Root diameter does not appear to have a significant effect on the successful transfer of *P. weirii* mycelium. Roots as small as 1.5 cm in diameter have been successfully inoculated (Wallis and Reynolds 1962) and it has been suggested that a 6 mm diameter root be considered the minimum size capable of serving as an infection source to other roots (Reynolds and Bloomberg 1982).

The frequency of successful transfers of *P. weirii* between roots as ectotrophic mycelium is very high compared to its transfer as endotrophic mycelium (Reynolds and Bloomberg 1982). On susceptible hosts, initial infection occurs wherever mycelium is successfully transferred to roots; ectotrophic mycelium appears to be able to penetrate through intact and injured bark (Wallis and Reynolds 1962). Literature on the infection process of *P. weirii* is sparse. Mycelium invading bark tissues apparently causes some lesions to form in the bark and tissues become densely impregnated with resin. It has been suggested that the rapid ectotrophic spread of the fungus enables it to 'find' and utilize existing infection courts such as bark abrasions, wounds, or sites of injured or recently dead feeder roots (G. Reynolds, Pacific Forestry Centre, pers. comm.). More research on this subject is needed. .

Whatever the infection process, hyphae of *P. weirii* eventually invade the host's cambium to form a characteristic red-brown stain in the wood; this stain represents the early stages of the decay process. An examination of the cut surface of a freshly felled, infected tree will often reveal irregular to crescent-shaped patches of stain in the inner sapwood, or throughout the outer heartwood. These areas of stain are usually directly above the infected roots.

From its point of initial infection, *P. weirii* spread distally and proximally. In large roots of susceptible species, ectotrophic mycelial fronts may precede endotrophic (i.e. decay) fronts by as much as 200 cm. In small roots the distance between fronts may range from a few centimetres to about 32 cm (Wallis and Reynolds 1965, Reynolds and Bloomberg 1982).

Roots very often respond defensively to the pathogen with resinosis and with the production of adventitious roots. These roots are initiated in callus tissue occurring where the ectotrophic growth of *P. weirii* has been halted (Buckland et al. 1954, Esau 1977). Trees capable of initiating adventitious roots in numbers sufficient to maintain 'normal' vigor sometimes survive despite *Phellinus* infection. Such trees may be considered resistant to killing by the fungus.

Phellinus weirii causes a white rot of wood. It uses lignin as its primary source of carbon but can also degrade cellulose and hemicelluloses. In advanced stages of decay wood infected by *P. weirii* contains numerous tiny pits about 0.5 X 1.0 mm and tends to separate into sheets at the junctions of annual rings - hence the term 'laminate decay'; thin layers or tufts of reddish brown whisker-like mycelium are usually found growing between these sheets. Crusts of cinnamon to dark brown mycelium often form where ectotrophic mycelium is exposed to some air, such as at the root collar. In the final stages of decay, the wood breaks down into a loose, stringy mass.

Phytophthora lateralis

Phytophthora lateralis causes a very destructive root rot of one conifer host in particular - Port Orford cedar. Believed to be of Eurasian origin, the fungus was likely introduced into North America in the 1910's. The disease occurs over the planted and natural range of Port Orford cedar which extends from northern California to southern British Columbia (Roth et al. 1972).

Most root infections by *P. lateralis* are initiated when zoospores (carried in surface and soil water) penetrate succulent root tissues such as rootlets or root tips. Apparently Port Orford cedar produces an abundace of such tissues in the humus layer of soil above it's large lateral roots (Gordon and Roth 1976). Root infections by *P. lateralis* may also be initiated by mycelial transfer of the fungus at root grafts between healthy and infected trees (Gordon and Roth 1976). Wounds are not required for infection to occur (Zobel et al. 1985). Vegetative growth of *P. lateralis* is confined to living host tissue; it does not occur independently in the soil (Ostrofsky et al. 1977).

Infection progresses to the inner bark and cambial region where tissues quickly go from a healthy cream color to cinnamon brown (Tucker and Milbraith 1942). Infection and discoloration extend up the main roots through the root collar into the lower bole for a distance equivalent to about two stem diameters. The foliage of trees thus girdled by the fungus withers and discolors simultaneously, turning successively chlorotic, bronze, and brown. *Phytophthora lateralis* attacks trees of any age or size; it kills small seedlings within days or weeks and large trees within two to four years. Infected trees always die.

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Armillaria ostoyae in the Southwest: its pathogenicity and virulence on indigenous and exotic trees

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Armillaria spp. are significant pathogens of trees and shrubs worldwide (Wargo and Shaw 1985). Armillaria root disease had been attributed to a single basidiomycete species, *Armillaria mellea* (Vahl:Fr.), until research into the fungal mating system showed that there were many different intersterility groups (Korhonen 1978). To date, nine biological species of *Armillaria* are known in North America (Guillaumin *et al.* 1991).

So that were not confused about semantics, two words that I'd like to define at the outset are 'pathogenicity' and 'virulence'. Pathogenicity is a qualitative term and is defined as the capability to cause disease. Virulence, on the other hand, is the quantitative amount of disease that a pathogenic isolate can cause in a group of plants.

Clearly sufficient inoculation experiments have been performed with a wide enough array of *Armillaria* isolates to convincingly demonstrate that several pathogens occur in the genus. What is still unclear, however, is which species and clones of *Armillaria* are pathogenic on which hosts, as well as the virulence of these species on given hosts.

Armillaria ostoyae (Romagn.) Herink is a widespread and aggressive pathogen on conifers in interior western forests; however, inoculation trials with conifer seedlings have given variable results (Gregory 1985; Mallett and Hiratsuka 1988).

The objective of this study was to determine the pathogenicity and virulence of New Mexican isolates of *A. ostoyae* on ponderosa pine, Southwestern white pine, white fir, Douglas-fir, blue spruce and aspen - all species native to the Jemez Mtns. Western larch and lodgepole pine were also included, larch because of its inherent resistance to Armillaria root disease and lodgepole pine because it is not an uncommon species in similar habitats elsewhere.

Vegetative compatibility studies revealed that the isolates utilized in this study belonged to ten different clones of *A. ostoyae*. Seedlings were potted in plastic containers and inoculated with infested alder sticks. Autoclaved branch segments were used for controls.

The experiment was laid out as a randomized complete block design and contained eight tree species x 14 treatments and 15 replications for a total of 1680 seedlings. Seedlings were assessed monthly for symptoms of root disease for three growing seasons. Trees that died during this period were removed and signs and symptoms of root disease were recorded. The study was terminated in October 1991.

The length of time for symptom expression and mortality varies considerably in inoculation experiments with *Armillaria* spp. and so the length of time one monitors a pathogenicity trial may impact the pathogenicity and virulence rankings obtained. Figure 1 displays the survival curves for the eight hosts examined in this study. After the second growing season there were no significant differences in mortality among the eight species and two of them had yet to exhibit any mortality. It was not until the third growing season that we began to observe significant differences in mortality.

In a similar graph (Fig. 2), only this time displaying the clones with which the seedlings were inoculated, after 18 months there were no significant differences in pathogenicity across all clones and three clones were non-pathogenic. It appears that certain clones take longer than others to cause mortality.

One probable explanation for this lag period was the time required for rhizomorph production. We observed a highly significant correlation ($r= 0.94$, $p < 0.001$) between the ability of a clone to incite disease and its ability to produce rhizomorphs. So although we did not record directly the timing of rhizomorph initiation or infection, we may deduce from the survival curves that some clones were able to initiate rhizomorph production sooner and more frequently than others.

The literature suggests that there is little difference in susceptibility to *A. ostoyae* among conifers less than 15 years old (Hadfield *et al*. 1986). Our results do not bear this out completely. For example lodgepole pine was significantly more susceptible to infection by *A. ostoyae* than either white fir or Douglas-fir (Fig. 3).

We also observed significant differences in resistance of infected seedlings to *A. ostoyae*. Aspen was frequently infected but rarely killed by *A. ostoyae*. The exotics on the other hand, although less resistant, differed little from most of the native species (Fig. 4).

Our results also suggest that there is considerable variation in the virulence of clones within a local population of *A. ostoyae*. After three growing seasons one clone was non-pathogenic while those that were pathogenic infected between 15% and 70% of the seedlings to which they were inoculated.

The most virulent clones also killed the most seedlings but there is no statistical difference in the ability of pathogenic clones to kill infected seedlings. In other words they appear to be equally aggressive on infected seedlings.

To summarize, this study clarifies the pathogenicity and virulence of *A. ostoyae* on eight forest tree species with which it is frequently associated. Pathogenic variation within the species is considerable, which suggests that it may be spurious to report findings of *A. ostoyae*, and possibly other *Armillaria* spp, at the species level. Equally variable is the virulence of clones found within the species. Variations in both virulence and pathogenicity is suggestive of the need to evaluate the responses of several isolates, before one can draw meaningful inference about the character or nature of species and clones of any *Armillaria*.

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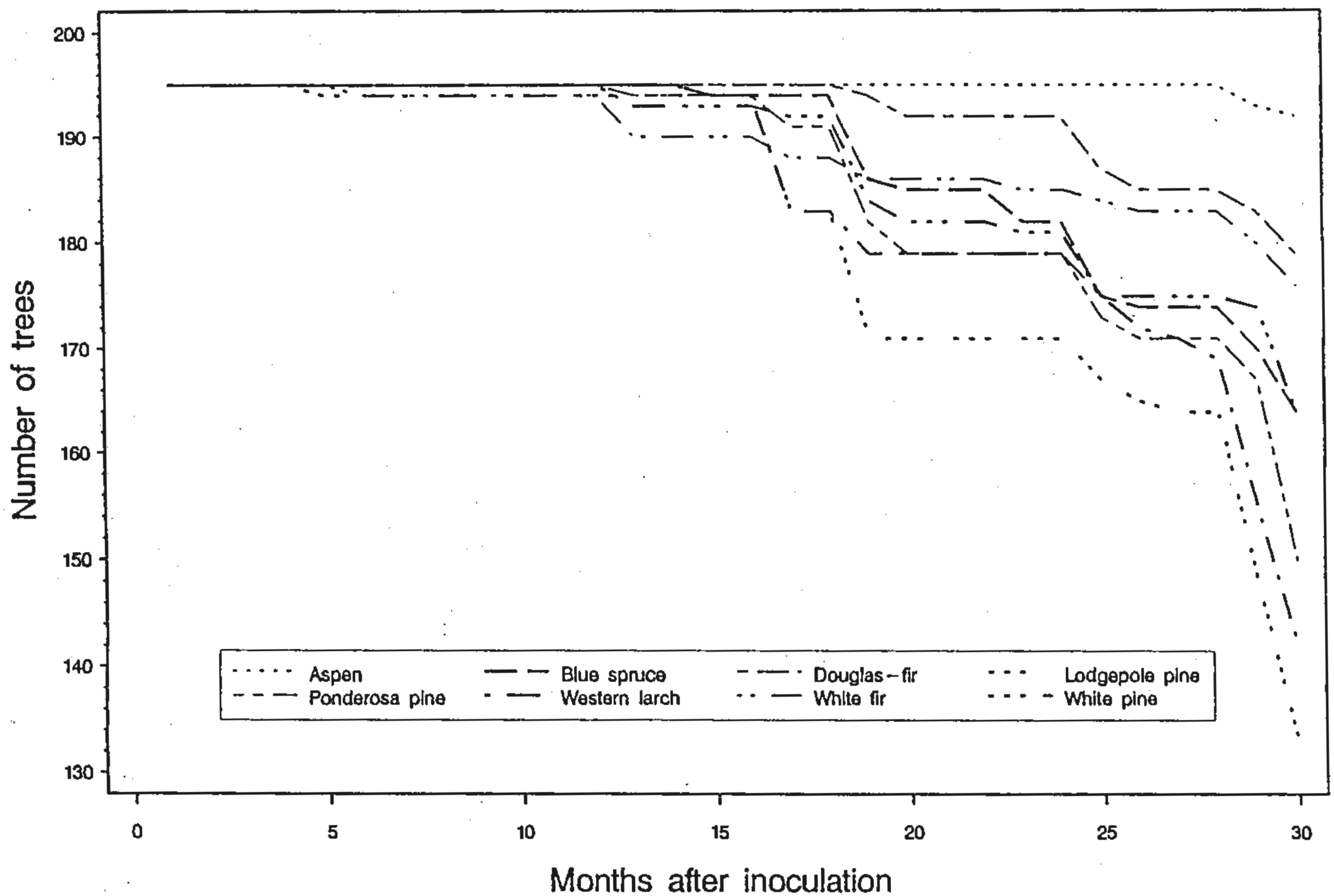

Figure 1. Survival curves for eight tree species inoculated in the shade house with *Armillaria ostoyae.*

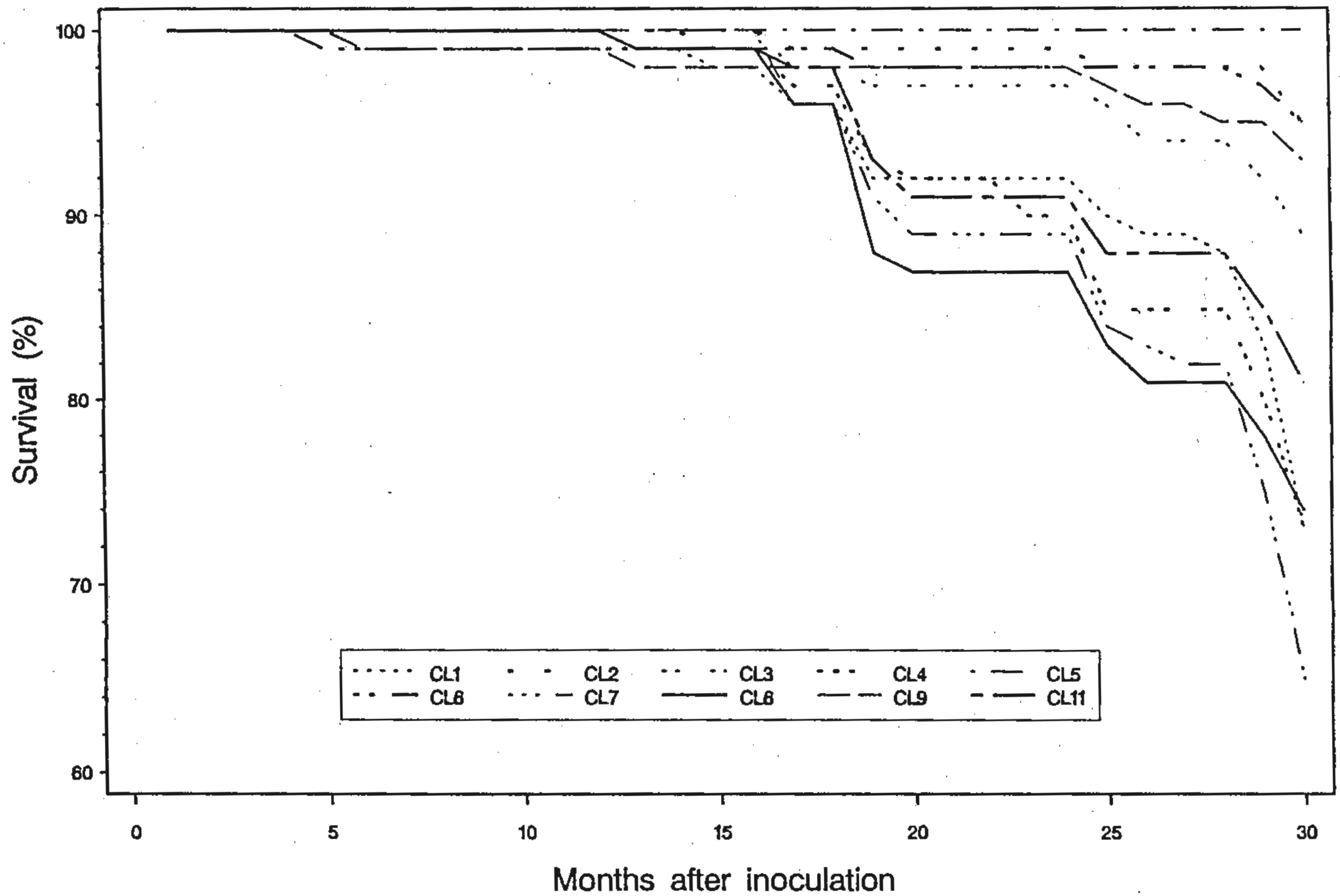

Figure 2. Survival curves for ten clones of *Armillaria ostoyae* across eight tree species inoculated in the shade house.

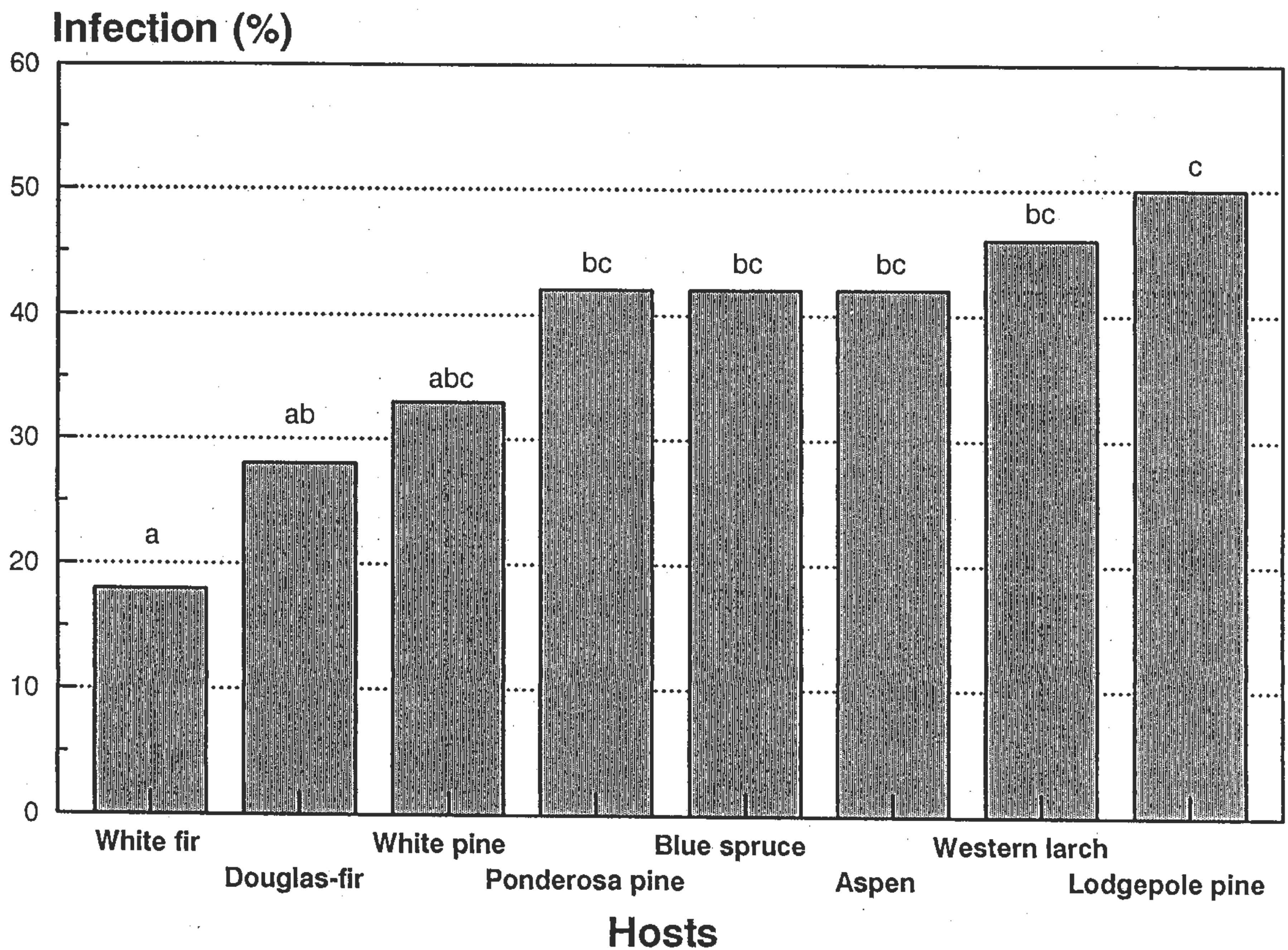

Figure 3. Infection levels of eight tree species to *Armillaria ostoyae* after three growing seasons.

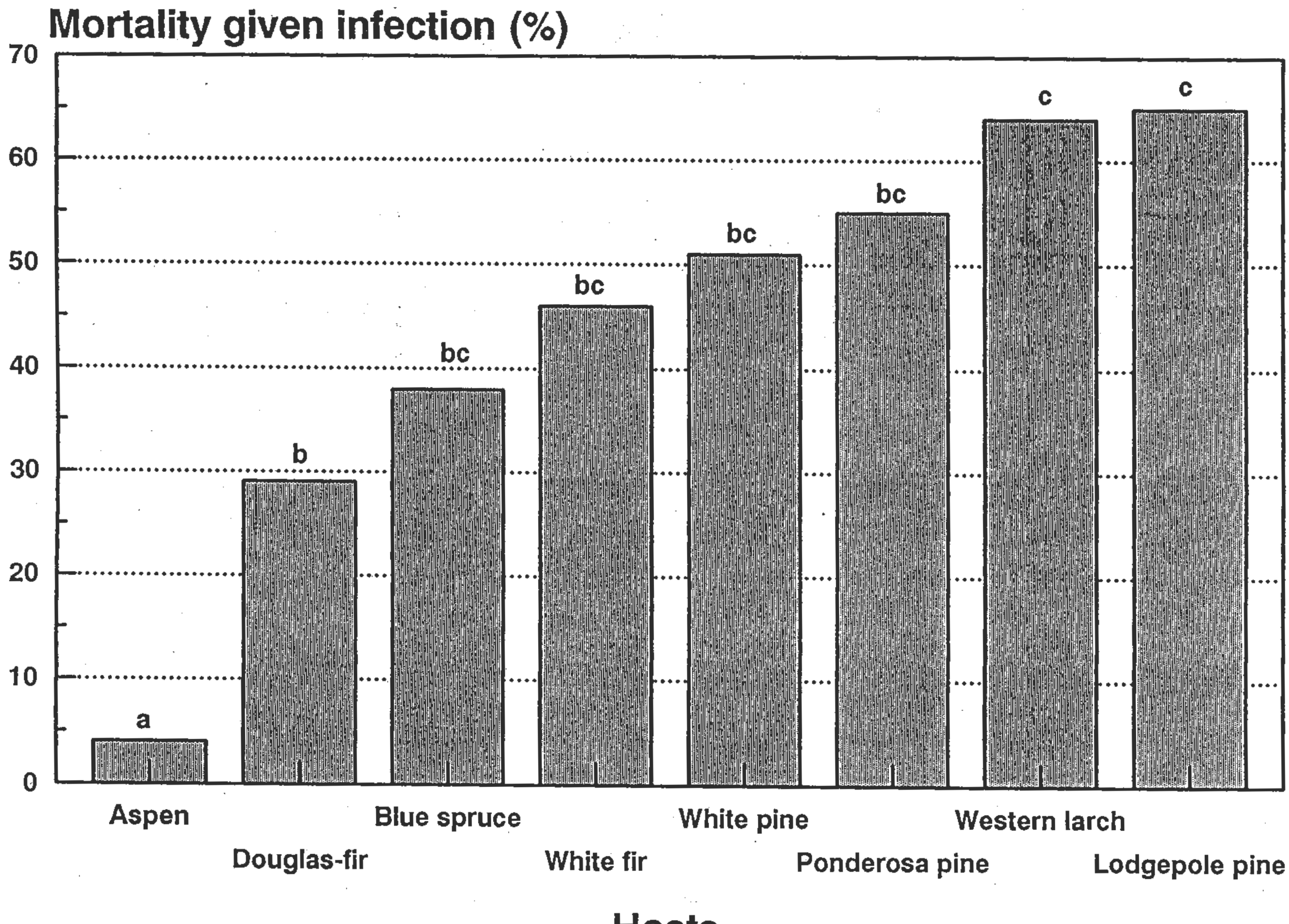

Figure 4. Mortality levels of infected seedlings representing eight tree species.

"SO, YOU WANT TO LOOK AT ROOTS?"

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INTRODUCTION

Excavation of stumps and roots is inevitable for those who study root diseases of forest trees. Usually stump removal for management purposes is done with a goal of getting the wood out of the ground or breaking it up into pieces small enough to no longer be a problem. Researchers may wish to examine the roots or study a belowground process and to do so may need to recover all roots from a particular stump relatively undamaged. In addition to manual excavation or bulldozing, a variety of other techniques have been used in the Pacific Northwest to expose root systems for study: hydraulic excavation (McMinn 1963; Reynolds and Bloomberg 1982), bulldozing in combination with hydraulic cleaning (Thies 1980), compressed air (Weir 1964), log forks (Thies 1984), a vibrating stump puller (Arnold 1981), and explosives (Hertert et al. 1975, Bertagnole and Partridge 1988).

The extraction technique must be tailored to the needs of the study being conducted. For some studies we may wish to be able to collect undamaged roots of 100 or more second growth Douglas-fir stumps in a few weeks. Many of the previously described techniques are best used for special objectives or for a few stumps and some have significant drawbacks: manual systems have a high labor cost; heavy equipment (bulldozers and log forks) often remove bark and smash roots; a vibrating stump puller works best on healthy roots and is in short supply in the Pacific Northwest; hydraulic excavation works best on a slope, requires a good source of water and must be located such that soil laden runoff does not get into a stream. This paper describes a technique using an excavator, commonly used in industrial forestry operations, to quickly recover undamaged roots of mature Douglas-fir for examination.

TECHNIQUE

The technique can be divided into three steps:

1. Undermine the stump and root system by using an excavator.
2. Split the stump into sectors separating major roots.
3. Extract the sectors from the soil and shake.

UNDERMINE

For easiest extraction select a stump with a separation from other stumps of at least 2 m. Position the excavator so that the target stump is between the tracks with at least 8 m of open ground beyond the stump. Extend the excavator arm across the stump to place the bucket as far beyond the stump as possible. The dig starts by removing shallow (30-45 cm) scoops of soil successively in a line towards the stump. The scoops are taken by putting the teeth of the bucket perpendicular to the ground, pushing the teeth and bucket into the soil, and rotating the bucket towards the stump to scoop soil. This will allow small roots to pull out of the soil mass and not be crushed or broken off as would happen if the bucket was dragged toward the stump. When small roots from the target stump are exposed, begin to dig the hole deeper as far from the stump as necessary to avoid the exposed roots. Deposit the soil in one or two piles. As each scoop of soil is deposited, it spills down the pile making possible recovery of inadvertently severed roots. Expand the hole right and left by repeating the above. Two observers should work with the excavator to assure that roots pulled from the root system are noticed as missing and are found.

Depth of the hole depends on the rooting depth of the subject tree, but in most cases the hole will be 3 to 4 meters deep. With the elbow of the excavator arm beyond the edge of the hole, remove soil from under the root system. As the root system is undermined soil falls away from the roots and can be removed. If exposed roots are at risk of being crushed by the excavator arm, remove the roots and label them. Continue this process until the cavity under the roots extends nearly to the stump. Soil may be further encouraged to fall away from the root system by either pounding on the top of the stump with the bucket of the excavator or by collecting a heaping scoop of soil in the bucket and gently lifting up under the root system. The intent is to breakup and loosen soil packed around the roots to cause the soil to fall away from the root system so that major roots can be easily detected.

Split the stump

Based on a "best guess" of major root locations, mark the stump top along three to five radii each dissecting two major roots. With a chainsaw, cut a groove along each marked radius to provide a starting place for a wedge and to better assure that the stump will split at that location. Place the edge of the wedge into the groove and tap the wedge with the bottom of the bucket. After driving the wedge into the stump, remove the wedge and repeat at the other grooves. The wedge can be removed by hooking a tooth of the bucket on a bar welded on the top of the wedge. Splitting will be easier if all grooves are split before the stump is undermined. If the stump is large or appears that it may be difficult to split, cut the grooves deeper. If a groove is near perpendicular to the axis of the excavator arm, it may be possible to split the stump by using the teeth on the bucket instead of the wedge.

Extract the stump sectors

Extract first the sector that has been undermined. After the stump is opened by the wedge, insert the teeth of the bucket into the split. Pry the stump apart through a combination of pressure and rocking of the bucket. The split must be opened wide enough to both assure separation and allow that sector of the stump to be gripped between the hydraulically operated thumb and the teeth of the bucket. It may be necessary to pry on the second split associated with the first sector of the stump to be removed.

Grip the first sector of the stump between the thumb and bucket and lift the stump sector and associated roots free. Suspend the roots over the pile of soil and shake them until all possible soil has fallen away from the roots. Any roots that break off will be easily found on the pile of fresh loose soil. The sector can then be labeled and placed in a convenient location for further examination.

Each remaining sector of the stump can be removed in turn. Each sector can be split from the remaining by prying with the teeth of the bucket. Before removing the second and successive sectors, additional undermining may be necessary. If the roots of a sector are still partially buried, the sector must be pulled so that the roots move towards the stump with minimal lifting until the roots are free of the soil. While each sector is suspended, it can be examined for evidence of broken roots. Lost root pieces are easily found by excavating and examining additional scoops of soil.

One variation on the system involves using a choker to grip a sector when it is difficult to use the thumb and bucket. Use a choker if the sector slips and falls into the hole, or if the bucket does not have a thumb. It is best to notch the stump portion of the sector to receive the choker cable. The cable can be put around one or more main roots; however, it may cut into the root or knock off bark, which may be undesirable depending on the needs of the study. A sector held by a choker can be violently shaken by quickly tipping the bucket in small increments.

Equipment

It is important to have a large enough excavator to easily undermine the root system and to be able to pull and lift the stump sectors. The following are the specifications for the smallest excavator we have used to successfully extract second-growth Douglas-fir root systems: weight 20 000 kg; 118 hp; hydraulic activated thumb; bucket capacity 1 m^3; bucket width 1 m; with a reach of 10.6 m; tracks 80 cm wide and 3.2 m between the outside edge of the tracks. The bucket has a hook welded to the bottom to attach a choker. A larger excavator would be acceptable but a bucket exceeding 1.75 m^3 may get in the way.

The wedge is not commercially available and needs to be fabricated. The wedge we use is made of 32-mm thick T-1 steel with a piece of 6-cm-square carbon-steel bar welded to the top edge. The bar extends 6 cm beyond the width of the wedge on both sides. The wedge is 37 cm wide (leading edge), 46 cm long, and weighs about 30 kg. The lower 40 mm is tapered to form a keen edge. The wedge needs to be wide enough and thick enough to cause a split but light enough to be easily handled in the field.

The choker cable is 16 mm in diameter and 5 m long.

TIME

Time needed by the excavator to excavate the roots of 140 stumps ranging in diameter from 30 to 70 cm averaged about 45 min per stump, including time to move from stump to stump.

SAFETY

There is significant risk in working to the side or behind an excavator. Modern excavators turn very rapidly, are noisy, and limit the view of the operator. An individual working around an excavator must be alert and look out for their own well being. Of particular concern is the rear-mounted counterweight. The back of the machine swings faster than most people expect and can unexpectedly hit an individual walking around the machine. The operator has a good field of vision to the front but is blind to the back and has a restricted view to the sides. Hence it is important that anyone working around an excavator be aware of its movement at all times and that individuals not required to work with the machine maintain a distance of at least 30 m from it.

Safety equipment in the form of hardhats, steel-toed boots, safety glasses, and hearing protection should be worn at all times when working near an excavator. When soil is being shaken from the roots, chunks of soil, rocks, or pieces of root can dislodge and fly with enough force to cause injury. Also, rocks excavated with the soil may roll down the pile of soil and injure a foot.

ACKNOWLEDGMENTS

This technique has evolved during work on several studies over the past 12 years, with much trial and error and many contributed ideas from folks with significant experience to offer--the machine operators. It is with appreciation and respect that I extend thanks to the following operators: K.C. VanNatta of VanNatta Bro. Tree Farm, Ranier, OR; Larry Bair of Bair Logging Co, Vernonia, OR; Don Bird and Bruce Graves of Miami Corp., McMinnville, OR; and John Richards of Laughlin Logging Co, Yamhill, OR.

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LIVE-TREE FUMIGATION OF DOUGLAS-FIR

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INTRODUCTION

Laminated root rot, caused by Phellinus weirii (Murr.) Gilb., is the most damaging root disease of conifer forests in the northwestern United States and Canada. The pathogen survives in dead trees and stumps to later infect trees in succeeding stands (Hadfield 1985). The fungus spreads among living trees through root contacts (Wallis and Reynolds 1965). Chloropicrin or methylisothiocyanate (MITC) can be used to greatly reduce or eradicate P. weirii from infected stumps and roots (Thies and Nelson 1982). This study was begun in 1981 to test the hypothesis that a fumigant (chloropicrin, MITC, or Vorlex[1]), injected into live Douglas-fir, could reduce the volume of root wood occupied by P. weirii without killing the treated tree.

METHODS

Selection of Trees

The study was conducted in a 47-year-old, naturally regenerated stand of Douglas-fir in the Oregon Coast Ranges near Apiary, Oregon (46° 1' N. latitude, 123° 4' W. longitude). The site has been described elsewhere (Thies and Nelson 1982, 1987b). Dominant and codominant Douglas-fir, with clearly visible crowns, but lacking severe distress symptoms, were selected. Candidate trees were examined for the presence of P. weirii by carefully exposing major lateral roots within 60 cm of the base of the tree, examining each root surface for characteristic ectotrophic mycelium, and, at times, boring with an increment borer to detect stained or decayed root wood. Because tolerance to fumigants might be affected by laminated root rot, we selected for treatment 45 trees in each of three infection classes: I, infected by P. weirii; II, probably infected, with crown symptoms and inoculum within 5 m; and III, probably uninfected, having no symptoms and no identified inoculum source within 25 m.

Each infection class was separated (blocked) into five groups of nine trees each based on similarities of diameter at breast height (dbh) and tree location. Study trees ranged in dbh from 27.4 to 62.2 cm. Treatments were randomly assigned to trees within each group.

[1] This paper reports the results of research only. Mention of a pesticide does not constitute a recommendation for use by the U.S. Department of Agriculture, nor does it imply registration under The Federal Insecticide, Fungicide, and Rodenticide Act as amended. Also, mention of a commercial or proprietary product does not constitute recommendation or endorsement by the U.S. Department of Agriculture.

Treatments

Chloropicrin and MITC (the active ingredient in Vorlex) were applied at several dosages, and Vorlex was applied at a single dosage.

Thies and Nelson (1982) suggest that a dosage of 6.7 ml of either chloropicrin or Vorlex per kg of stump and root biomass is sufficient to eradicate P. weirii. For this study, a standard dosage (1D) was 6.7 ml of chloropicrin, 6.7 ml of Vorlex, or 1.5 g of MITC per kg of treated biomass. The dosage for MITC was based on the concentration of MITC in Vorlex. We assumed that the dose tolerated by a tree would vary linearly with the estimated biomass of its major roots and first 2.4 m of bole, and that the treated biomass of each tree could be accurately estimated from the tree's dbh (Thies and Nelson 1987a).

In March, 1982, seven treatments were applied: Check; chloropicrin 1D, 0.5D, 0.25D; MITC 1D, 0.5D, 0.25D. Application of a 2D dosage of both fumigants was planned but postponed for one season pending evaluation of the toxicity of the lower dosages to the treated trees. Based on that evaluation, two alternative treatments were applied in April, 1983: chloropicrin 0.125D and Vorlex 0.5D.

Application of Fumigant

Fumigant was applied to holes drilled in a helical pattern starting 15 cm above the litter layer and moving up the tree. Holes were drilled down (45° below horizontal) towards the center of the tree at 15-cm intervals as needed to accommodate the dose of fumigant. A dose of chloropicrin or Vorlex, both liquids, was distributed equally to all holes in a tree; MITC, a solid, was applied in small polyethylene sacks, and each sack was broken as it was pushed into a hole. Each hole was tightly plugged with a dowel sealed at the lower end with resorcinol glue (to resist passage of the fumigant). Check trees were not altered. Additional details of the treatment and biomass determination have been previously discussed at this conference and described (Thies and Nelson 1982, 1987b).

Detection of Viable P. weirii

Trees dying over the course of the study and all trees remaining after 10 growing seasons were felled and their stumps and roots removed from the soil and cleaned. Roots were marked at 30-cm intervals from the root collar and cut perpendicular to the root axis at each marked location. When stain or advanced decay typical of that caused by P. weirii was found, a 5-cm-thick disk was removed, labeled, measured for diameter, placed in a plastic bag, and kept up to 2 weeks in an unheated shed until processed.

Root disks were sampled for viable P. weirii by attempting to isolate the fungus from five chips taken from stained or decayed wood on freshly split faces of each disk. Each chip was placed in a culture tube containing 1.5 percent malt agar with 200 ppm streptomycin sulfate. The sampled disks were further incubated at ambient (5 to $20^{\circ}C$) temperatures for 4 to 8 weeks. Presence of P. weirii was confirmed by distinctive morphological features of colonies which developed within 14 days (Nelson 1975). Tubes without colonies were kept an additional 14 days and reexamined before being discarded.

Bagged split disks were examined for presence of the thick felt of mycelium and setal hyphae typical of P. weirii. A disk was recorded as having P. weirii if the fungus was found either in the associated culture tubes or on the incubated disk.

Each disk collected represented a middle cross section of a 30-cm long root segment assumed to contain viable P. weirii at the time of fumigation. Volume of each root segment was calculated as a 30-cm long cylinder having a diameter equal to that of its center disk. The total of these sections for any one tree was considered to be the volume of the initially infected root wood. If P. weirii was not recovered from a symptomatic disk it was assumed that the treatment had killed the fungus. Success of treatment was judged by the percent reduction of viable P. weirii in the stained and decayed portion of the root system.

Data Analysis

All data were subjected to analysis of variance (ANOVA) to detect significant (alpha = 0.05) differences between treated and untreated trees.

RESULTS AND DISCUSSION

Effects on Trees

Most of the treated trees survived 10 growing seasons. Of 120 treated trees in the study, 88 survived to harvest (Table 1). Most mortality occurred within two years of treatment. Of 32 treated trees that died, 22 died within one year of treatment. Methylisothiocyanate proved to be much less phytotoxic than Chloropicrin. All 45 MITC treated trees survived to harvest as compared to 16 of 45 chloropicrin treated trees at similar dosages.

Table 1. Reduction in Phellinus weirii-colonized root wood and survival of Douglas-fir trees fumigated with chloropicrin, methylisothiocyanate (MITC), or Vorlex.

Treatment	Dose	Live trees 1991	Reduced P.w.[1]
		(No.)	(%)
Chloropic.	1D	2	87.0
Chloropic.	0.5D	4	68.2
Chloropic.	0.25D	10	64.7
Chloropic.	0.125D	15	50.7
MITC	1D	15	82.6
MITC	0.5D	15	77.9
MITC	0.25D	15	90.4
Vorlex	0.5D	12	81.4
Control	--	12	8.8

1. That percent of root wood volume containing stain or decay, typical of P. weirii but with no evidence of surviving P. weirii after 10 growing seasons.

Effects on the Pathogen

Fumigant killed P. weirii in much of the colonized (stained and decayed) root wood thus reducing residual inoculum (Table 1). The amount of inoculum reduction for all fumigant treatments was significantly different from the check treatment. Each of the fumigants totally eliminated the pathogen from some root systems: chloropicrin--16 of 31 infected trees; MITC--10 of 21 infected trees; Vorlex--4 of 6 infected trees.

We believe that this is the first report of successfully reducing the presence of wood-decaying fungi in living trees by treatment with chemical fumigants. The methods described here are original and resulted in a major reduction of P. weirii inoculum. Treatment with MITC probably resulted in increased longevity of the treated trees. This study demonstrates that fumigation can effectively reduce P. weirii infection in living Douglas-fir trees without adversely affecting the host tree. Refinements in methodology will make it practical to treat diseased trees of higher than normal value or those located in sensitive areas.

ACKNOWLEDGMENTS

Our thanks to K.C. VanNatta of Rainier, Oregon, for providing study trees, equipment, and personal services. We also thank NOR-AM Agricultural Products, Inc. (Naperville, Illinois) and Great Lakes Chemical Corporation (Fresno, California) for supplying fumigants, advice, and financial assistance. Our appreciation goes to Dr. R.D. Graham, Dr. M.E. Corden, Dr. J.J. Morrell, and Dr. B.C. Goodell (Oregon State University, Corvallis, Oregon) for advice, to Harlan Fay for technical support, and to Joe McNeil, Mike McWilliams and Bob Merola for their assistance in the laboratory and in the field.

Some of these results were presented as a poster at the IUFRO 8th Conference on Root and Butt Rot, Uppsala, Sweeden and Helsinkie, Finland, August 9-16, 1993 and will be published in the proceedings of the conference.

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A SHORT STORY OF STAND DENSITY AND RESILIENCE IN THE BOISE BASIN

-- IDAHO CITY RANGER DISTRICT

by
Ray Eklund

This presentation illustrates how the native ponderosa pine and Douglas-fir stands in the Boise Basin have changed from pre-settlement times to the present, and the impact of these changes on today's stand resilience.

The Boise Basin, located in the southwest portion of the Boise National Forest, supports some the most productive ponderosa pine stands in southern Idaho. This 160,000 acre basin contains relatively contiguous stands dominated by ponderosa pine. Land ownership is mixed and includes National Forest, Idaho Department of Lands, Bureau of Land Management, Boise Cascade Corporation, and individual small private land holdings. Today the basin is essentially all second growth forest seldom more than 100 years old.

Prior to the 1860's the basin was maintained as an open "parklike" ponderosa pine forest of large trees, by frequent low intensity ground fires occurring on a 10 to 20 year cycle. Fires were most likely of lightening and Native American origin.

In 1862 gold was discovered in the Boise Basin and towns quickly sprang up. Early mining was primarily placer using hydraulic pressure to wash away soil and expose mineral deposits. Mined areas were generally stripped of unwanted forest cover and trees were regarded as a hinderance to reaching mineral deposits. Sawmills were established near towns to support the rapidly growing communities, and many nearby stands were essentially clear cut.

Between mining, logging, and slash fires the structure of the basin forests became drastically altered. The heavy forest clearing and site disturbance in the Boise Basin led to the creation of a "new" forest of a much different structure and density. The open old growth stands have been replaced by very dense, nearly pure ponderosa pine stands now 60 to 100 years in age. Ponderosa pine established itself very successfully with very large numbers of seedlings. As these seedlings grew rapidly in a generally favorable environment most stands became overcrowded. As the stands grew in size and age, competition between trees for moisture, nutrients and light markedly increased in intensity.

The recent drought has made dense stands in the basin much more susceptible to insect attack as intensely competing trees have become severely weakened by lack of water. Since 1985, the Boise Basin has been drier than it has been in fifty years. Insects killing stressed trees in the basin are primarily western pine beetle, pine engraver beetle, and Douglas-fir beetle. These bark beetle species have always been present in the basin, but drought has tipped the balance in favor of the beetles. Drought coupled with overstocked stands of suitable host tree species, plus longer, warm summers during this period has supported an epidemic build up of bark beetles.

High stand density has also had a marked influence on tree growth and form. Over dense stands have developed small crowns, are poor in vigor, slow growing, and are structurally weak and vulnerable to weather related damage.

The role of fire in regulating stand structure and composition has also changed during the last 100 years. Due to fire protection measures, a build up of ground fuels has occurred. These additional fuels, plus a much less fire resistant stand structure of dense poles has favored fires of a more stand replacing nature than of stand thinning.

Short and long term objectives on National Forest lands are to move stands more toward their original structure, density, and composition, and to re-introduce light fires into the ecosystem. Silvicultural treatment of overstocked stands on National Forest lands in the basin the past 20 years has primarily been thinning. Stands that have been thinned have better survived the recent bark beetle epidemics than those that were not thinned. Thinning on National Forest lands in the basin is usually from below, meaning the weaker, smaller trees are targeted for removal, and the larger, more vigorous and better formed trees are retained in the stand. Thinning lessens catastrophic fire risk by opening the canopy, and reducing and re-arranging fuels. In many thinned ponderosa pine stands, low intensity fire can be re-introduced without significant tree damage. Thinning supplies needed wood products while still maintaining forested tree cover. Aesthetic values and wildlife cover needs can be better met over time. If stand rotations are based on tree vigor or maximizing wood volume, rotations can be lengthened. This means a more resilient stand of older, larger trees can be grown compared to an unthinned, overstocked stand.

In summary, today's ponderosa pine and Douglas-fir forests in the Boise Basin are not "natural" in the sense that they are the product of man created events such as mining and logging, and man's control of wildfire. Old growth, pre-settlement forest structure will not develop from existing overstocked stands in the basin without thinning. Nature is trying to restore equilibrium in the ecosystem by reducing tree stocking, but we may not like the way or results that she now chooses.

With the highest snowfall in southwest Idaho in recent years, is the current drought ending? If the climatic trend lapses into a moister cycle, overstocked stands will likely increase in density with little immediate detriment. But what about the next drought cycle? With less growing space and a higher water demand, over dense stands will be at even greater risk to future drought driven bark beetles epidemics. What if global warming is true? If so, even greater water deficits for overstocked stands can be expected.

The results of not thinning stands in the Boise Basin will ultimately lead to a loss of silvicultural options. Stand regeneration by clearcutting, insect devastated stands, or catastrophic wildfires are likely alternatives. Thinning will maintain a wider array of silviculture options for the future, including both even-age and uneven-age strategies.

Is density management of stands in the Boise Basin necessary for future stand health and resilience? YES!!

Demonstration and Validation of Spatial Root Disease Sampling

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We have developed a technique using small pits to characterize the extent of root symptoms in a forest. We located 8 pits at the midpoints and corners of a 3.2m square plot. After examining the roots we found in these pits, we predicted that 93% of the roots on the plot would have symptoms. We then used hydraulic excavation to expose the root systems of Douglas fir showing thin foliage. We examined 238m of roots, 118 from the Douglas-fir, and 98m originating from off the plot. Eighty percent of the roots on the plot had some symptoms of root disease. The most common symptoms were a brown decay (22% of the root length), brown central stain (20%) and a reddish stain (8%). These symptoms reduced the hydraulic conductivity of the roots. Symptoms were found in 222 of 256 grid cells. The pathogens are still being identified. We will report the fungal identities and more specifics on the reduction in root hydraulic conductivity to the root disease committee for inclusion in a future proceedings.

We feel that the pit-based sampling technique adequately predicted the proportion of root symptoms, and on this site predicted the proportion of the area with symptoms. Given the preponderance of symptoms on this site, it is likely that root diseases are causing moisture stress, which in turn may predispose the trees to bark beetle attack.

We thank the volunteers from Earthwatch for their assistance with the fieldwork in this study. We also thank Jim Hoffman and Forest Pest Management for both financial and moral? support during this project.

Estimating the proportion of ponderosa pine roots with *Heterobasidion annosum*.

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SUMMARY

A Monte Carlo sampling simulation was developed to estimate confidence intervals for the proportion of ponderosa pine root segments with symptoms of infection by *Heterobasidion annosum*. The proportion of symptomatic root segments was estimated by sampling roots from a given number of 20X20 cm pits. We simulated the sampling distributions of the proportion of symptomatic segments for various numbers of pits and various proportions of symptomatic segments. Confidence limits at different significance levels were determined using corresponding percentiles of the empirical sampling distribution. The resulting table of confidence intervals permits (1) evaluation of the effect of sample size on the reliability of the estimate of the proportion of symptomatic root segments based on pit sampling; and (2) approximate confidence intervals to be assigned to observed sample proportions which otherwise have no valid interval estimate. A measure of goodness for this method of interval estimation is whether the approximate confidence interval for an observed sample proportion contains the actual proportion. Five field plots were sampled and then completely excavated. The interval estimate captured the actual proportion of symptomatic root segments for two plots; just missed a third; and was too low for two plots immediately adjacent to mortality centers where annosus root disease was obvious. Thus, pit sampling may provide a useful indicator of the proportion of symptomatic ponderosa pine roots in the absence of above-ground symptoms of annosus root disease.

INTRODUCTION

Incidence (proportion of trees infected) and severity (proportion of an individual root system infected) must be known in order to apply appropriate silvicultural prescriptions. Simply determining whether a tree is infected is often difficult, or at least labor intensive and harmful to the sample tree, because roots must be exposed for examination. There are many techniques for estimating root disease severity based upon the extent of above-ground symptoms (eg. Bloomberg et al 1980). The use of such methods in, at least some host-pathogen combinations,should be questioned, however, as trees may have substantial portions of their root system affected by root disease before they exhibit symptoms.

Alexander (1989) and Zeglen (1991) have developed methods for quantifying the severity of root disease for stands (average proportion of root systems infected) using estimates derived from sampling areas of a stand. Alexander uses sample variation to compute confidence limits; Zeglen used a theoretical model. Here, we report on an empirical method for use in detecting *Heterobasidion annosum* in ponderosa pine stands.

DATA USED IN SIMULATION

Data for simulation trials were collected from 4 plots in ponderosa pine stands on the Modoc National Forest in northeastern California. All plots were located in areas where annosus was known to be present. Plots 3m square were established in areas where trees had no above ground symptoms. Trees were felled, the duff was removed and the soil was washed away from the roots with water. Exposed roots were mapped with a 20cm grid, and root segments were removed at the grid boundaries. Each segment was examined for symptoms, and diameter, length and root designation were recorded. Cultures were made from some of the symptomatic root segments. *Heterobasidion annosum* was recovered from each sample plot.

SIMULATION

A Monte Carlo sampling simulation was implemented in a FORTRAN program. The program simulated a 16 x 16 "base grid" of cells. The number of root segments assigned to each cell was drawn randomly from the empirical distribution of the number of root segments per grid cell pooled over the 4 excavated plots (Figure 1).

An "infected grid" was created using the base grid and a target level for the proportion of infected root segments. Root infection levels varied from 0.1 to 0.9 in increments of 0.1. Infection of root segments in the base grid was randomly assigned and depended upon the target proportion. For example, if the target proportion was 0.3, then 30% of the root segments were characterized as infected.

Infection was assigned independently to each segment; in other words, the probability of infection for a particular root segment was not affected by the infection status of other root segments in the same cell. Various statistics including aggregation indices and the mean number of infected roots per cell were computed for each infected grid (Table 1).

The sampling distribution of the mean proportion of infected roots was approximated by drawing 2000 simple random samples of a given size from each infected grid. The sampling unit was a grid cell. Samples of size 3,4,5,6,8,and 12 were used. In each sample, the proportion of infected roots was computed for each grid cell, and the mean proportion of infected roots was computed over all sample cells. Confidence intervals for the mean proportion of infected roots were determined using corresponding percentiles of the empirical sampling distribution. The proportion of samples which contained no infected grid cells was computed (Figure 2).

Table 1. Aggregations indices for excavated and simulated plots. Values for simulated plots are means of 5 Monte Carlo simulations.

Plot	Proportion Infected	Mean[1]	Variance	VTM[2]	Intensity[3]
Simulated	.20	0.68	0.81	1.20	0.45
3	.21	1.92	3.78	1.97	0.74
2	.27	1.06	2.08	1.96	0.52
Simulated	.30	1.01	1.43	1.42	0.57
4	.32	0.86	1.45	1.69	0.44
Simulated	.40	1.35	2.11	1.56	0.65
1	.47	1.57	2.88	1.84	0.69
Simulated	.50	1.70	2.95	1.73	0.71

[1]Mean and variance are for number of infected root segments per cell.
[2]VTM = variance to mean ratio.
[3]Intensity is the proportion of cells with symptomatic root segments.

EVALUATION

During the 1992 field season, the sampling method was tested on 5 plots in ponderosa pine stands on the Lassen National Forest in northeastern California. A sample plot was located in an area of a stand without aboveground symptoms. A 3m square plot was established to include at least 3 ponderosa or Jeffrey pines. At each corner and midway between the corners, small pits approximately 20 cm square were dug. All root segments encountered were examined for disease symptoms. Pit means were averaged to estimate the proportion of roots with symptoms on the plot. The plot was then excavated as described above to determine the actual proportion of roots infested. These results are in Table 2.

Table 2. Estimated and observed proportions of symptomatic roots on plots in areas of ponderosa pine forests in northeastern California without aboveground symptoms.

Plot	Proportion of symptomatic roots Observed	Estimated	90% Confidence Interval
1	.39	.47	.31 - .70
2	.36	.33	.15 - .46
3	.50	.14	.02 - .20
4	.48	.18	.08 - .35
5	.39	.57	.41 - .79

A measure of goodness for this method of interval estimation is whether the appropriate confidence interval for an observed sample population contains the true proportion. The estimates on the first two plots were acceptable; the fifth plot was marginal. The technique was less accurate on plots 3 and 4, which were in the same stand. These plots had fewer roots in the 0.5-0.8 cm diameter class, and an unexpectedly large amount of external mycelium on larger roots, which were not well represented in our samples. These plots were also near mortality centers, however, where the need to detect root disease is less critical because of aboveground symptoms.

The validity of the model which provides the confidence intervals may be limited by the assumption of independent assignment of infection to root segments. That is, the condition of one root segment had no effect on the assignment of infection to other root segments within the same cell or in adjacent cells. The nature of root disease spread suggests that this assumption is violated in nature, but we have yet to examine the statistical nature of this contagion.

We consider this pit-based sampling method using empirically derived confidence intervals to provide useful estimates of root disease severity. We are using it to explore relationships between annosus root disease and habitat/site characteristics.

ACKNOWLEDGEMENTS

We greatly appreciate the support of Earthwatch and the contribution of Earthwatch EarthCorps volunteers for their assistance in collecting the field data.

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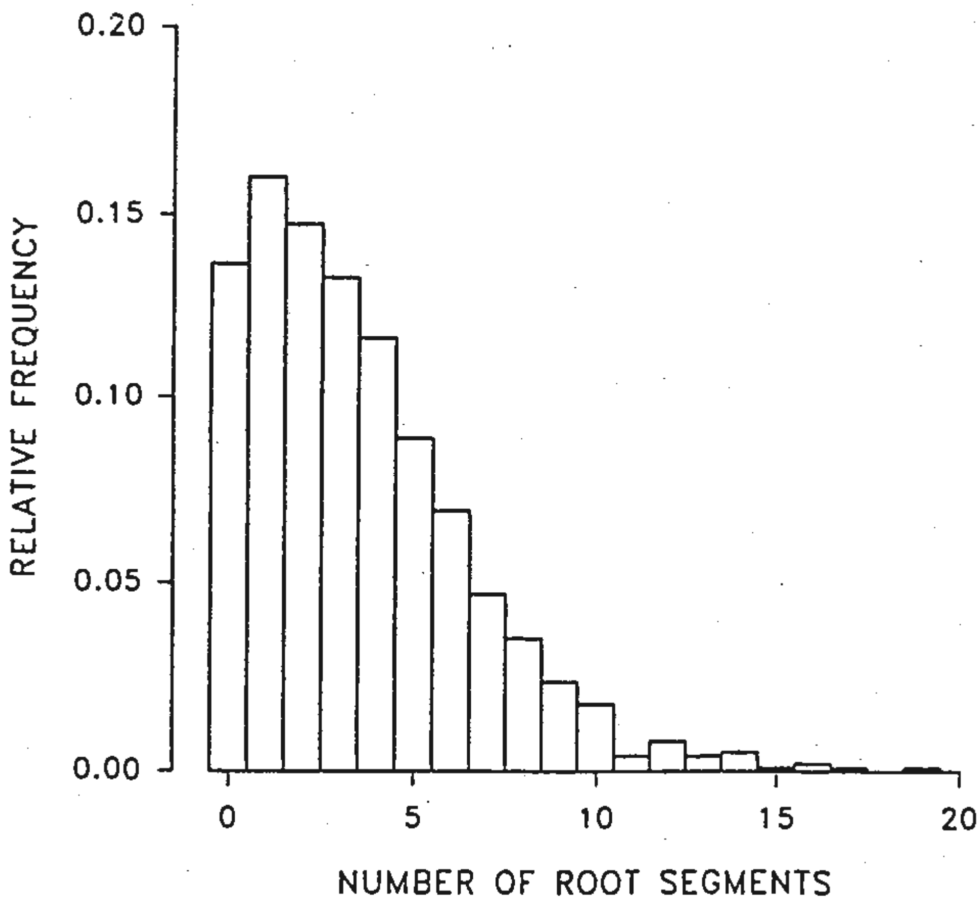
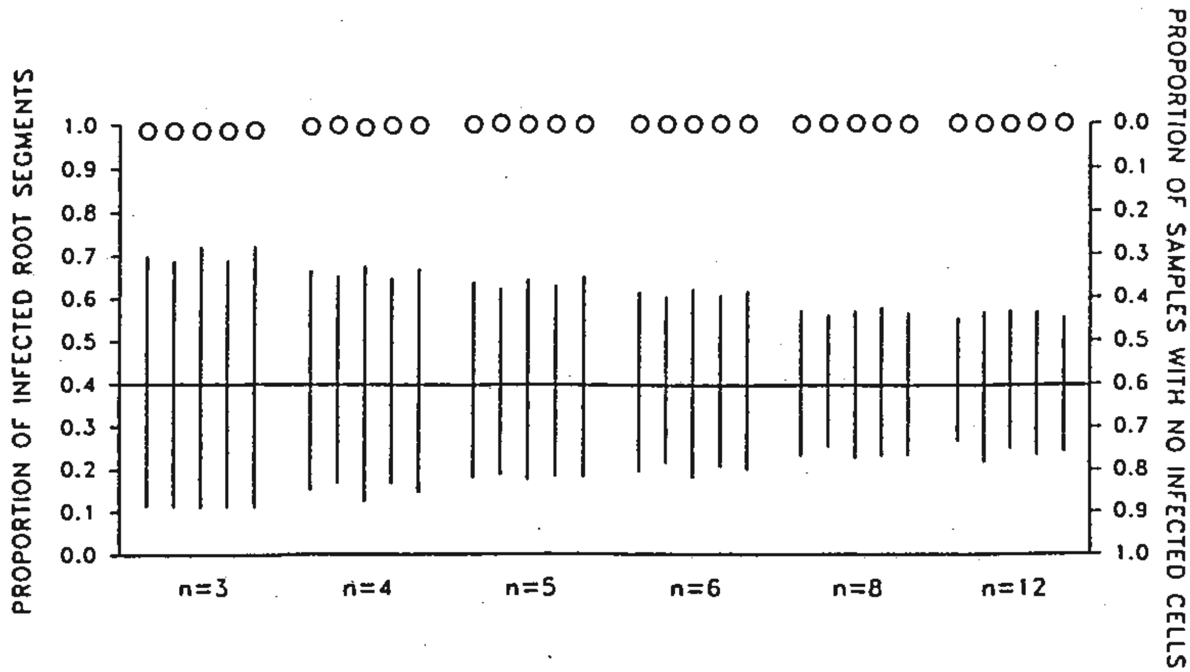


Figure 1. Empirical distribution of the number of root segments per grid cell, pooled from all four excavated plots.



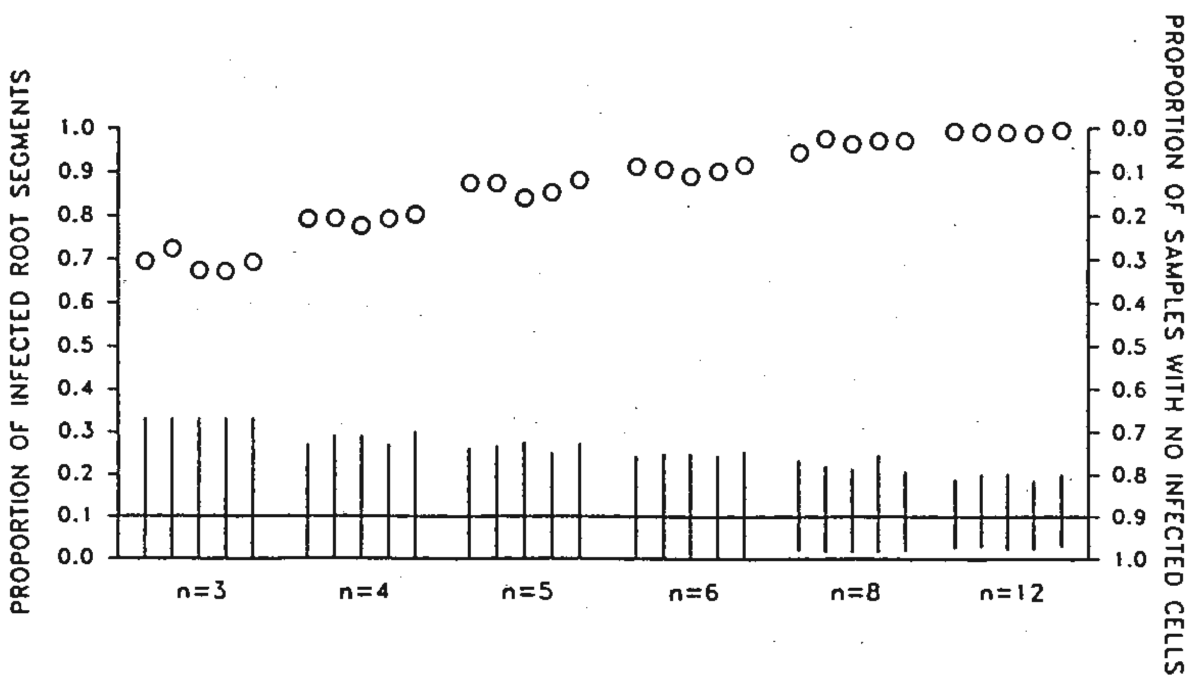


Figure 2. Confidence intervals and proportion of samples yielding no infected cells for populations with lower: 0.1 and upper: 0.4% of root segments infected.

Root Disease Reduces Hydraulic Conductivity of Mature Douglas-fir and Grand Fir Roots

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SUMMARY

This study investigated the effect of root disease symptoms on the hydraulic conductivity of symptomatic Douglas-fir and grand fir root segments. The fungi involved include *Heterobasidion annosum, Armillaria ostoyae, Inonotus tomentosus, Phaeolus schweinitzii, Phellinus weirii* and *Leptographium wagnerii*. Root segments were excavated from Douglas-firs or grand firs lacking aboveground symptoms. Flow rate through root segments was measured by perfusing the root segments with 10 mM oxalic acid and weighing the flow periodically until it stabilized. Hydraulic conductivity was computed from the flow rate, the segment length, and the pressure forcing the liquid through the segment. Root segments with staining had a 30% reduction in root hydraulic conductivity when compared with asymptomatic roots; root segments with decay had an 80% reduction. More than 420 m of roots were examined from an area of about 20 m^2; 76% had symptoms of root disease. The prevalence of symptoms and the drastic reduction in root hydraulic conductivity suggest Douglas-firs and grand firs could experience root disease-caused moisture stress in the early stages of root infection.

Keywords: translocation, predisposition

INTRODUCTION

Root diseases are the most serious pathogens affecting forests in the western United States. For example, James et al (1984) reported root disease losses of at least 3 dead tree/ha on more than 14% of the commercial forest land on seven National Forests in the northern Rocky Mountains. Including growth losses in non-symptomatic trees further magnifies the impact of root diseases. Root disease fungi decay butts and roots, weakening root structure and leading to windthrow. Root diseases may kill the root cambium, ultimately killing the tree. More often, however, root diseases weaken trees, predisposing them to attack by bark beetles (i.e. Geiszler et al 1980, James et al 1984, Partridge and Miller 1972). The exact mechanism(s) of predisposition are unknown.

For trees to be healthy, they must have adequate moisture and nutrients. Root diseases can disrupt water transport and nutrient uptake. Coniferous trees transport water from the soil to their branches and leaves using tracheids in the xylem of their vascular system. Evaporation of water from the leaves creates a tension which provides the driving force for water movement. The rigid structure of the xylem wall and the cohesiveness of water molecules facilitate this form of water transport. The physical operation of this process depends upon a contiguous water column with no breaks or air pockets (emboli). When the rate of evaporation at the leaf surface exceeds the rate of supply by the roots, the tension on the water column increases. Cavitation occurs when the tension on the water column becomes too great and breaks the water column. Following breakage of the water column, an embolism forms when the tracheid becomes air-filled, and is no longer available for water transport.

If the stress on the water column is not relieved, cavitation can proceed at an increasing rate and the plant may suffer from a lack of xylem conduits capable of water transport. To reduce water stress, in the absence of increased supply, the tree can respond by reducing the rate of evaporation through stomatal closure or foliar loss. This reduces the tension on the remaining water-filled tracheids, but it also reduces the ability of the plant to obtain energy through photosynthesis. If the rate of xylem cavitation increases too rapidly and the tree does not respond by reducing evaporation, "runaway" cavitation may occur, resulting in a total loss of the water transport network and plant dessication and death.

The ability of a plant to avoid cavitation depends on the tension of the water column and the size of the tracheid and pit membrane pores. Any pathogen attack which results in cell wall digestion also will increase vulnerability to cavitation (Zimmerman 1984). The physical blockage of xylem elements by pathogen or host also restricts water conductivity, decreasing water potential, further increasing cavitation. Trees respond to wounding, and presumably to the fungi that invade wounds, by producing terpenes, alpha-pinene being one of the more abundant. Injecting the boles of trees with alpha-pinene or pine wood nematodes (*Bursaphelenchus xylophilus*) induced cavitation (Kuroda 1991). It is reasonable to assume that roots also produce terpenes in response to fungal invasion, which could lead to cavitation and disruption of water transport and nutrient uptake.

The integrity of a plant's water conducting system is directly tied to its productivity. When a tree's foliage suffers from a lack of water it cannot fix sufficient carbon to continue growing. Setbacks in tree growth and vigor can result in further complications from pathogen attack and a reduction in the tree's ability to compete for limited resources. A tree experiencing moisture stress may become more susceptible to root diseases. Indeed, H. annosum infects more trees and spreads further in drought stressed trees (Towers and Stambaugh 1968; Lindberg and Johansson 1992). Thus, besides the direct action of the pathogen, the tree's response to root pathogens may result in an increase in moisture stress, which further increases its susceptibility to that pathogen.

Cavitation can be quantified indirectly using various stains to track the pathway of water transport (LoGullo and Salleo, 1991). The ratio of stained tracheids to non-stained tracheids is an indication of percent cavitation. Loss in hydraulic conductivity also provides a useful indication of cavitation. As the number of tracheids available for water transport decreases, the conductivity also decreases (Tyree and Sperry, 1988). Change in root conductivity and percent cavitation following pathogen attack have not been explored. This study evaluated the effects of symptoms caused by root pathogens on root hydraulic conductivity.

EXPERIMENTAL METHODS

This study was done in a Douglas-fir (*Pseudotsuga menziesii*) / grand fir (*Abies grandis*) stand on the Nez Perce National Forest in north-central Idaho. The stand is in the ginger-ginger habitat type of the ABGR/ASCA/XETE habitat type series. Overstory trees range in age from 75 to 85 yr old, with occasional grand firs older than 200 yr. This stand, like many others in this region, is impacted by a root disease complex. The fungi involved in this stand include the pathogenic basidiomycetes *Heterobasidion annosum, Armillaria ostoyae, Inonotus tomentosus, Phaeolus schweinitzii. Phellinus weirii* and the Deuteromycete *Leptographium wagnerii* are present but less common (S. Hagle, Forest Pest Management, USDA-FS R-1, Personal communication).

Two 3.2 m square plots were located 6 and 13 m from the nearest tree with aboveground symptoms. After the trees were felled, the duff was removed from the plot. Water was then used to wash the soil from the roots. As portions of the roots were exposed, they were mapped, removed, and examined for root disease symptoms. The length and small diameter of each root segment was recorded.

Following excavation and examination of the root segments, a subsample of root segments was selected for conductivity measurements based on species, root diameter, and symptom. Because of the predominance of root disease symptoms on these two plots, additional non-symptomatic root segments were excavated from trees elsewhere in the stand. After marking the distal end of the root segment, it was placed in a plastic bag on ice in a cooler, and taken to a laboratory the same day.

In the laboratory, the root segments were trimmed by at least 1 cm under water to limit the introduction of air into the water column. Segments were 5-10 cm long after trimming. The remainder of the root was retained for culturing. A tygon tube of the appropriate diameter was attached to the segment, and sealed with parafilm. The root segments were perfused with a 10mM oxalic acid solution filtered to 0.2um (LoGullo and Salleo, 1991). The oxalic acid solution was passed through the stem segments under a pressure of 10kPa. Flow rate was measured by weighing a sponge-filled vessel placed on the distal end of the root. Measurements were made every 60 seconds until a constant flow rate was observed.

Hydraulic conductivity (L) was calculated using the following equation:

$$L = m/(dP/dL)$$

where:

m = flow rate
dP = change in pressure (10kPa)
dL = segment length

To determine the path of water flow, a 0.2% w/v safranin solution dissolved in distilled deionized water and filtered (0.2um) was passed through the root segments under 10kPa of pressure. Following perfusion, the segments were disconnected from the apparatus and evaluated.

The untreated remainders of root segments were refrigerated until cultures could be made. A sterile scalpel was used to slice a layer of bark from the root. The scalpel was flamed, and another thin layer of wood and bark removed. This process was repeated several times to expose symptomatic wood. Small pieces of symptomatic wood and adjacent non-symptomatic wood were removed and placed on 2% malt extract agar, three to four pieces on a single 10 cm petri plate. Cultures were incubated at room temperature. Cultures suspected of being H. annosum were allowed to grow for 10 days and examined for the Spinager spore form. Other basidiomycete cultures were identified using Nobles' (1965) and Stalpers' (1978) methods and comparing them with known cultures.

We tested the null hypothesis that symptomatic roots have lower hydraulic conductivity than non-symptomatic roots. Means were compared using t-tests.

RESULTS

All trees examined had root disease symptoms, though they were asymptomatic aboveground and located some distance from symptomatic trees. The four trees on plot 1 had symptoms on 72% of their root system; the 7 trees on the second plot had 84% with symptoms (Table 1).

Table 1. Characteristics of plots excavated in a mixed stand of Douglas-fir and grand fir.

Plot	Distance from symptomatic trees (m)	Tree Number[1]	Species[2]	Root length examined (m)	Length with symptoms (%)
1		1	GF	102	85
		2	DF	57	59
		99		69	60
1	6	Total		230	72
2		1	GF	2	100
		2	GF	4	88
		3	GF	84	87
		4	GF	38	86
		5	GF	7	100
		6	GF	3	44
		99		58	74
2	13	Total		195	84

[1]Tree number 99 indicates roots originating from trees off the plot.
[2]GF = grand fir (*Abies grandis*); DF = Douglas-fir (*Pseudotsuga menziesii*).

Hydraulic conductivity was determined for 57 grand fir root segments and 37 Douglas-fir segments. Root segments with decay or pronounced symptoms had root conductivity 80% lower than roots without symptoms (Figure 1). Root segments with less severe symptoms had 30% lower root hydraulic conductivities. Some symptoms had greater effects on hydraulic conductivity than others. For example, root segments ending in profuse branching, or those with a small dead rootlet, without other internal symptoms, had hydraulic conductivities similar to roots without symptoms (Figure 2). Resin soaking, or combinations of symptoms were associated with reduced hydraulic conductivity. A relationship between stained tissue (functional conduits) and hydraulic conductivity was evident (Figure 3).

Cultures were obtained from 29% of the root segments used in this study; 6% were contaminated, and the remaining 65% were sterile. To date we have identified *H. annosum I tomentosus, P. schweinitzii* and several imperfect fungi from these samples.

DISCUSSION

The most common symptom observed was a reddish stain inside the root, occurring on 21% of the total root length examined. *Heterobasidion annosum, P. schweinitzii, and I. tomentosus* have been cultured from some of these stained roots, along with several other fungi which are being identified (probably including *P. weirii*). These fungi cause similar symptoms in other species (Lewis et al 1992, R. Williams, USDA Forest Service, personal communication). Harrington (1986) and Rizzo and Harrington (1988) report similar staining in roots of declining spruces and firs wounded by excessive movements of the bole in rocky soil, but they cultured no pathogenic fungi. However, we have not observed the "dry areas" in Douglas-fir or grand fir (Shain 1979). Barnard et al. (1991) attribute some of the resin soaking and staining to a physiological response to mechanical injury. The stand in which we have worked has not been entered, and is relatively undisturbed except for some light grazing. This suggests causes other than mechanical wounding.

Culturing from resin-soaked or stained roots is often unsuccessful. Barnard et al (1991) obtained cultures from 28% of roots with staining and resin soaking; Lewis et al (1992) obtained cultures of I. tomentosus from 22% of attempts from stained wood. These results raise questions about the presence of fungi and the reaction of the host. We propose that a fungus invades a root, and the tree reacts at the site of the infection, and perhaps for some distance from this site. This reaction forms the symptom that we see. Cultures made away from the infection site thus would not yield a pathogen, accounting for the low recovery of a pathogen as compared with culture attempts made from decayed wood. If the symptom we see is a site of accumulated host defense chemicals, these chemicals could further inhibit the ability of the fungus to grow onto the culture medium.

While pathologists may consider such minor staining and resinosus less serious than, for example, advanced decay, such symptoms may have a considerable impact on the tree. Root segments with staining had a 30% loss in hydraulic conductivity when compared with asymptomatic segments. When decay or more pronounced symptoms were present, hydraulic conductivity was reduced by 80%. A brown stain within the wood of Douglas-fir root segments was related to a reduction in their specific conductivity by more than 70% ($p=0.06$). Roots which terminated in profuse branching had specific conductivities no different from asymptomatic roots. Yet, when red stain was present in a profusely branched root, the specific conductivity was reduced by about 50% ($p= 0.10$). Root segments with red stain plus other symptoms, had 50% lower specific conductivity than roots with the red stain alone ($p=0.10$). In grand fir roots, the symptoms we examined had considerably less impact upon specific conductivity than similar symptoms in Douglas-firs, except for decay, which greatly reduced specific conductivity ($p=0.02$). That these differences were statistically detectable despite the relatively small sample size with a given symptom suggests that the observed reduction in specific conductivity may be biologically important. Apparently as symptoms become more complex they have a greater effect on specific conductivity, and perhaps root function.

The high proportion of root systems with symptoms, when associated with a greatly reduced root hydraulic conductivity, suggests that such trees may be experiencing serious moisture deficits. We know of no other studies which have assessed the impact of reduced root hydraulic conductivity on leaf water potential and stomatal conductance, especially in mature trees. Stem hydraulic conductivity, however, can affect stomatal conductance. Borghetti et al (1989) found that after severe moisture stress and subsequent xylem cavitation, hydraulic conductivity was reduced sufficiently to impact stomatal conductance. This suggests that the seedlings were unable to supply sufficient water to maintain transpiration. Our observations taken with the increased root length and increased root branching by trees subjected to the root disease (Baker et al in prep.) lead us to postulate a new role for root diseases in stand demise. Root diseases, by direct action or by stimulating host response, may cause a reduction in specific hydraulic conductivity of roots. If the root disease affects substantial portions of a tree's root system, the tree may experience increased water stress. This water stress could affect photosynthesis and nutrient uptake, and thereby predispose the tree to insect or further root disease attack.

ACKNOWLEDGEMENTS

We greatly appreciate the assistance of volunteers from Earthwatch EarthCorps for their assistance with the fieldwork in this study.

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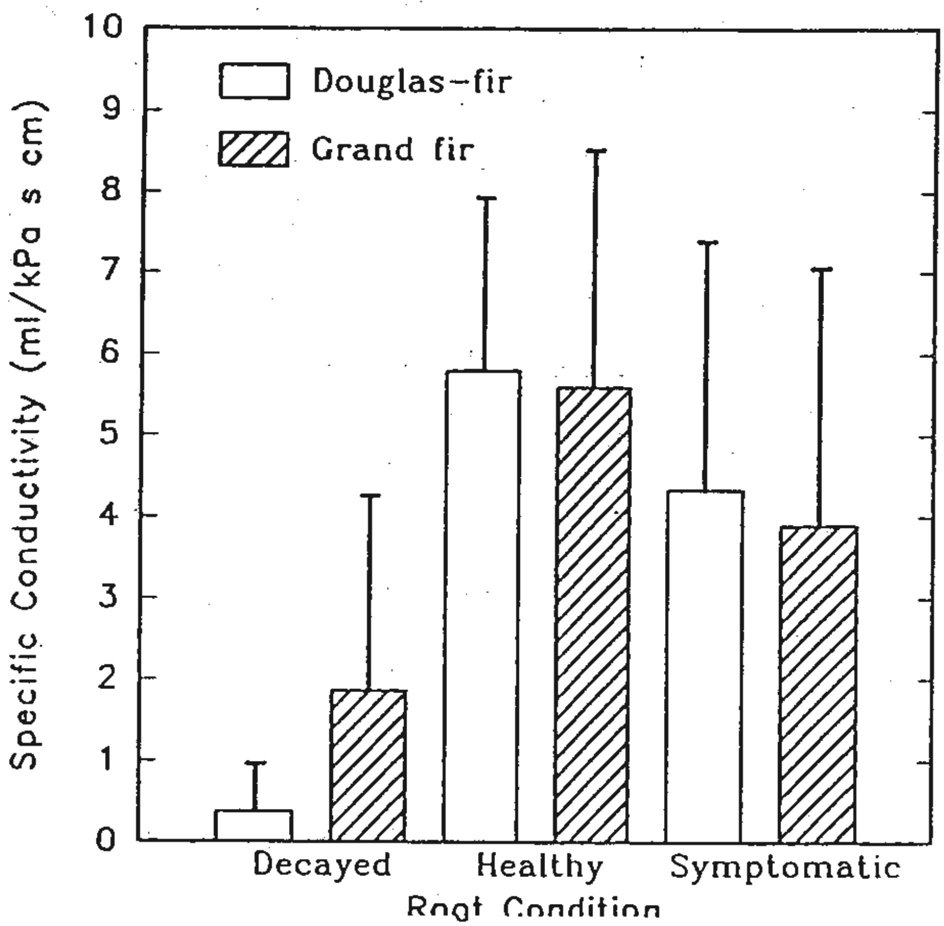

Figure 1. Specific conductivity of Douglas-fir and grand fir root segments with symptoms of root disease. Decayed roots include those with decay columns, resin soaking, and/or large stain columns. Roots were considered healthy if they had no symptoms.

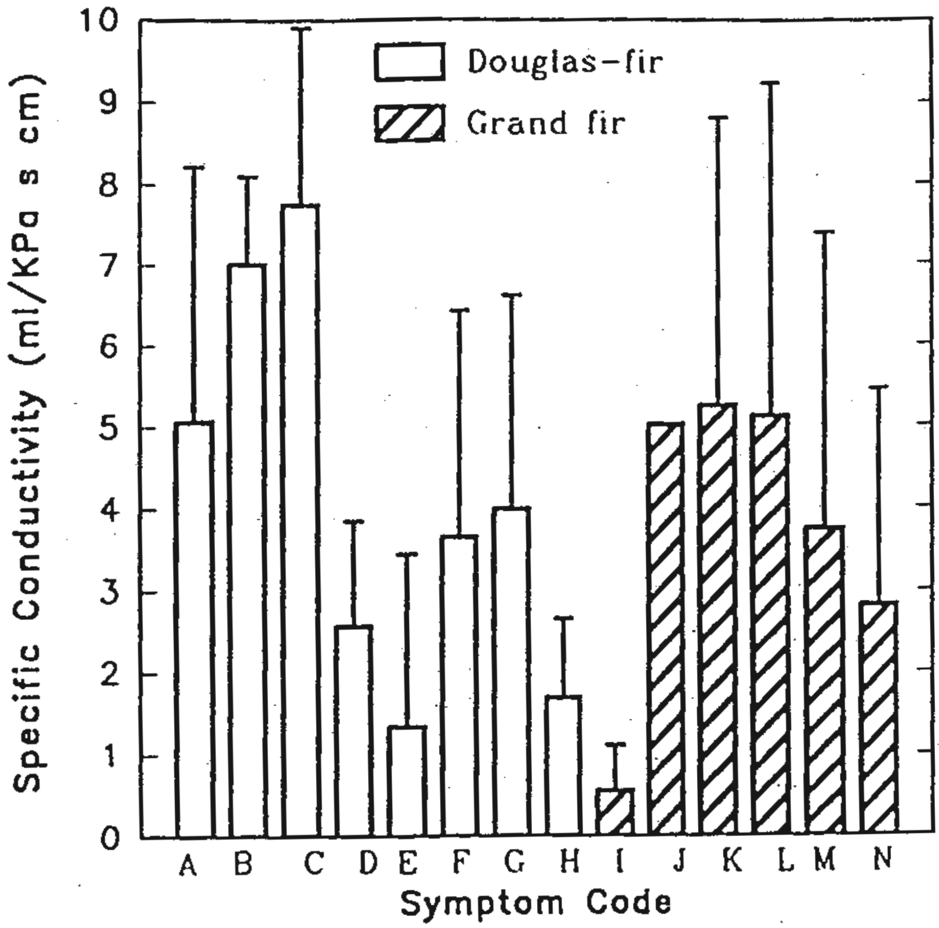

Figure 2. Specific conductivity of Douglas-fir and grand fir root segments. A-H: Douglas-fir; I-N Grand fir. A: no symptoms; B: root ended in prolific branching; C: dead terminal; E: brown stain; F: prolific branching and other symptoms; G: red stain; H: red stain and other symptoms; I: decay and other symptoms; J: no symptoms; K: dead terminal; L: red stain; M: red stain and prolific branching; N: red stain and other symptoms.

Association of Armillaria Root Disease In Jack Pine Infected with Arceuthobium americanum

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Jack pine dwarf mistletoe *Arceuthobium americanum* Nutt *ex*. Engelm. may be associated with Armillaria root disease (*Armillaria ostoyae* (Romagn.) Herink) in accounting for significant decline and mortality of jack pine (*Pinus banksiana* Lamb.) in the Belair Provincial Forest, Manitoba, Canada. Sixty jack pines were randomly selected from three mortality centers and categorized into three vigor classes, each with and without dwarf mistletoe. For each tree, the root collar and all primary lateral roots within 1m of the bole were excavated and examined for signs and symptoms of Armillaria root disease. Cultures were made from symptomatic roots to confirm the presence of *Armillaria*. Preliminary nonparametric analysis suggests that the odds of jack pine being infected with both dwarf mistletoe and *Armillaria* are not significantly greater than jack pines being infected with dwarf mistletoe only ($p=0.05$). Other analyses indicated a weak tendency for increased *Armillaria* colonization of dwarf mistletoe infected jack pines. Trends observed within the data suggest that *A. ostoyae* acts opportunistically, attacking jack pines weakened by dwarf mistletoe. For example, vigorous dominant and codominant trees, with or without dwarf mistletoe, were less frequently and less extensively colonized by *Armillaria*. Declining trees with dwarf mistletoe had more extensive colonization than trees without dwarf mistletoe. Root systems of dead trees, regardless of dwarf mistletoe rating were completely colonized. Crown position also appears to play a role in the extent of *Armillaria* colonization of this shade intolerant species. However, small sample size reduced the power of statistical tests for detecting significant results.

DETERMINING THE IMPACT OF WHITE PINE BLISTER RUST ON SUGAR PINE IN CALIFORNIA

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Introduction

This paper presents a brief history of white pine blister rust (*Cronartium ribicola*) incidence and impact surveys in California, the results of a pilot survey conducted in the summer of 1992, and then discusses how best to obtain the type of incidence and impact information we need, both for sugar pine (*Pinus lambertiana*) and for the rust. Blister rust is used only as an example; the real question is, how can we do ground-based surveys for diseases, that are statistically valid and with limited resources?

For all diseases, we need survey and monitoring methods that tell us where the pathogens are, how much is there, and how they effect ecosystems, over time. With white pine blister rust, we need to measure the incidence and impact of the disease with limited resources (at present, both dollars and personnel are limiting factors), and in a statistically valid manner. We need statistically valid information because of the importance of sugar pine, the importance of blister rust, and the need for defensible data. Observations alone are not good enough. We need to be able to defend the data in court. In the past few years, there have been concerns raised by various publics that sugar pine is being eliminated as a species by the introduced rust disease.

Historical Surveys

Several types of historical surveys in California have given us useful information on spread and intensification of the rust, and on its impact in localized areas. These surveys will be summarized briefly, with the objective being to describe how the information was obtained, and how it was used.

The Pacific Southwest Region has records, by year, from 1929 through about 1970, of new reports of the rust. Locations of sugar pine, and high hazard streamside sites, were mapped, and scouted for the rust by using surveillance and detection. Early in 1967, the USDA Forest Service began a comprehensive review of the entire rust control program in California. By 1971, surveys to provide up-to-date information on the distribution and intensity of the disease in the central Sierra Nevada were completed. The results of these surveys were presented in a 1979 biological evaluation (Byler and Parameter 1979).

CENTRAL SIERRA NEVADA

In 1969 and 1970, an incidence survey was made at selected locations in the central Sierra Nevada to determine the proportion of sugar pines infected within established disease centers. Field data were collected from 114, 600 acre, areas on the Lassen, Plumas, Tahoe and Eldorado National Forests. Within each 600 acre area, survey lines were run 10 chains apart, and point samples were taken at 5-chain intervals along each survey line. The two sugar pines nearest each sample point were examined for blister rust. The incidence survey found that a substantial proportion of the sugar pines were not infected. The mean level of infection was less than 20%, even in and around the oldest known infection centers.

An impact survey was made in 1971 and 1972 to determine the size distribution of trees killed by the rust. A strip cruise was made through 14 selected locations. Sugar pines were recorded by dbh, crown class, and presence or absence of infection. The impact survey found that rust infection does not always result in tree mortality; sugar pines larger than about 4 inches in diameter had no lethal (nonprunable) cankers.

SIERRA NATIONAL FOREST

The streamside surveys of the late 1960's and early 1970's found the rust at only 6 areas on the Sierra National Forest. However, during the mid and late 1970's, there was an alarming increase in reports of the rust in the Southern Sierra, especially on the Sierra and Sequoia National Forests. These reports led to an incidence and impact survey on the Sierra National Forest in 1982 (Kliejunas 1982). The objectives were to determine the rate of new blister rust establishment, by scouting for the rust in locations reported rust-free in 1972, and to determine the levels of damage caused by the rust in known infection centers.

For the incidence survey, streams known to have sugar pine, based on previous blister rust surveys, were marked on a Sierra Forest map. Those streams that were crossed by an accessible road, or that were within two chains of an accessible road, were selected, and a portion of them systematically sampled. At each sample point, a 1-chain-wide strip was examined on each side of the stream, for 4 chains upstream and 4 chains downstream. Information, including sugar pine diameter class, presence or absence of rust infection, and canker characteristics were recorded. Previously unreported rust infection centers were found at 5 of the 16 stream locations surveyed. Of 226 sugar pines examined at the 5 sites, 27% were infected.

For the impact survey, 2 sites without rust in 1972 were surveyed using a strip cruise. One-chain-wide strips, placed at 10-chain intervals, were examined. Data recorded included sugar pine diameter class, presence or absence of infection, classes of bole and branch cankers, and year of wood infected.

An example of the impact data collected at Forked Meadow Creek is presented in Figure 1. About 77% of the sugar pines had one or more rust cankers; 38% (64 of 166 trees) were lethally infected. These figures are equivalent to 10 of 13 sugar pine infected per acre. It was estimated that about 4 trees per acre would die before reaching merchantable size.

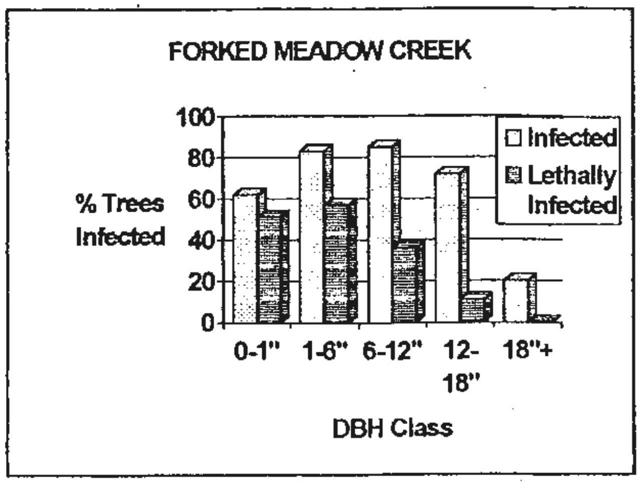

Figure 1. Percent of sugar pine infected and lethally infected, by tree diameter class.

SEQUOIA NATIONAL FOREST

In 1983, a similar survey was conducted on the Sequoia National Forest (Kliejunas 1984). The incidence survey found previously unreported rust infection centers at 17 of the 40 stream locations surveyed. Of 377 sugar pines examined at the 17 sites, 36% were infected.

An example of the impact information collected at French Joe Creek is presented in Figure 2. About 44% of the sugar pines examined had one or more blister rust cankers; 26% were lethally infected. Infection was more common on trees 1 to 12 inch dbh.

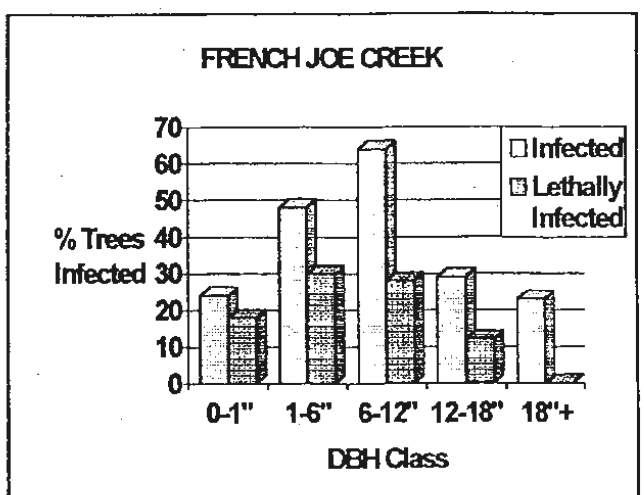

Figure 2. Percent of sugar pine infected and lethally infected, by tree diameter class.

The results of the two surveys were used to provide information to the Forests, and to the Region, on locations and impact of the rust, and to develop strategies for managing the existing and future sugar pine resource.

PLANTATION SURVEY

In 1986, a survey of selected plantations with sugar pine was conducted in the central Sierra Nevada (DeNitto 1987). The objective of the survey was to determine the incidence and impact of the rust on sugar pine regeneration. Plantations to sample were selected by asking four central Sierra Nevada forests for locations of plantations that were 5 to 25 years of age, had at least 10 percent sugar pine stocking, and that were on low hazard (ridge top) sites. Twenty -nine plantations were systematically sampled by placing predetermined transects in each plantation, and recording blister rust infection data within a 1/2 chain wide strip centered on each transect line.

Survey results confirmed that white pine blister rust is a major limiting factor in the growing of sugar pine in the central Sierra Nevada. Of the 29 plantations surveyed, 28 were infested with the disease (Figure 3). Infection levels ranged from 44 to 98%, with an overall average of 69%. It was estimated that the rust would reduce stocking to below acceptable levels in 4 of the plantations. No relationship between the incidence of rust and estimated site hazard was found.

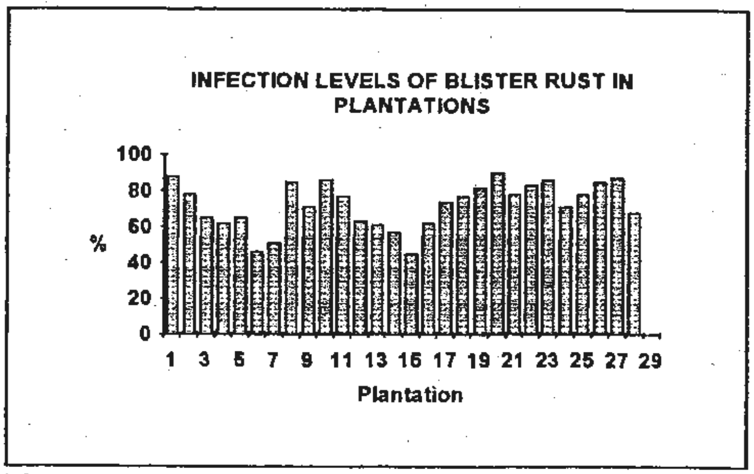

Figure 3. Blister rust infection in 29 central Sierra Nevada plantations.

MOUNTAIN HOME STATE DEMONSTRATION FOREST

Additional surveys in a localized area are being conducted at Mountain Home State Demonstration Forest in the southern Sierra (Kinloch and Dulitz 1990). The demonstration forest had only several, small, localized, infection centers in the late 1960's. To quantify the impact of the disease, a systematic survey was initiated in 1980, to recur at five-year intervals. The sampling design involves recording the amount of infection, on both sugar pine and *Ribes*, on 119, 0.2 acre, fixed, Continuous Forestry Inventory plots, on a 20 by 20 chain grid, that covers the entire 4,600 acre forest. Rust was found on 28% of the sugar pine in 1980. Incidence increased to 36% in 1985.

CONCLUSIONS

Three conclusions can be drawn from these surveys. First, the surveys gave the Region a good picture of what the rust was doing in selected, localized areas (it had increased). Second, only the Mountain Home survey used permanent plots, so trends can be followed over time. Third, the surveys answered the questions that they were designed to answer -- blister rust is impacting sugar pine in some areas. It is also generally agreed that knowledge of the impact over the entire range of sugar pine in California is limited.

In the last few years, a new question is being asked by various publics. The question is -- what is the effect of the rust, Region-wide, on sugar pine, and what are the expected trends for the future? The public is demanding a greater role in the management of our forested lands, and the answers to their questions must have a statistically sound basis.

Current Situation

In the Spring of 1990, the California Department of Fish and Game received a petition to list sugar pine as a threatened species. Basically, the contention was that because blister rust is affecting the viability of sugar pine, the species has the potential to become threatened and endangered. The Pacific Southwest Region and the Pacific Southwest Forest and Range Experiment Station responded to the contention by recognizing the spread and impact of the disease, and by citing the previous surveys and the rust resistance program as evidence of a coordinated effort to manage sugar pine. The petition was dropped.

However, the petition did raise an important issue. Because no comprehensive, Region-wide, surveys have been conducted since the early 1970's, we cannot adequately describe the current disease situation, nor can we accurately predict the future threat of the rust. Furthermore, no methods are in place to measure trends of the disease over time.

1992 PILOT SURVEY

To remedy the situation, Forest Pest Management proposed a long-term survey of sugar pine in the Region. The objectives were to characterize the current condition of sugar pine, including the incidence and severity of white pine blister rust, and to characterize changes in sugar pine over time.

Three approaches to meeting the objectives were considered. The first was to design an entirely new, independent, comprehensive survey. Because of current and projected limitations in funding and personnel, this approach was not considered feasible. It would take a tremendous effort to plan, install, and maintain such a long-term project. The second was to tie into the National Forest Health Monitoring effort. However, a sugar pine survey would require a much greater sampling intensity than that used by the Forest Health Monitoring program, the cost would be prohibitive, and mensurational trend data would not be available for four years. The third approach considered was to utilize existing timber inventory plots. Region 5's Forest Inventory group conducts a continuous forest inventory of timbered land on the national forests in California. Each Forest is inventoried on a 5-year cycle; plot locations and data from previous inventories would be available to us.

The utilization of already existing timber inventory plots was chosen because the cost of plot establishment has already been incurred; it would be known in advance which plots contained sugar pine, avoiding the need to pre-screen plots for sugar pine; and if the plots could be relocated, (they were not meant to be permanent), mensurational trend data would be immediately available for some Forests. The inventory design is based on strata, including timber type, size class, and stand density. The design consists of a multistage, variable probability, sampling procedure in which plot locations are randomly selected within stratum polygons. The polygons are selected randomly, using a probability proportional to the acreage of the stratum which occurs on each randomly chosen quad sheet.

In the Spring of 1992, a tentative sugar pine survey design was developed by adapting the Forest Inventory design to meet our objectives. A pilot survey of the design was conducted during the Summer of 1992. The objectives were to test the methodology and overall feasibility of the survey design from a logistical standpoint, and to determine if useful and valid conclusions could be drawn from the small data set collected.

methods

Two National Forests were chosen: the Sequoia, which had a forest inventory completed in 1990; and the Shasta-Trinity, which last had a forest inventory in 1980. Rather than using the Forest Inventory's variable radius plot design, we established two, fixed-radius, nested, plots around the center point of the original cluster plot. Twenty-three plot centers on the Sequoia and 11 plot centers on the Shasta-Trinity were relocated, and two nested plots at each center were sampled; a 3/4 acre plot (102 ft radius) for trees greater than 1 inch dbh, and a 1/4 acre plot (58.9 ft radius) for seedlings. Tree height, tree age, and damage, including blister rust, were recorded for each sugar pine.

results

Results of the pilot survey were presented in a 1993 biological evaluation (Marosy 1993). Rust incidence on the 34 plots was low. On the Sequoia National Forest, 30 of 270 trees (or 11%), were infected; 89% were free of the rust. The 30 infected trees represented all diameter classes, except for the 15-21 inch class (class 5 on the graph, Figure 4). On the Shasta-Trinity National Forests, 5 of 46 trees (or 3%), were infected; 97% were rust -free. The 5 infected trees were in the seedling and pole size classes (classes 1 and 3 on the graph, Figure 5).

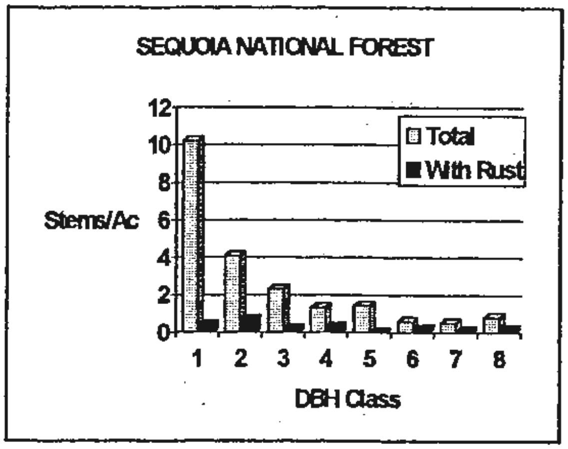

Figure 4. Average live sugar pine stems per acre, and stems with rust, by dbh class.

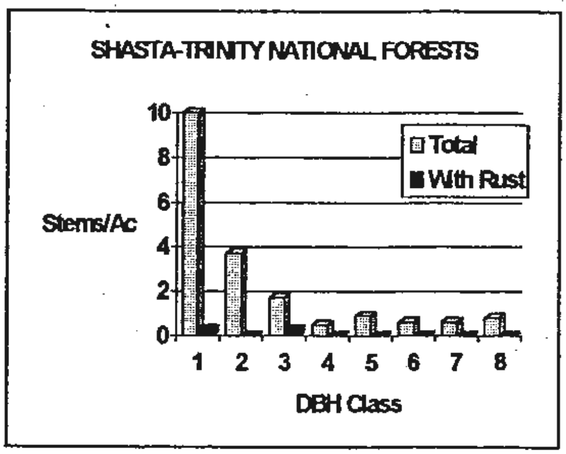

Figure 5. Average live sugar pine stems per acre, and stems with rust, by dbh class.

Canker Location (branch vs. bole) was recorded as an indicator of rust severity. On the Sequoia, 15 of the 30 infected trees had branch cankers only, while 15 had at least one bole canker. On the Shasta-Trinity, 1 tree had branch cankers only, while 4 had at least one bole canker.

On trees 10 or more years old and less than 35 feet in height, Rust Index was used as another indicator of rust severity. The Rust Index was developed in the Intermountain Region (Hagle et al. 1989) as an indicator of stand rust hazard. The index represents the number of cankers per 1,000 needles per year. The rust index on the Sequoia National Forest ranged from 0.00018 to 0.02779, and on the Shasta-Trinity from 0.00003 to 0.2222. The values obtained are indicative of from very low, to high, rust hazard.

Percent crown affected was recorded as an indicator of rust severity on trees less than 10 years old, or 35 ft or more in height. No rust was found on trees younger than 10 years. Rust was found on 8 trees on the Sequoia and 1 tree on the Shasta-Trinity greater than 35 feet tall. Of the 9 trees with rust, 8 had less than 10% of the crown affected, and 1 had 50% of the crown affected.

The presence of damaging agents, mortality, and cause of death if known, were recorded as indicators of the overall health of sugar pine. On the Sequoia, other damaging agents recorded were fire (1 tree), and mechanical (4 trees); and on the Shasta-Trinity, fire (1), mechanical (5), dwarf mistletoe (1), and Atropellis canker (1). On the Sequoia, cause of mortality (18 of 270 trees were dead) was rust (8 trees) and other (10 trees); and on the Shasta-Trinity (3 of 146 pines were dead), rust (1) and other (2).

Discussion

Several logistical problems were encountered. The pilot project involved 21 person weeks, 5 person weeks of pre-survey planning and gathering of old records, plus 16 person weeks of actual field time. Each two-person crew averaged about one plot per day. One of the questions to be answered by the pilot survey was whether the timber inventory plots could be re-located. We were unable to find, and had to re-establish, 36% of the plot centers we attempted to re-locate.

The data collected has limited use. As the data now stands, we cannot draw statistically valid conclusions about the target population. Because the Forest Inventory design was not based on the distribution of sugar pine in California, use of the design will not allow us to draw statistically valid conclusions about the target population. This can be remedied by calculating expansion factors for the plots that the data points represent. The data collected are estimates of only the plots surveyed. They are not estimates of all plots with sugar pine on the two forests, of all sugar pine on the forests, nor of all sugar pine in California. Again, proper weights and expansion factors need to be calculated in order to have the data represent more than just the points surveyed.

Conclusions

The incidence and impact of blister rust is known for some areas, but not state-wide. The pilot survey suggested that obtaining statistically valid, ground-based data for a single pest on a state-wide basis is feasible only if we coordinate efforts with other disciplines. Forest Pest Management can not afford to establish its own plots state-wide for single pests, nor can we afford the time and effort to re-locate and sample Forest Inventory plots that are already established. However, we can integrate pest surveys with the Forest Inventory survey, or with other established permanent plot systems. Pest information can be taken as the plots are being established or re-visited. Forest Pest Management can train crews or send a Forest Pest Management person with the crew. This appears to be the most efficient, if not the only, way that Forest Pest Management can provide information on pathogen inidence and impact over large areas.

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PRUNING AND THINNING EFFECTS ON WHITE PINE SURVIVAL AND VOLUME IN NORTHERN IDAHO

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ABSTRACT

In 1969, a total of 48 one-quarter acre plots were established on five western white pine plantations in north Idaho. Four treatments were replicated at lower-, mid-, and upper-slope positions, and included: thinning and pruning white pine, thinning and pruning of all species, thinning only, and no treatment (control).

After 22 years, white pine mortality was reduced by nearly one-half in the thinned and pruned plots. In some cases, thinning alone resulted in greater white pine mortality than doing nothing. Although there were fewer live white pine remaining than other species in most study areas, plots that were thinned and pruned had twice the number of live white pine per acre as the thinned or control plots and contained 65-75% of the uninfected trees.

The plots that were pruned and thinned produced an average of 60% more total merchantable volume than the controls and nearly 20% more than the plots that were thinned only. White pine volumes increased by more than 50% over the thinned only treatment, and were more than 90% greater than the control plots.

Since the increase in total volume on the pruned and thinned plots was primarily in white pine, its higher market value greatly compounds the benefits of the pruning treatment. In stands where natural western white pine is a desirable species, the additional investment of pruning white pine in conjunction with thinning should receive high consideration.

INTRODUCTION

Although we now have an opportunity to plant white pine bred specifically for blister rust resistance, we have many areas where natural white pine regeneration is abundant. Currently we tend to ignore these natural white pine in routine silvicultural practices such as precommercial thinning. (White pine are frequently treated as "ghost trees", assuming they will be killed by blister rust before reaching commercial size.)

In 1969 the Intermountain Research Station initiated a study to see if pruning and/or thinning would reduce blister rust mortality. Pruning was expected to eliminate many infections plus reduce target area for new infections. Thinning was expected to create a less favorable microclimate (warmer, drier) for blister rust infection while increasing tree growth so that fewer infections would be lethal.

1969 PROCEDURES

In 1969 these theories were tested on five northern Idaho white pine stands between 10 and 20 years of age and at least 20 acres in size (Figure 1). Study sites were in stands in

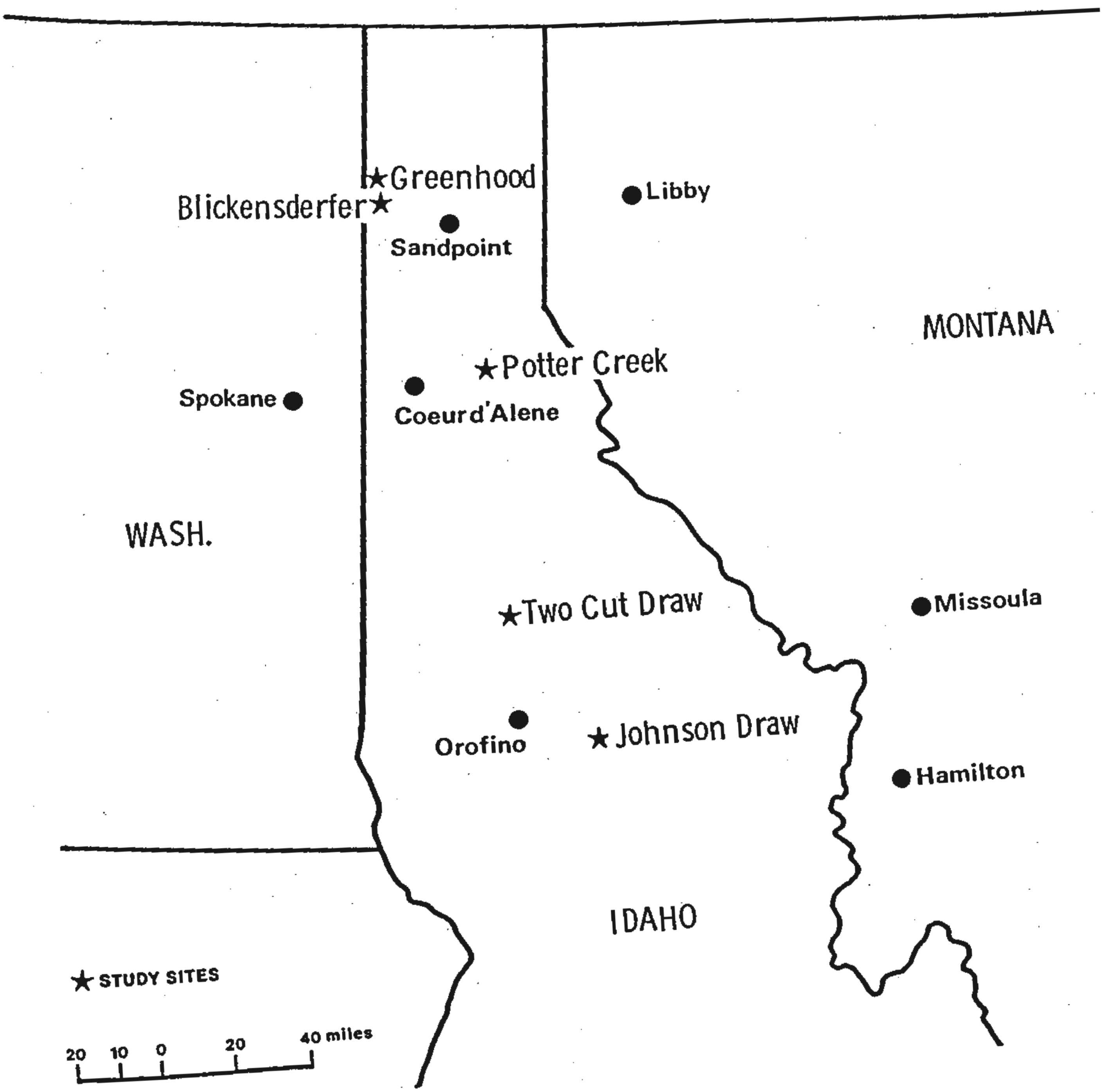

Figure 1. Location of study sites within Northern Idaho are marked with a star.

hemlock or cedar habitat types (Daubenmire and Daubenmire, 1968) and were dominated by white pine. The white pine had been established by natural regeneration or by planting or interplanting with "woods-run" stock (Table 1). Trees were 1.0 to 2.8 inches in diameter and seven to 17 feet in height (Hungerford et al., 1982). A total of 48 plots were established; three replications of four treatments in four areas. Treatments consisted of 1) thinning and pruning all white pine crop trees, 2) thinning and pruning all species of crop trees, 3) thinning only, and 4) no treatment (control). The replications were based on relative slope position of the stand: lower, middle or upper. The Priest Lake area is a combination of two stands; Greenhood had eight plots representing the lower and upper slope replications while the four mid-slope plots were installed in a nearby stand called Blickensderfer. Plots were one-quarter acre in size and were nested within one acre treatments.

Table 1.-- Age and origination of white pine in north Idaho study sites.

AREA	AVERAGE AGE 1969	1991	ORIGINATION
Johnson Draw	18	40	natural regeneration plus 1951 interplant
Greenhood	15	37	planted in 1954
Blickensderfer	14	36	planted 1955, some replanting
Two Cut Draw	18	40	all natural regeneration
Potter Creek	10	32	planted in 1959

Trees were thinned to a 10 foot by 10 foot spacing, and crop trees were selected based on standard guidelines except that white pine was not discriminated against unless it had obvious bole infections or had branch infections within four inches of the bole (considered lethal infections). Pruning consisted of removing all branches (live and dead) from the lower one-third of the total tree height plus removal of infected branches that could be reached above that level. All crop trees in each plot were individually tagged and their diameters, heights, and crown lengths were recorded. The location and age of every blister rust infection was also recorded. Plots were remeasured in 1974, five years after treatment.

1991 PROCEDURES

In 1991, the plots were re-monumented and trees were re-tagged as necessary. Diameters, heights, and crown lengths were recorded along with a general tree condition: dead, alive but infected, alive with no infections observed.

Cubic foot (CuFt) volumes for each tree were calculated using the latest versions of the Montana/Idaho volume equations developed by Moisen et al. (1992) which modify Kemp's equations (1957) to more accurately estimate the volume of small trees. Board foot (BF) volumes were derived using formulas developed by Allen et al., (1974) and values were calculated using average 1992 delivered log prices reported by several mills to the Idaho Department of Lands for white pine and other species in northern Idaho (personal communication)($405 per thousand board feet (MBF) for white pine and $260/MBF as a weighted average value for all other species).

In the statistical analyses of this experiment, the plot is the basic unit of measurement because thinning must be applied on a unit area. The areas are used as blocks in which all treatments are repeated, generating a randomized block design. Tukey's Paired Comparison Procedure is used to test for significance between treatments (Box et al., 1978). The alpha= 0.05 level was used as the critical level in all testing.

RESULTS

Trees are now 32-40 years old, with diameters up to 12-14 inches and maximum heights of 65-75 feet. Since the stands that were treated had a high proportion of white pine initially, the prune only white pine treatment was nearly identical to the prune all species treatment, especially in the Priest Lake area. Therefore, these treatments are combined in some of the analyses. Initially, there were a total of 4,707 trees in the 48 quarter-acre plots. Over half of these were white pine (2,437), but after 22 years, only half of the white pine were still alive, and nearly half of the these were infected by blister rust. Other species now account for 60% of the live trees and outnumber the live white pine in all but the Priest Lake sample area. Seventy-five percent of the other species were grand fir (59%) and Douglas-fir (16%) followed by hemlock (6.6%), spruce (5.6%), and less than five percent of subalpine fir, larch, western redcedar, lodgepole pine, and ponderosa pine. White pine mortality, percent of uninfected trees, and volumes were significantly affected by treatment but not slope position.

EFFECTS ON MORTALITY/SURVIVAL

Nearly 70% of the white pine were still surviving in the plots that were pruned as well as thinned, while only 40% survived in the control and thinned only plots (Figure 2.) This means white pine mortality was cut almost in half by pruning (from an average of 60% mortality in the control and thinned only plots to just over 30% mortality in the plots that were pruned as well as thinned). This pattern was true across all four areas; the two thinning and pruning treatments consistently had significantly (20-35%) better white pine survival than the control or thinned only plots.

UNINFECTED WHITE PINE

Since the future of the stand depends largely on the remaining uninfected white pine, it is important to focus on the treatment effects on these trees. Figure 3 shows that a total of 65-75% of all uninfected white pine in each area are in the two pruned and thinned treatments. This graph also indicates that white pine blister rust was actually more severe in the thinned only plots than in the control plots in all four areas, although differences were not statistically significant.

Table 2 compares the percent of uninfected white pine by treatment and area in 1974 and 1991 (five years and 22 years after treatment). The percent of uninfected white pine was closely related to the overall blister rust infection levels observed at each stand. In 1974 the amount of blister rust infection was very high in Johnson Draw, lowest in Potter Creek and intermediate in the other stands (Hungerford et al., 1982). There were so few uninfected trees remaining in Johnson Draw that there were strong doubts about any white pine surviving to maturity.

Table 2.--Percent of white pine by treatment and area with no visible blister rust infections five years (1974) and 22 years (1991) after treatment.

AREA	THIN & PRUNE		THIN ONLY		CONTROL	
	1974	1991	1974	1991	1974	1991
Johnson Draw	12	20.8	6	8.0	10	10.1
Greenhood	28	36.5	9	9.2	29	18.4
Blickensderfer	53	38.5	12	13.2	16	27.3
Two Cut Draw	33	44.8	13	14.1	23	21.8
Potter Creek	72	53.2	43	31.9	44	28.1
Average (weighted by plot)	39.6	38.8	16.6	15.2	24.4	21.2

The percent of uninfected white pine in the thin only and control plots has not changed much since 1974. In 1991, the percent of uninfected white pine in the pruned and thinned plots in 1991 was generally double that of the control plots. The thinning only treatment resulted in lower percentages of uninfected white pine than the controls for all area except Potter Creek.

EFFECTS ON TPA (Trees per acre)

Although percentages are good for making these comparisons, it is important to look at the actual trees per acre (TPA) to get a realistic picture of the treatment effects on these stands. Table 3 shows the initial, 5 year and 22 year average TPA for white pine, all other species, and the uninfected white pine for each area and treatment. (The two thinning and pruning treatments were combined.) The TPA of the other species in 1991 surpass that of the white pine in most areas, especially in the thin only and control plots. The TPA of white pine is significantly greater in the pruned and thinned plots than either the thinned only or control plots. The TPA of uninfected white pine remaining in 1991 ranges from only 12 TPA in the thinned only plots at Johnson Draw to 117 TPA in the Priest Lake area plots that were pruned and thinned. Even though the thinning and pruning treatment at Johnson Draw resulted in doubling the number of uninfected white pine, 31 TPA may not be worth the additional pruning effort. Therefore managers need to be careful in selecting sites that will be treated with pruning.

Table 3.--Initial, five, and 22 year average TPA for white pine, other species and uninfected white pine by area and treatment.

AREA	YEAR	Thin and Prune Ave TPA/Plot			THIN ONLY Ave TPA/Plot			CONTROL Ave TPA/Plot		
		Other sp.	All WP	Uninf WP	Other sp.	All WP	Uninf WP	Other sp.	All WP	Uninf WP
Johnson Draw	1969	243	151	39	281	149	36	264	145	55
	1974	205	140	18	240	132	9	249	127	15
	1991	203	88	31	221	47	12	229	33	15
Priest Lake	1969	105	315	236	108	337	271	192	341	280
	1974	93	282	128	93	323	35	164	321	77
	1991	89	200	117	69	107	35	144	148	69
Two Cut Draw	1969	175	193	64	273	123	37	208	159	72
	1974	161	189	64	209	115	16	203	145	37
	1991	135	147	87	183	53	17	180	65	35
Potter Creek	1969	185	167	138	165	159	114	169	185	122
	1974	175	155	120	165	145	21	155	167	81
	1991	170	119	89	159	77	51	144	93	52
All Area Ave.	1969	177	206	119	194	192	115	208	208	132
	1974	159	191	83	177	177	20	193	190	53
	1991	150	139	81	158	74	29	174	85	43

TREATMENT EFFECTS ON VOLUMES

Significant treatment effects were also observed on total and merchantable volumes. Merchantable volumes of all species in all treatments averaged about ten percent less than total volumes, but the volume per acre was significantly less on the control plots than the other three treatments (Figure 4). The thinned plots produced a thinning response in all species, but the total volume was not significantly greater than the control plots. However, plots that were pruned as well as thinned produced significantly more total volume than plots that were only thinned.

The increase in volume in the pruned and thinned treatment is primarily due to the survival of more white pine. White pine volumes on pruned and thinned plots were significantly greater than both the thin only and control plots. The white pine volumes increased an average of 1730 BF/Ac (365 CuFt/Ac.) or 53% over the thinned only plots and increased 2400 BF/Ac (515 CuFt/Ac.) or more than 90% more than the control plots. The average volumes of the others species declined slightly in the plots that were pruned, but they were not significantly different than the volumes on plots that were thinned only (Figure 4).

The increase in white pine volume was consistent across all areas, even though total volumes varied considerably (Figure 5). The greatest white pine volumes were recorded on Priest Lake plots which were nearly pure white pine compared to the other areas. All volumes in the Potter Creek area were lower partly because the stand is 8-10 years younger than the other areas.

EFFECTS ON VALUES

Although timber prices are highly volatile, and it is impossible to predict what future values will bring, it is possible make comparisons between treatments based on recent values. If these volumes are converted into dollar values at 1991 prices ($405 MBF for white pine and $260 MBF for the weighted value of other species), the total value of merchantable volume increased from an average of $1700/Ac. on the control plots to $2250/Ac. on the thinned only plots to over $2800/Ac. on the thinned and pruned plots (Figure 6). This increase in value is almost exclusively due to the white pine component. The thinning treatment resulted in a 32% value ($545/ac) increase over the controls, but the pruning and thinning resulted in an additional 25% ($567/Ac) gain or a 65% gain in value ($1112/Ac) over the controls. (These values do not include any increase that might be added due to better wood quality as a result of the pruning making clear wood.)

The initial cost of pruning varied from $70 to $100/Ac in addition to the thinning costs. The result of this investment after 22 years is an average of $567/Ac which equates to an 8-10% annual return.

CONCLUSIONS

Although additional monitoring should be conducted to further validate these findings, if natural white pine are desired as part of a stand component, it may be well worth the investment to prune crop trees. However, in areas of high rust hazard, the net gain in white pine may not be worth the pruning effort even though the treatment may double the TPAof uninfected white pine. Therefore an assessment of rust hazard should be made to get a broad feel for the degree of success the pruning treatment might produce. (See Hagle et al., 1989 for hazard rating procedures.)

The trees in these stands are still quite young, so they would ordinarily be grown another 30-40 years. However, half of the remaining live white pine are currently infected, so many can be expected to die before reaching an 80 year rotation. Since 65%-75% of the uninfected trees were in the pruned and thinned treatment, volume differences observed in 1991 may increase dramatically over the next 30-40 years.

Historical evidence strongly indicates that white pine is the best suited tree species for many of these sites but it has been widely replaced by grand fir and Douglas-fir. These species are generally not as desirable (or valuable) as white pine and are also more susceptible to root disease, so it is ecologically as well as economically wise to encourage more white pine on these sites. In addition, white pine can tolerate shade and competition better than the other species such as larch that are currently being planted in some of these sites.

White pine has historically had a much higher lumber value than most other species, and there is no reason to expect this to change. There is a strong case being made by many to prune at least one log high to receive a premium value for clear wood. Even if the value of white pine were to equal that grand fir or Douglas-fir, the pruning and thinning treatment resulted in significantly more volume and significantly more uninfected white pine.

It is time to quit treating natural white pine as "ghosts", and start selecting and pruning at least some as crop trees (especially since the thinning-only treatment may be worse than doing nothing). Even though losses may be higher than with genetically improved stock, this practice can help to maintain the genetic diversity of our stands by improving the survival of natural white pine.

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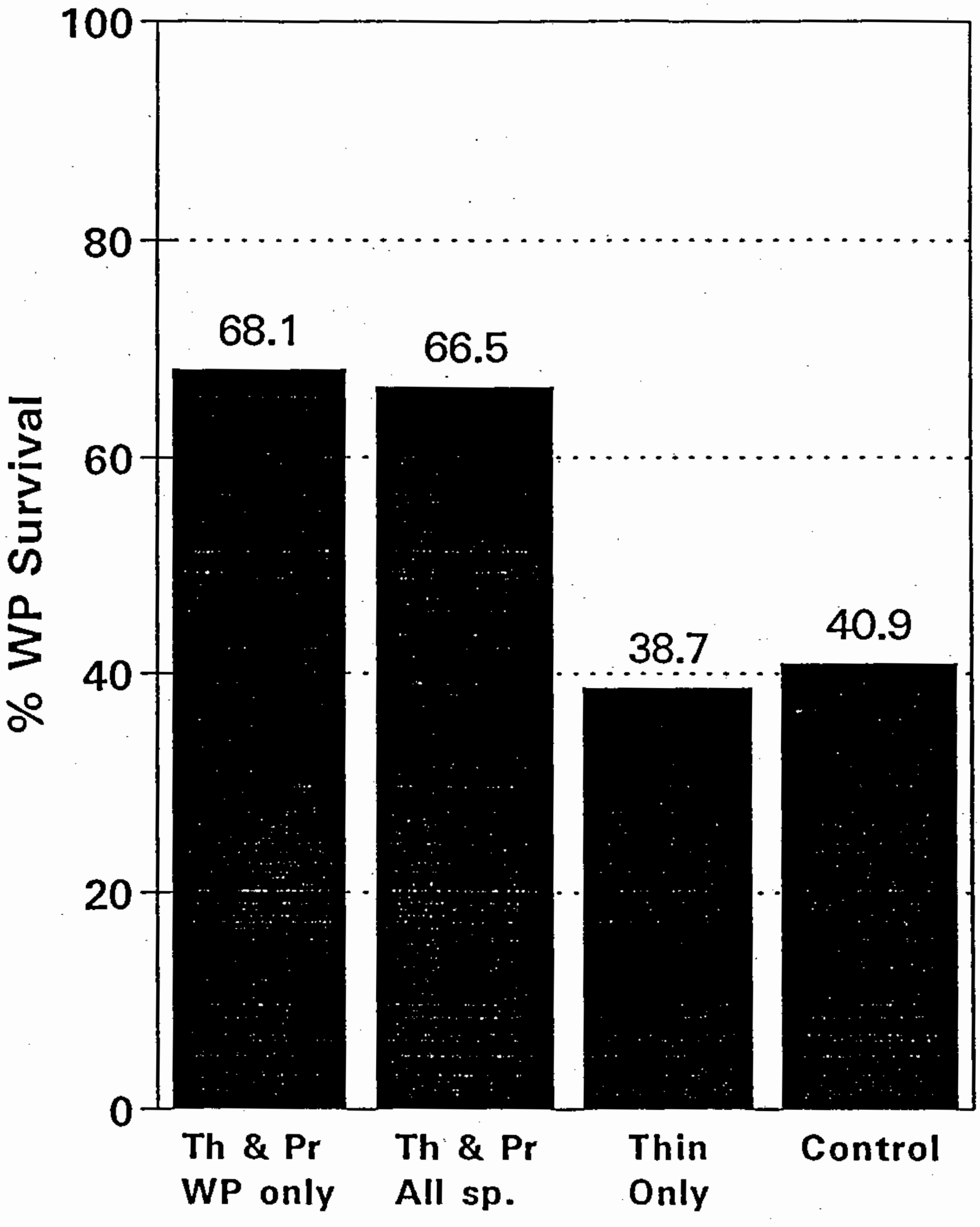

Figure 2. Treatment effects on white pine survival; average percent of white pine survival per plot.

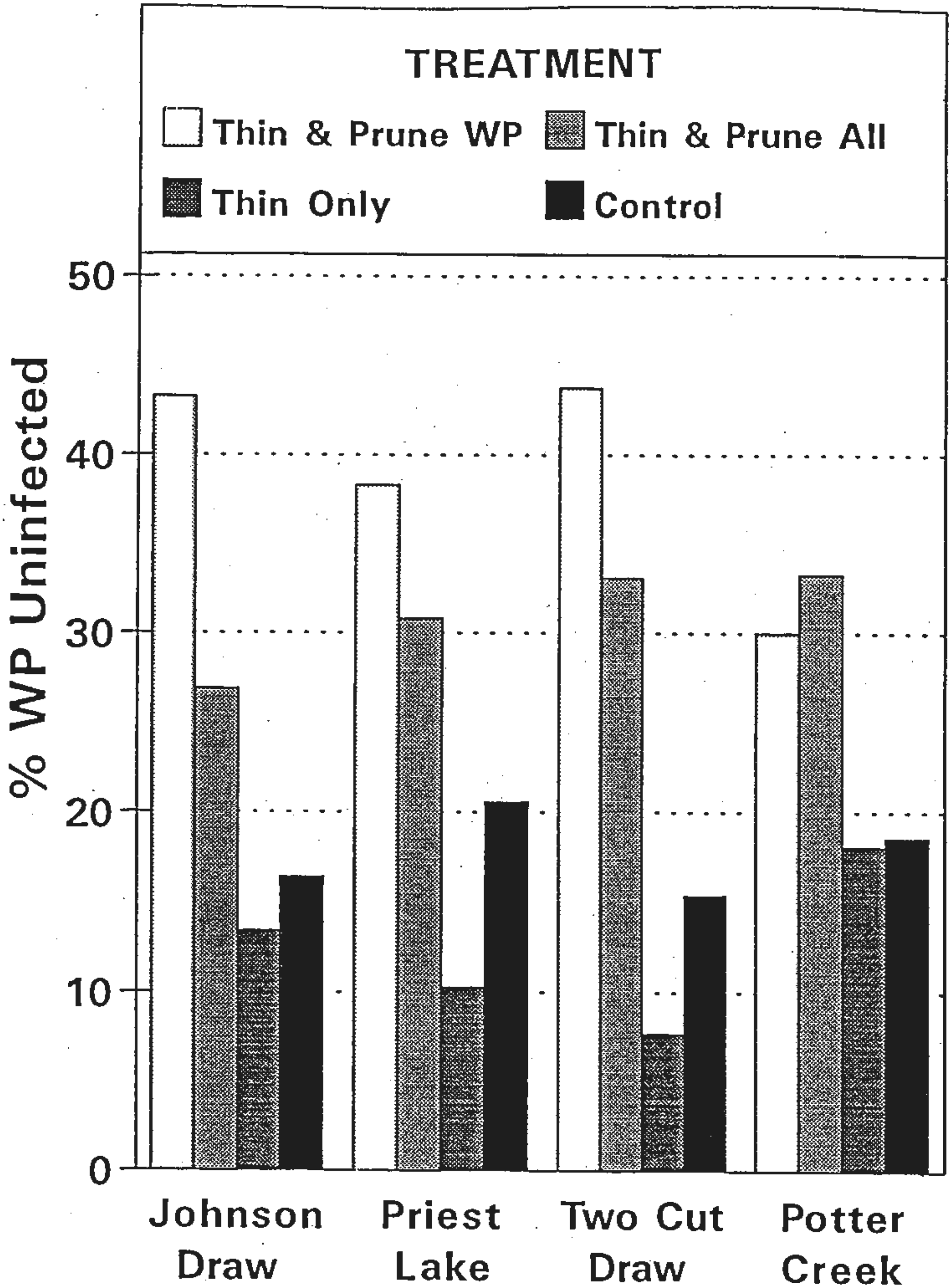

Figure 3. Percent of white pine in each area with no visible blister rust infections (uninfected).

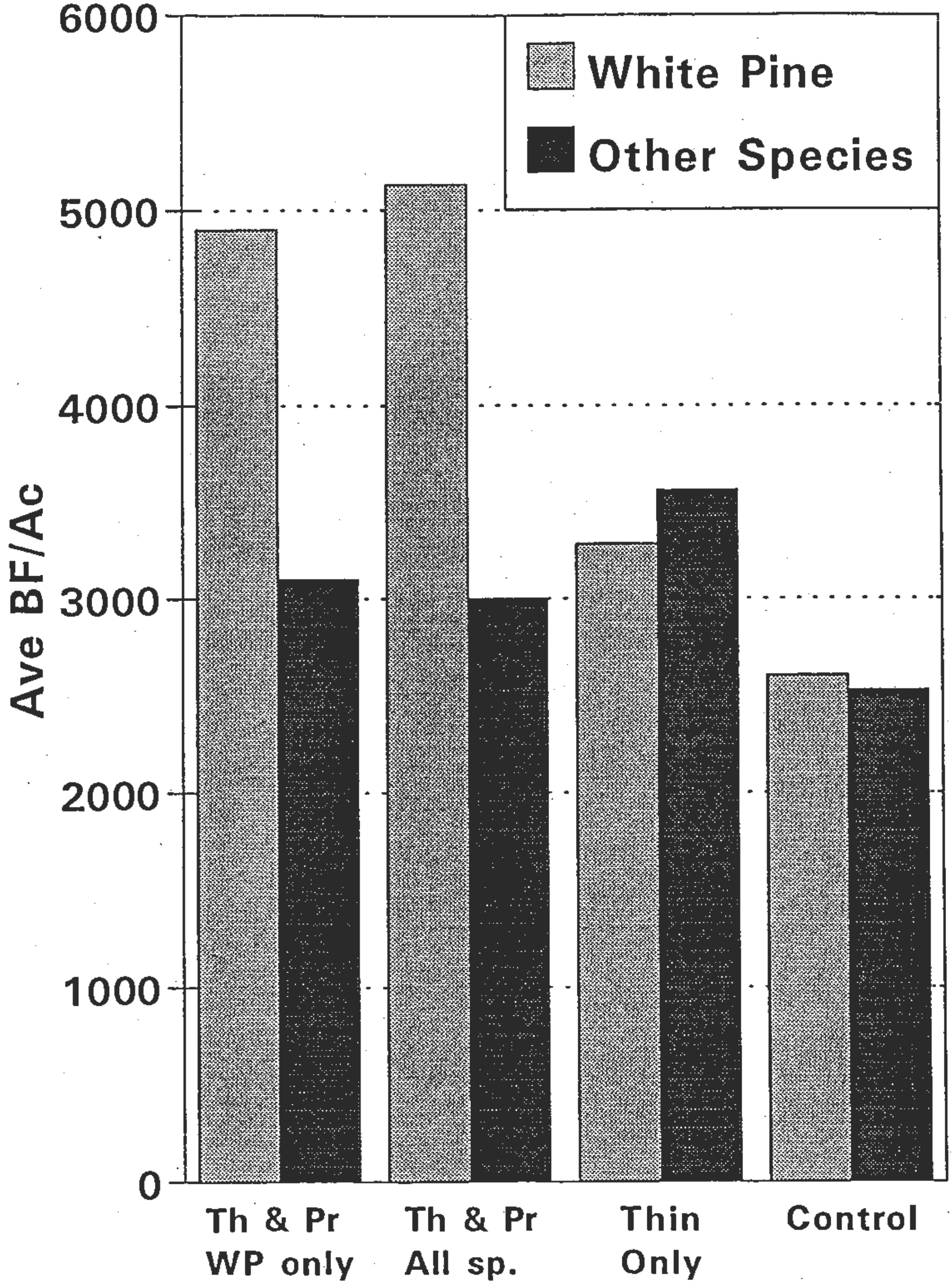

Figure 4. Treatment effect on merchantable board foot volume per acre for white pine and all other species combined.

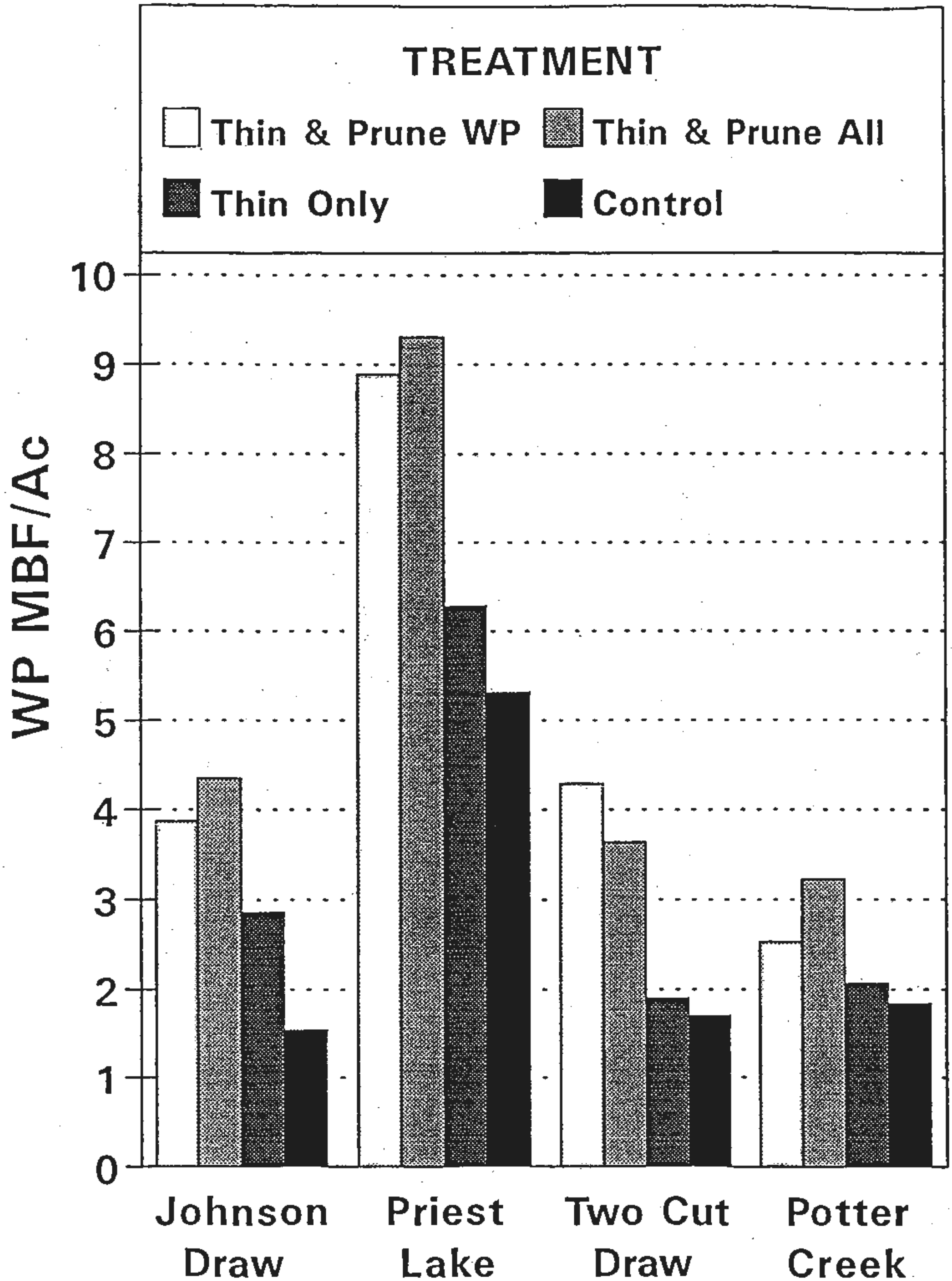

Figure 5. Treatment effects on white pine merchantable board foot volumes per acre in each study area.

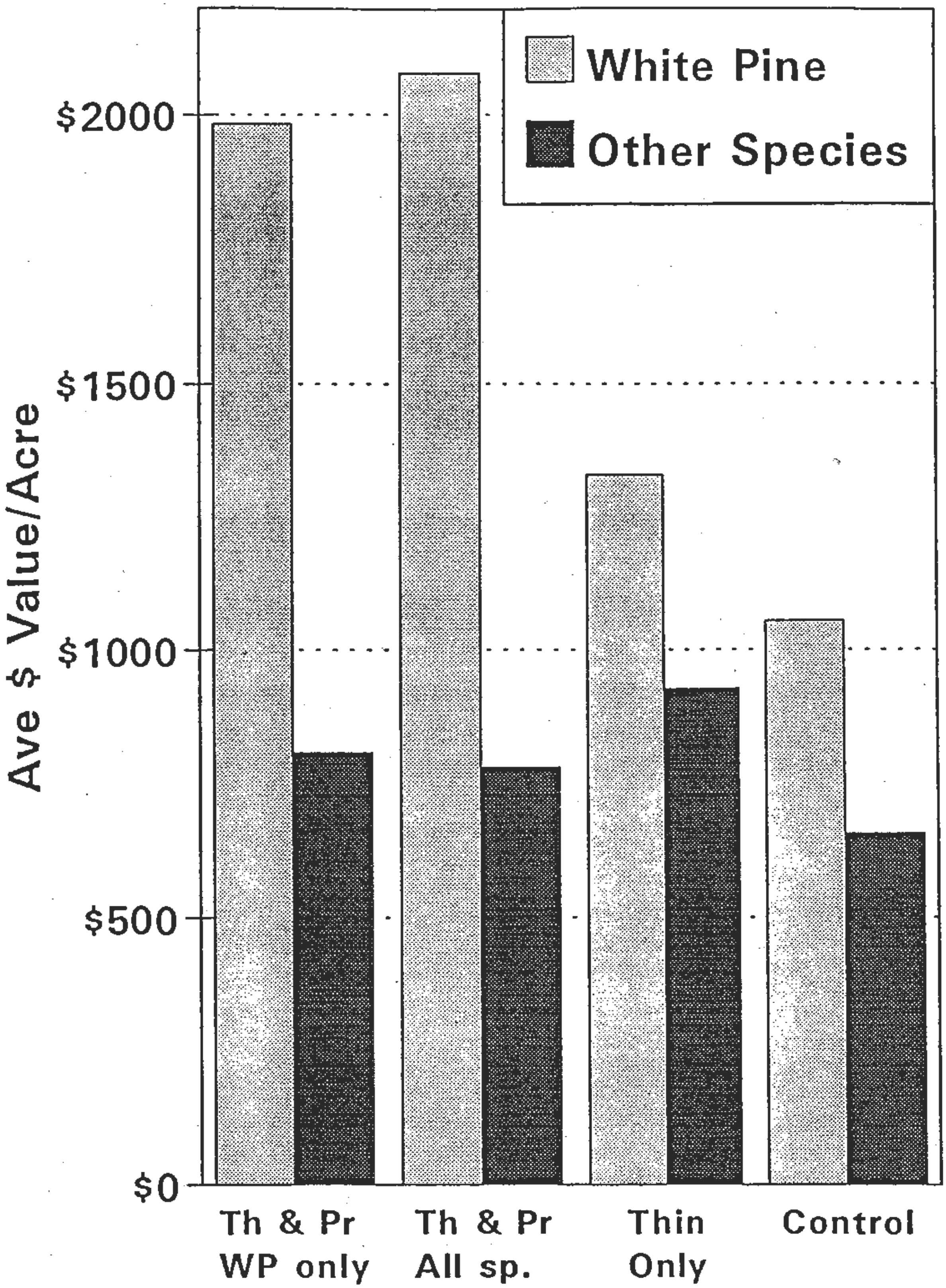

Figure 6. Treatment effects on timber values per acre (at $405/MBF for white pine and $260/MBF for other species.)

AN OUTLINE FOR PROPOSED RESEARCH AND COOPERATIVE STUDIES ON BLISTER RUST OF SOUTHWESTERN WHITE PINE

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HISTORY

White pine blister rust (*Cronartium ribicola* J. C. Fisch.) was first reported on southwestern white pine (*Pinus strobiformis* Engelm.) by Hawksworth (1990) from the Sacramento Mountains of south-central New Mexico. Based on canker distributions and ages, the rust apparently became established several kilometers south of Cloudcroft circa 1975. By 1991, the rust was widely distributed throughout the Sacramento and adjoining White Mountains. The majority of cankers examined by Conklin and Geils (unpublished observations) originated from 1985 to 1987. Surveys in nearby mountain ranges, including the Capitans and Guadalupes, failed to detect further incidence of the rust.

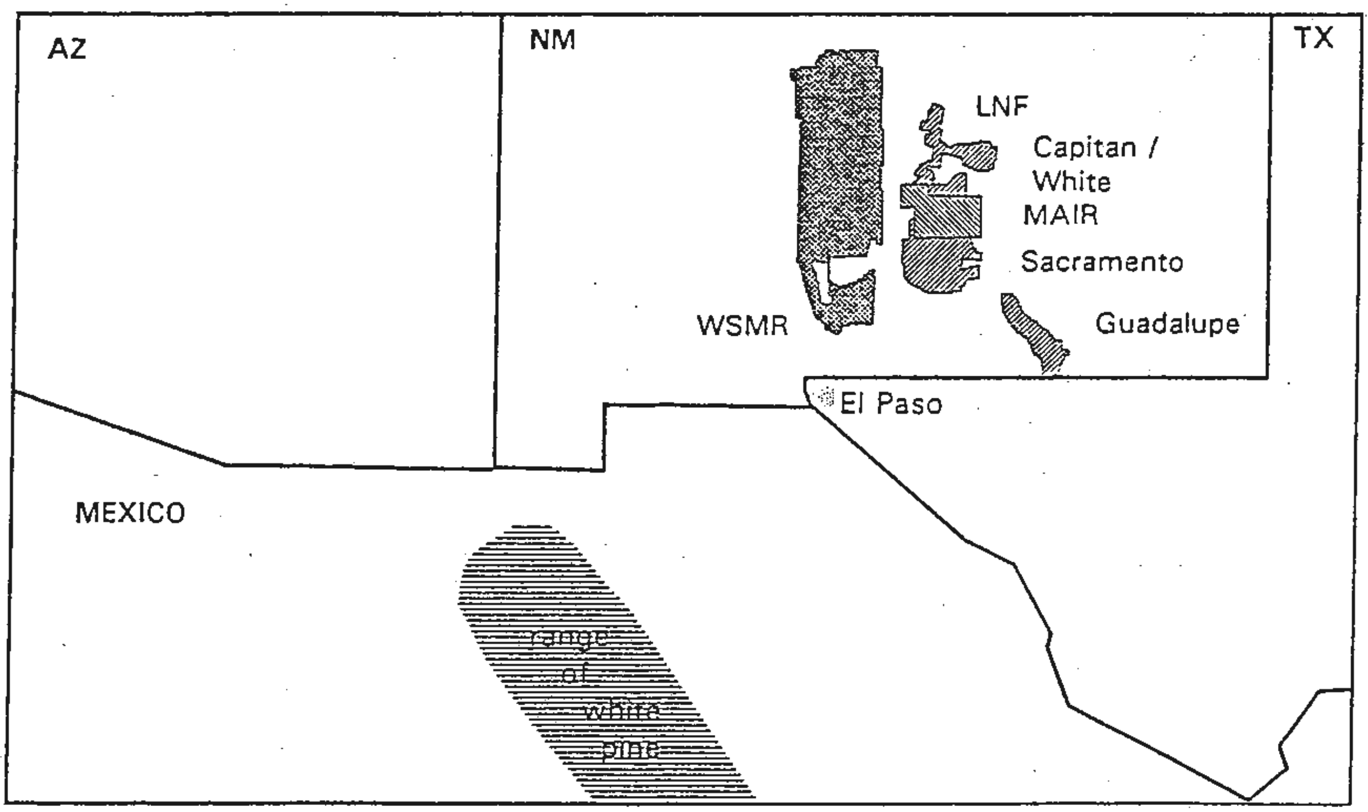

Fig. 1. Portions of the southwestern United States and adjacent northern Mexico illustrating the location of the Lincoln National Forest (LNF), Mescalero Apache Indian Reservation (MAIR), and White Sands Missile Range (WSMR). The Capitan, White, Sacramento, and Guadalupe Mountains; city of El Paso, TX; and range of white pine in northern Mexico are also shown.

It is unknown whether the introduction resulted from transplanting infected seedlings or from long-distance aerial dispersal of spores. Southwestern white pine seedlings raised in an Idaho nursery had been used for planting stock. However, this nursery was thought to be south of the range of blister rust in Idaho, and some rust cankers appear to be older than the plantations established with these seedlings. Alternatively, infected white pine trees or currant bushes (*Ribes* spp.) may have been imported for landscaping. Although the nearest known populations of rust-infected white pine are 800 km north (southern Wyoming, collected by Geils: Forest Pathology Herbarium, Fort Collins #6804C) and 1100 km west (southern California, reported by Kliejunas 1985), these distances might have been bridged by transport of thick-walled, pigmented aeciospores or by successive jumps of repeating urediniospores. (Intermediate populations have not been located and could be mistaken for *Cronartium occidentale* which alternates between *Ribes* and pinyons, see Hedgcock and others 1918.) Spread of blister rust to other disjunct pine populations over long distances has been reported recently (Draper and Walla 1993; Lundquist and Geils 1992).

POTENTIAL IMPACTS

Because risk is high that this outbreak will cause serious ecological and economic impacts, forest managers are concerned over its ultimate extent and severity (Forest Service 1993). Although the current Lincoln National Forest Plan does not specifically mention white pine blister rust, there is general direction to "conduct evaluations designed to develop alternatives to prevent or reduce damage to acceptable levels". The existence of this outbreak raises considerable uncertainty about the adequacy of present management plans.

Until now, the easily observed results of this outbreak have been restricted to a few locations of flagging in large trees and mortality in saplings. But, host and climatic conditions in the Sacramento Mountains are favorable for development of an epidemic. Both southwestern white pine and *Ribes* are common and well-distributed throughout the area (Alexander and others 1984, Martin and Hutchins 1980). Seedlings of southwestern white pine are very susceptible to infection and canker formation (Hoff and others 1980). Several local species of *Ribes* produce large leaves and bushes and support abundant telial production (Hawksworth and Conklin 1990; Geils and Popp, unpublished observations based on telia identification given by Miller 1967). Finally, humid July and August weather typical of southwestern mountains (DeMastus 1976) is especially favorable for rust intensification (Kimmey and Wagener 1961). With concurrence of pathogen, susceptible hosts, and favorable environment, further expansion and intensification of this outbreak is expected. We cannot as yet, however, predict how fast the outbreak will develop or what will be its final proportions.

An extensive and severe outbreak of blister rust in the Sacramento Mountains would seriously impact the forest. Southwestern white pine is a significant component in mixed conifer stands; it is a vital biodiversity component, has high aesthetic value, and when utilized as a product results in high quality timber. The large cones and seeds of white pine trees are vital to several species of wildlife (for example, Tomback 1977; also see Tomback and Linhart 1990). Southwestern white pine is important for its good regeneration and rapid growth that quickly closes forest canopy gaps caused by natural mortality or selective cutting. Because southwestern white pine is rarely attacked by insects and pathogens that are prevalent on other tree species, the presence of healthy southwestern white pine reduces the overall impact of forest pests. The cumulative effects of near elimination of southwestern white pine from the Sacramento Mountains could be detrimental to management objectives for timber production, fire protection, and maintenance of habitat for Threatened and Endangered Species.

The outbreak also could have effects that go beyond the Sacramento Mountains. With a greatly expanded rust population, there would be an opportunity for the rust to improve its epidemiological fitness (McDonald and Andrews 1982). Not only could a new strain develop that would be even better adapted to Southwestern hosts and weather, but that strain might also be able to overcome resistance mechanisms selected in breeding programs for economically important white pines in other regions (see McDonald and others 1984). From a large outbreak in the Sacramento Mountains, the rust would be more likely to spread to the white pine forests of northern Mexico (Eguiluz-Piedra 1991, Shaw and others 1993).

RESEARCH AND MANAGEMENT NEEDS

The blister rust outbreak on southwestern white pine has the potential for causing serious losses; but we currently do not have adequate information to predict the extent, severity, and effects of this outbreak. There are numerous cultural and genetic practices that could be used to reduce impacts from the outbreak (Hagle and others 1989, McDonald 1979, also see Leaphart and Wicker 1968), but their utility or need in this outbreak is unknown. Therefore, research and cooperative studies should be undertaken to assess the rust outbreak from ecological, genetic, and economic perspectives and to evaluate options for the mitigation of adverse impacts. Three perspectives are required to address the principal management issues in the affected forests: biodiversity, general forest health, and forest products (see Haack and Byler 1993). The ultimate products of the proposed studies are: 1) a site-specific rust hazard model; 2) an ecological effects assessment; 3) a genetic evaluation; and 4) an economic analysis.

Site-specific Rust Hazard Model

McDonald and others (1990) describe the proposed rust hazard model as an integrated set of computer simulation models for weather, epidemiology, and forest growth that operate in a spatial context. Outputs of this model include maps of expected distribution and incidence of blister rust on southwestern white pine after the outbreak has stabilized (see Holling 1973 on ecological resilience; at least 10 years will be required before rust intensity reaches equilibrium). Maps would have a spatial resolution of 100 m and a maximum geographic coverage of one-half degrees latitude and longitude. Although results from model runs could be displayed as hard-copy color maps, outputs would more commonly be generated as data files for a geographic information system (GIS). These files could be used in forest and project planning to determine expected levels of damage and benefits of alternative suppression efforts.

The Lincoln National Forest and the Mescalero Apache Indian Reservation already possess information on landform and tree distribution in GIS databases. A weather simulator has been developed for the nearby White Sands Missile Range (WSMR) and could be modified to fit the complex topography of a forested mountain range (R. Cionco, WSMR, personal communication). A model for the epidemiology of blister rust on western white pine in Idaho has been formulated by McDonald and others (1981). Elements of this model are being integrated with the Forest Vegetation Simulator (FVR) to construct a rust damage model suitable for use in the Pacific and Northwest United States (B. Eav, Methods Application Group, personal communication). A series of plots in young plantations of southwestern white pine have been established to follow early rust development (Hawksworth and Conklin 1990).

McDonald's original model could also be revised and calibrated for new, expanding outbreaks in the Southwest (as well as southern California and Northern Region whitebark pine forests) Edminster and others (1991) have developed a forest growth model for mixed conifer stands in the Southwest and relationships from this model have been adapted for the FVR. A prototype, spatial hazard model with weather, epidemiology, and tree growth has been programmed by Tom Rice (Intermountain Station, personal communication). Completion of a rust hazard model for the Sacramento Mountains would require additional development and integration of sub-models, local calibration, and independent validation.

Ecological Effects Assessment

The ecological effects assessment provides information on the environmental consequences of an outbreak of the extent and severity projected by the hazard model. This assessment requires an understanding of forest disturbance and recovery pathways at appropriate spatial scales. For example, at a forest scale, Baker and others (1991) describe a model for examining how large-scale disturbances related to climate change could affect landscape patterns. At a stand level, Marsden and others (1993) illustrate how a yield simulation program can project the synergistic effects of root disease and mistletoe on volume increment. At a patch scale, Lundquist (1993) demonstrates how canopy-gap characteristics and spatial statistics can provide useful information on the interactions and effects of disturbance agents.

The ecological assessment describes how direct and indirect impacts affect ecosystem processes, disturbance regimes, successional trends, landscape patterns, forest structure and composition. Although direct and indirect effects of a rust epidemic cannot be quantified at this time, many likely effects can be identified and quantified with techniques being developed in related studies. Direct effects are those associated with disease progression on individual trees -- sporulation, flagging, topkill, cone crop failure, growth loss, and death. Indirect effects are cumulative and secondary results of tree damage; for example, reduced seed production leads to decreases in the population of red squirrel because of loss of an important food resource. Because indirect effects involve subtle and complex interactions, they cannot be attributed to single factors and should be evaluated as part of a "disturbance pathway" (Lundquist and others 1993). For example, dwarf mistletoes (*Arceuthobium* spp.) tend to be host-specific (each conifer species has its own primary mistletoe species); and spread is slower in stands of mixed species. Therefore, loss of southwestern white pine (caused by blister rust) could increase losses in other species from mistletoe (because intensification is more rapid). Lundquist and others (1993) are currently developing methods to evaluate ecological effects of pests in the Sacramento Mountains with particular focus on disturbance-caused impacts to the Mexican Spotted Owl. These methods have already been implemented on two plots where additional data were collected for southwestern white pine and blister rust.

Genetic Evaluation

Additional studies on the genetics of the blister rust-white pine pathosystem would provide research with an evolutionary perspective and management with an evaluation of expected gain from resistance breeding (Bingham and Gremmen 1971). These studies relate to epidemiology and therefore support work with the hazard model and ecological assessment. Tree improvement programs in other Regions exist for western white pine and sugar pine (Hoff and McDonald 1980, Kinloch and Dulitz 1990). Experience from these programs and knowledge of the importance of quantifying rust hazard (McDonald and Hoff 1982) are useful for efforts already begun by the Southwestern Region to identify resistant trees.

Economic Analysis

Economic analysis for the projected outbreak would identify investment costs and social benefits of alternative management policies and additional research. A similar analysis has been completed for fusiform rust on southern pines (T. Holmes, Southeast Station, personal communication). That project, however, focuses on costs of genetic improvement and dollar returns from increased wood products. The economic analysis of the white pine blister rust outbreak requires additional consideration of non-market values for biodiversity and forest health. Economic analysis methods are also needed to determine the circumstances under which various disease control measures (thinning, pruning, sanitation, and species conversion) should be implemented.

AN ACTION PLAN

The work described above is a comprehensive proposal that requires a series of cooperative projects to be completed over many years. At this initial stage, research should focus on developing assessment methods and monitoring the extent, severity, and effects of the outbreak. Before the opportunity is lost, priority should be given to reconstructing the establishment phase of the outbreak and to characterizing baseline ecological conditions. Because the rust hazard model and ecological assessment will require several years to complete and are fundamental to other studies, these projects should also be given high priority. Likewise, those genetics-epidemiology studies that are needed for the ecological assessment and the hazard model should be started soon. Economics studies to develop or refine methods need not be delayed, but completion of the analysis will require information from the other studies. Other efforts such as identifying candidate selections for genetic improvement programs would also be done more effectively after hazard modeling techniques are developed and resistant trees can be distinguished from "disease escapes" (McDonald and Hoff 1982).

Site-specific Rust Hazard Model

The rust hazard model requires three tasks: integrating the sub-models, adapting a weather simulator, and calibrating/validating the epidemiology and forest growth sub-models. Model framework development is a current project of McDonald and Rice at the Intermountain Station. They are integrating weather, epidemiology, and tree growth sub-models to simulate disease progress over a 50-year period in 100 m quadrats with conditions typical for northern Idaho. This prototype uses a raster spatial data management and analysis program (IDRISI, Eastman 1992). After their conceptual model is completed about 1995, additional computer programming would be required to construct a shell program that interfaces weather, epidemiology,and forest growth models for the Sacramento Mountains with the appropriate GIS/computer platform. Forestwide estimates of outbreak progress would be generated by simultaneous projection of numerous 100 m quadrats with site-specific meteorological and forest inventory data. A cooperative proposal with the Army Research Laboratory, White Sands Missile Range (Cionco 1993) has been submitted to adapt and verify a 100 m resolution weather simulator to the Sacramento Mountains.

The epidemiology and forest growth models also would require calibration and verification. Studies to accomplish these two tasks are identified as: 1) host distribution analysis, 2) rust distribution surveillance, 3) phenological observations, 4) rust intensification plots, 5) incidence monitoring network, and 6) stem-foliage allometry study. The scope and possible participants in these studies are briefly described below:

1) The host distribution analysis uses currently available forest inventory data and habitat information to map the expected location and stocking of southwestern white pine and *Ribes* on the Cloudcroft and Mayhill Districts of the Lincoln National Forest and Mescalero Apache Indian Reservation. This work would be cooperative between the Forest and Station and the Reservation and Station. Results of this work would be useful in immediately preparing a biological evaluation describing a "worse-case scenario" based on current data and judgement. Information on host distribution is also needed to effectively plan other studies.

2) Surveillance in forests of the Southwestern Region should be undertaken to discover the extent of the rust and to locate the likely source(s) of the original introduction. This work would be predominately a Forest-Reservation-Region project with Station participation. Examination of mesic forests in northern Mexico should also be completed to obtain a preliminary assessment of rust hazard. This work would be an international effort of the Station with cooperators from Mexico and possibly with participation of the Region.

3) Phenological observations are made to determine occurrence and frequency of sporulation, correlation with on-site meteorological conditions, and relative importance of various *Ribes* species for inoculum production. Biological data are collected on the same plots established to monitor rust intensification; meteorological data are taken at two or

more sites. This would be a Station study with assistance from the Forest, Sunspot National Solar Observatory, and Apache Peak Observatory.

4) To track rust intensification and effects on individual southwestern white pine trees, a series of 5 to 15 fixed-area plots of 1 to 3 ha would be established and remeasured periodically. Sufficient data would be collected on these plots to quantify disease incidence, *Ribes* abundance, and tree growth and mortality. These plots could be incorporated into the Pest Trend Impact Plot System as a Regional project with Station assistance.

5) An incidence monitoring network should be established to trace the spread and intensification of blister rust across the Sacramento Mountains. This network would consist of 100 to 200 monumented stations, remeasured periodically to monitor the percent of southwestern white pine cankered by blister rust. This project could be a Forest, Reservation, and Region effort with assistance from the Station in network design and data analysis. This network could be part of the Forest's inventory system for monitoring forest ecosystem health.

6) A stem-foliage allometry study would be conducted to correlate the distribution and abundance of live needles to various crown and stem variables such as tree age, diameter, and height. This relationship is required to estimate the rust index for an individual tree (cumulative number of cankers per year per unit of foliage) based on number of cankers and standard inventory descriptors of tree size. This study would be primarily a Station effort with field and laboratory assistance from the Region, Forest, or Reservation.

Ecological Effects Assessment

Initial work for the ecological assessment in terms of both method development and data collection could be accomplished with support to the disturbance ecology study of Lundquist and others (1993). As planned (but not yet fully funded), this study would include detailed analysis of twenty 4-ha plots. Data collected includes a canopy density map, an inventory of live trees, snags, and logs, an identification of the causes and interactions of mortality agents, and a survey of small mammal distribution. Disturbance plots and rust intensification plots can be coincident and share common data. Analysis will examine distribution patterns for gaps, trees, snags, and logs and relate those patterns to associations of mortality agents and subsequent effects on wildlife habitat. Study design and analysis are primarily Station responsibilities, but Region, Forest, and Reservation participation would be helpful.

Genetic Evaluation

Population studies should begin with additional investigations of genetic variation in *C. ribicola* and *P. strobiformis*. An epidemiological laboratory study (Bega 1960) should determine germination and growth characteristics of the rust population from the Sacramento Mountains. These characteristics would be compared to those of populations from other areas such as Idaho and California and would be used to calibrate the epidemiological simulator of the hazard model. This work could be performed as either a graduate study or sabbatical project.

Another study should be initiated to examine the genetic diversity of rust populations (Hoff and McDonald 1993) across North America with particular attention to isolated populations and using molecular techniques with either isozyme or DNA markers (Vogler and others 1992). This study could help establish the origin of the outbreak and address the general question of whether this outbreak is the result of circumstances particular to the Sacramento Mountains or the inevitable "naturalization" of the fungus. The study could be a collaborative effort supported by the National Science Foundation or the USDA Competitive Grants Program and involve participation of the University of California, Berkeley for analysis and numerous other pathologists for collecting samples. Variability in host resistance for selections representing the geographic range of southwestern white pine should be investigated by screening seedlings at an appropriate testing center with extreme care taken to prevent spread of novel strains to new areas.

Economic Analysis

Inputs to the economic analysis are required from the hazard model, ecological assessment, and genetic evaluation, but work can proceed on developing methods appropriate to analyses for non-market studies such as would be needed for the rust outbreak in the Sacramento Mountains. This work could be a cooperative project involving the Rocky Mountain and Southeast Stations.

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MONITORING BLISTER RUST INFECTION IN RUST-RESISTANT WESTERN WHITE PINE PLANTATIONS IN NORTHERN IDAHO

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Although rust-resistant western white pine have been operationally planted in northern Idaho for over ten years, monitoring of blister rust infection in plantations has not been conducted until recently (Bingham 1983, Hagle and others 1989). Potlatch Corporation was the first to initiate a monitoring effort in 1987. In 1992 Potlatch remeasured 21 plantations that were first sampled in 1987 and conducted initial surveys of 15 additional plantations. Since 1987 Potlatch has surveyed over 120 western white pine plantations. In 1991 the USDA Forest Service and Idaho Department of Lands initiated small-scale monitoring projects. So far these agencies have surveyed 16 plantations; seven Forest Service and nine State plantations.

METHODS

The methods used to sample plantations have varied but much of the tree data collected has been similar. Potlatch has been monitoring plantations planted with wild stock and with rust-resistant stock from the Moscow Seed Orchard (F_2 stock). Potlatch has used temporary 1/100 acre circular plots spaced at five chain intervals. In plantations larger than 25 acres one plot was established for each 2.5 acres of the plantation. In smaller plantations a minimum of ten plots were established. Tree data recorded included species, status (live or dead), infection status, origin (planted or natural), seed source, vigor, height, dbh, and age (for naturals only). Ribes bushes were tallied on the north half of each 1/100 acre plot. Plantations are sampled again at five year intervals.

The Idaho Department of Lands and Forest Service decided to establish permanent plots that allow the same trees to be monitored over time. They have only monitored plantations planted with F_1 (Sandpoint Seed Orchard) or F_2 (Moscow Seed Orchard) rust-resistant stock. Their sampling design consisted of establishing 1/20 acre circular plots along line transects at two to four chain intervals in young plantations (3-9 years old). The distance between line transects was one to four chains. Each plot center was indicated with a metal or wood stake. A minimum of 100 western white pine were sampled in each plantation whenever possible. Tree data collected included species, status (live or dead), infection status, origin (planted or natural), height, and age (all trees). Ribes bushes were tallied on each 1/20 acre plot in State plantations. In Forest Service plantations Ribes counts were made in 1/300 acre circular plots nested at the center of each 1/20 acre plot. To save time, planted seedlings were not tagged with numbers in 1991-92, but were measured in a clockwise direction starting with the tree nearest the plot center and a due north azimuth bearing. However, State plantations were revisited in 1993, seedlings were tagged with metal numbered tags, the number of blister rust infections were counted, and the percentage of stem girdled was recorded for live cankers. Additional plots were established in two State plantations in 1993 (East Side 1 and 6) in order to sample at least 100 white pine. Plantations will be revisited again at three to five year intervals.

A second sampling design was used in 1992 in four State plantations that appeared to have areas with high rust infection. In these plantations strip transects of various sizes were run through the areas with high infection. The same tree data was collected as for the circular 1/20 acre plots. In 1993 these strip transects were revisited, trees were tagged, cankers counted and percentage of stem girdled recorded for living rust cankers. However, the areas sampled in 1993 were slightly smaller than in 1992. These strip transects will be revisited at 3 year intervals.

RESULTS

Eleven of the 15 plantations surveyed for the first time in 1992 by Potlatch had less than 10 percent blister rust infection, three plantations had between 10 and 20 percent infection and one plantation had just over 30 percent infection (Table 1). Nine of the 15 plantations were located in very high or high rust hazard sites (more than 1000 or 100 bushes/acre, respectively, Hagle and others 1989) based on Ribes counts within the plantation boundaries. Rust infection was not closely correlated with Ribes densities, except that the four plantations with the highest rust infection were in very high or high rust hazard sites. There was one plantation in a very high rust hazard site and four plantations in high rust hazard sites that had less than 10 percent rust infection. Two plantations where surveys did not detect Ribes bushes still had some rust infection (Corbett and Bear Creek), although infection was very low in both plantations.

Some of Potlatch's most interesting results are from the plantations they surveyed for the second time in 1992. In nine plantations with unimproved wild stock, initial rust infection averaged 20 percent in 1987, but increased to an average of 86 percent in 1992 (Table 2). In eight plantations with Moscow stock rust infection averaged five percent in 1987 and increased to an average of 23 percent in 1992. Three of the plantations with rust-resistant stock had over 30 percent infection and one had over 50 percent infection in 1992. Two of these plantations were in high rust hazard sites, but the other two were in low or moderate rust hazard sites based on Ribes counts.

Four plantations Potlatch remeasured in 1992 had both Moscow and wild stock planted within their boundaries. Each seed source was accurately mapped as to planting location. In the wild stock blocks rust infection was very high, increasing from an average of 48 percent infection in 1987 to 96 percent in 1992 (Table 3). Rust related mortality was high in these blocks also (greater than 50 percent). In contrast, rust infection in the Moscow blocks averaged 13 percent in 1987 and increased to 43 percent in 1992. Mortality rates from rust infection were much lower in the rust-resistant stock and many healed cankers and non-lethal branch cankers were observed on these trees as well. The highest infection rate for the Moscow stock was 58 percent, but infection of the wild stock in this plantation was 92 percent. Two of these four plantations were in very high rust hazard sites, one was in a high rust hazard site, and one was in a moderate rust hazard site based on Ribes counts (Table 3).

In 1992 seven of the 14 F_2 plantations sampled by State and Forest Service personnel had less than five percent rust infection including two State plantations with no rust infection (Table 4). Five other F_2 plantations had between 25 and 36 percent infection and two had over 40 percent rust infection. Only two F_1 plantations were surveyed, but they both had over 50 percent infection. The F_1 plantations were only four years old.

In 1992 mortality in the State and Forest Service plantations ranged from none in seven plantations to just over 20 percent in three plantations. Mortality in the remaining six plantations varied from seven to 16 percent (Table 4).

Rust hazard based on Ribes counts within plantations was very low or low for most of the State and Forest Service plantations with no rust infection or less than five percent infection (Table 4). Two plantations had low levels of rust infection but occurred on high rust hazard sites. Nine plantations (F_1 and F_2) with more than 20 percent infection had rust hazards rated as high or very high.

In 1993 rust infection increased slightly in the nine State plantations (Table 5). Many of the additional plots established in East Side 1 and East Side 6 had several infected trees. This accounts for the increased level of infection detected in these plantations. Mortality increased in several of the State plantations as well.

Rust infection in the four State plantations sampled with strip transects in 1992 ranged from 45 to 55 percent (Table 6). These transects were purposely placed in areas where high levels of rust infection were observed. Ribes densities in these transects were higher than estimates based on Ribes counts in the circular 1/20 acre plots systematically spaced in the plantations. However, the rust hazard rating based on both sampling methods was high for each of these plantations. Mortality in the strip transects ranged from 26 to 36 percent. These plantations were only 6 years old.

When the strip transects were revisited in 1993 not as many trees were sampled. Therefore, results from 1993 are not directly comparable with those in 1992. The trees measured in 1993 were tagged so that they can be remeasured. Infection and mortality levels in the 1993 sample were even higher than for 1992 (Table 7). Infection ranged from 45 to 59 percent and mortality varied from 30 to 49 percent. There were several trees within the strips that had died since 1992 from blister rust infection.

DISCUSSION

So what can we conclude from these monitoring efforts? In most of the plantations sampled, rust-resistant western white pine from the Moscow Seed Orchard are performing quite well. However, several plantations with Moscow stock are experiencing rust infection levels higher than would be expected (Goddard and others 1985) in less than 15 years after their establishment. The reasons for these high levels of rust infection are not yet clear, but there are several possibilities.

One possibility is that the plantations with high rust infection have already been exposed to one or more "wave years" where environmental conditions were highly favorable for rust infection. Nearly all of the plantations with high rust infection (greater than 30 percent) were in very high or high rust hazard sites based on <u>Ribes</u> counts. Therefore, there were a large quantity of rust spores present to cause infection when environmental conditions were favorable in these sites. During the "wave years" susceptible individuals are infected and it appears that the 35-40 percent infection levels predicted for Moscow stock (Bingham 1983) are being surpassed in some plantations. However, not all of these infected trees will necessarily die as a result of rust infection. Resistance mechanisms such as slow fungus growth (Hoff and McDonald 1980, Hoff 1984) may be activated and result in lower mortality rates than rust infection levels could indicate. However, when rust infection occurs early in the life of a plantation, many rust infections occur on the main stem and can girdle a small sapling very rapidly (McDonald 1979). In these cases, the slow fungus growth resistance mechanism may not have as good a chance to improve the survival of infected trees. This might explain why we found higher mortality rates in the State and Forest Service plantations that evidently were exposed to a "wave year" when they were very young. Potlatch plantations that evidently weren't exposed to a "wave year" until they were slightly older had much lower mortality levels. It will be interesting to follow the progress of rust-infected trees over time and see how many survive. Evidently the F_2 stock from the Moscow seed orchard has a small percentage of its resistance based on the slow fungus growth mechanism (personal communication with Geral McDonald, 1993).

The environmental factors influencing rust infection in some of the plantations with high rust infection is another set of variables that should be considered. If environmental conditions conducive to rust infection are commonly present at specific sites, then perhaps these sites experience "wave years" more frequently than would normally be expected. Sites with high densities of Ribes and where exceptionally moist conditions prevail throughout the late summer and fall may be possible examples of where these conditions might exist. Perhaps trees exposed to several consecutive "wave years" are not as capable of resisting infection.

The worst case scenario would be that more virulent races of the rust are present in northern Idaho. These races may be able to overcome some of the resistance mechanisms incorporated into the Moscow stock. Since a large percentage of the resistance in the Moscow stock is based on the premature shedding of infected secondary needles (approximately 70 percent), perhaps this mechanism is being overcome in some plantations. At present there is no conclusive evidence that this is the case. However, this possibility should not be overlooked because the occurrence of races of blister rust that can overcome the resistance mechanisms incorporated into the Moscow stock have already been reported elsewhere (McDonald and others 1984, Hunt and Meagher 1985).

Based on our results, and those of others working in British Columbia (Hunt and Meagher 1989), there does appear to be reason for concern about how well rust-resistant white pine from the Moscow Seed Orchard will perform in operational plantations over a long time period and in a wide range of geographic locations. This is particularly true for high rust hazard sites. Additional monitoring of rust-resistant western white pine plantations representing a wider range of rust hazard conditions and geographic locations is needed. Therefore, we are planning to expand our program and monitor the performance of additional plantations. We will continue to use permanent plots so that individual trees can be monitored over time. This will provide needed information on the survival of infected trees and how well resistance mechanisms that may prolong their life are succeeding. In addition, we will concentrate on young plantations, preferably less than 5 years old, so origin (planted or natural), infection and mortality can be more accurately documented over time.

Although we have found some plantations of rust-resistant stock with higher than expected levels of rust infection, the "jury is still out" on the performance of this stock. For now it is evident that rust-resistant stock is performing much better than wild stock on a short-term basis. But we need to evaluate operational plantings of all rust-resistant stock to determine how well they perform under a wide range of natural conditions over a long period of time. In addition, programs to breed white pine with a wide range of resistance mechanisms, both vertical and horizontal (McDonald 1979), are continuing.

ADDENDUM
December, 1993

Based on an intensive analysis of field data from the State plantations near Priest Lake (East Side 1-6) Geral McDonald concluded that there was a high probability that wild type western white pine stock was present in these plantations (see his paper in these proceedings). Upon further "detective work" in November utilizing techniques advocated by the late Sherlock Holmes, we discovered that two stock types had been used in the Priest Lake plantations and that one of the stock types was indeed wild stock. Therefore, the high rust infection found in these plantations can now be accounted for based on this new information. The wild stock was intermixed in the plantations and unfortunately there is no practical conclusive means of separating them from the rust-resistant stock planted there.

Idaho Department of Land's records indicate that State personnel thought the wild stock was actually rust-resistant stock from the Moscow Arboretum. It is not yet clear how this confusion developed, but our investigations are continuing. Scotland Yard and the FBI have not been brought into the case because it is not clear whether there was just some poor communication between State personnel and the contractors who sold the State the western white pine seedlings or a deliberate misrepresentation of the stock. Perhaps this delicate matter will never be resolved completely, but at least we now know the reason for the high level of rust infection in the State plantations near Priest Lake. Where is Sherlock when we really need him?

This incident clearly points to the need for keeping very accurate records as seed lots change hands between Federal or State agencies and private companies. It also indicates that research on the epidemiology of white pine blister rust is reaching the point where results can be used to evaluate the genetic background of different stock types (again see Geral McDonald's paper in these proceedings).

Although the high level of rust infection found in the State plantations near Priest Lake can now be explained, our monitoring effort has identified other rust-resistant western white pine plantations with relatively high levels of rust infection (see Tables 1-4). Therefore, we are still concerned about the long term performance of rust-resistant western white pine from the Moscow Arboretum and will continue our monitoring effort.

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Table 1. White pine blister rust infection and mortality in Potlatch Corporation rust-resistant white pine plantations sampled for the first time in 1992. Plantations were 5 years old and F_2 stock.

Plantation	TPA[1]	% Infected[2]	% Dead	Rust Hazard[3]
View Point	393	1.0	0	Low
Bear Creek	410	2.4	0	Very Low
Cedar Creek	439	2.7	0	Moderate
Walkers Park	370	3.2	0	Moderate
Corbett	480	4.2	0	Very Low
Ruby Creek	465	4.7	0	High
Grouse Creek	433	5.3	1	High
Eagle Creek	499	5.6	0	High
Mesa	217	7.8	0	Very High
Bald Mtn.	143	8.4	0	High
Cornwall Pt.	210	9.5	0	Moderate
Little Beaver	350	11.4	0	Very High
Rhodes	357	14.0	0	Very High
Ashenfeller	394	17.0	3	High
Martin Cook	285	30.8	3	Very High

[1] - Trees per acre.

[2] - Live and dead trees combined.

[3] - Based on Ribes bushes per acre within plantations.

Table 2. White pine blister rust infection and mortality in Potlatch Corporation white pine plantations remeasured in 1992.

Plantation	Age[1]	Stock Type[2]	% Infection 1987	% Infection 1992	% Dead 1987	% Dead 1992	Rust Hazard[3]
Camp 6-H	11	F_2	1	6	0	0	Very Low
Camp 6-S	11	F_2	1	7	0	0	Low
Bingo S	13	F_2	0	16	0	0	Very Low
Butte Cr.	13	F_2	1	20	0	1	Moderate
Cedar Cr.	13	F_2	10	31	1	6	Moderate
Isabella	10	F_2	15	36	2	13	High
Potato H	13	F_2	11	39	0	5	Low
NW Bertha	13	F_2	6	55	0	0	High
Chip S	10	W	2	46	0	0	Low
Round M	11	W	1	63	0	4	Very Low
Breakfast	11	W	0	64	0	9	Low
Tired Wolf	11	W	2	88	0	13	High
Bear Line	10	W	25	91	0	31	Very Low
Orogrande	15	W	63	94	6	36	High
Scaler	10	W	24	95	2	31	Very Low
Orogrande 2	15	W	64	95	2	62	Very High
Mary Mix	11	W	57	100	4	56	High

[1] - Plantation age.

[2] - W: Wild type; F_2: Second generation rust-resistant stock grown from seed produced at the Moscow arboretum.

[3] - Based on Ribes bushes per acre within the plantation.

Table 3. White pine blister rust infection and mortality in Potlatch Corporation white pine plantations planted with both wild type and rust-resistant white pine and remeasured in 1992.

Plantation	Age[1]	Stock Type[2]	% Infection 1987	% Infection 1992	% Dead 1987	% Dead 1992	Rust Hazard[3]
Robinson	13	F_2	4	36	4	8	Very High
		W	14	95	7	36	
Camp 43	11	F_2	9	46	6	12	Very High
		W	53	99	25	76	
Scofield	11	F_2	15	32	0	7	Moderate
		W	44	96	7	34	
French	11	F_2	25	58	3	16	High
		W	79	92	0	72	
Means		F_2	13	43	3	11	
		W	48	96	10	55	

[1] - Plantation age.

[2] - W: Wild type; F_2: Second generation rust-resistant stock grown from seed produced at the Moscow arboretum.

[3] - Based on Ribes bushes per acre within the plantation.

Table 4. White pine blister rust infection and mortality in Idaho State and Forest Service rust-resistant white pine plantations sampled in 1991-92.

Plantation	Age[1]	Trees Sampled	Stock Type	Percent Infection[2]	Percent Dead	Rust Hazard[3]
All The Way	7	101	F_2	0	0	Very Low
Paradise	7	169	F_2	0	0	Very Low
Halfway	9	132	F_2	1	0	Very Low
Varnum 11	3	99	F_2	1	0	High
Varnum 23-2	4	97	F_2	3	0	High
East Side 1	5	65	F_2	3	0	High
East Side 6	5	51	F_2	4	0	Low
East Side 5	6	209	F_2	25	14	High
Copper-G2	6	69	F_2	26	23	Very Hi
East Side 2	6	248	F_2	26	12	High
Copper-G21	9	161	F_2	32	14	High
East Side 4	6	302	F_2	36	21	High
East Side 3	6	206	F_2	40	23	High
Copper-G1	6	155	F_2	47	12	Very Hi
Varnum 23-1	4	108	F_1	51	16	Very Hi
Varnum 2	4	103	F_1	66	7	High

[1] - Plantation age.

[2] - Live and dead trees.

[3] - Based on Ribes bushes per acre within plantations.

Table 5. White pine blister rust infection and mortality in Idaho State rust-resistant white pine plantations remeasured in 1993.

Plantation	Trees Sampled	Percent Infection[1]	Percent Dead	Rust Hazard[2]
All The Way	99	1	0	Very Low
Paradise	112	1	0	Very Low
Halfway	132	2	0	Very Low
East Side 6	158	11	0	Moderate
East Side 1	111	43	27	High
East Side 5	213	28	19	High
East Side 2	251	31	16	High
East Side 4	306	41	30	High
East Side 3	206	46	33	High

[1] - Live and dead trees.

[2] - Based on Ribes bushes per acre within plantations.

Table 6. White pine blister rust infection and mortality in four Idaho State rust-resistant white pine plantations near Priest Lake, Idaho. Data from strip transects placed in areas with high rust infection in 1992.

Plantation	Trees Sampled	Percent Infected[1]	Percent Dead	Rust Hazard[2]
East Side 4	630	45	26	High
East Side 5	151	45	26	High
East Side 3	317	45	28	High
East Side 2	177	55	36	High

[1] - Live and dead trees.

[2] - Based on Ribes bushes per acre within strip transects.

Table 7. White pine blister rust infection and mortality in four Idaho State rust-resistant white pine plantations near Priest Lake, Idaho. Data from strip transects placed in areas with high rust infection in 1993.

Plantation	Trees Sampled	Percent Infected[1]	Percent Dead	Rust Hazard[2]
East Side 4	464	59	43	High
East Side 5	208	45	30	High
East Side 3	210	56	49	High
East Side 2	271	58	40	High

[1] - Live and dead trees.

[2] - Based on Ribes bushes per acre within strip transects.

MEASURING EARLY PERFORMANCE OF SECOND GENERATION RESISTANCE TO BLISTER RUST IN WESTERN WHITE PINE

Geral I. McDonald, Raymond J. Hoff, Thomas M. Rice, and Robert Mathiasen

Methods to analyze early performance of white pine populations resistant to blister rust were developed and equations (models) were calibrated using data from two test plantations. An associated height growth model was verified and a needle growth model was constructed (but not verified). These equations were used to program a rust index calculator that estimates canker accumulation rate or rust index of individual hosts and stands. Nonconformity of populations to the theoretical multiple infection transformation indexed the level of immunity in a resistant population of white pine. This was expressed as a measurable deviation factor attributable to a population. An equation combining calculations of rust index and deviation factor produced disease progress curves that describe population performance. Analysis of a commercial plantation composed of two lots of stock presumed to be resistant showed that a higher than expected level of infection was due to the fact that one of the presumed resistant lots was actually a mislabeled susceptible lot. Verification of seed-lot identity led to development of a method to separate mixed populations of susceptible and resistant white pine and to predict future performance of the mixed population.

Rust level for the year 2001 has been predicted for eight mixed populations. Accurate prediction will help establish the robustness of the foundation epidemiological theory. The newly developed methods can form the basis of a West-wide system of monitoring for appearance of new, more virulent races of blister rust. Other aspects of rust management such as breeding trees for rust resistance and integrated management can also benefit from these new methods.

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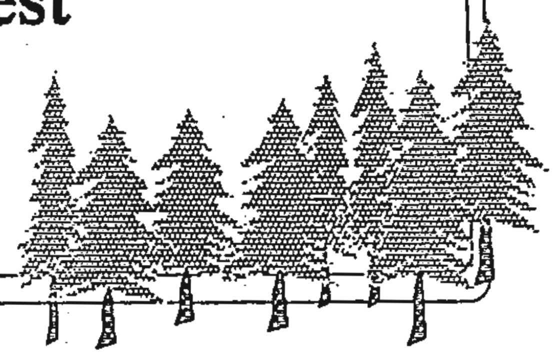
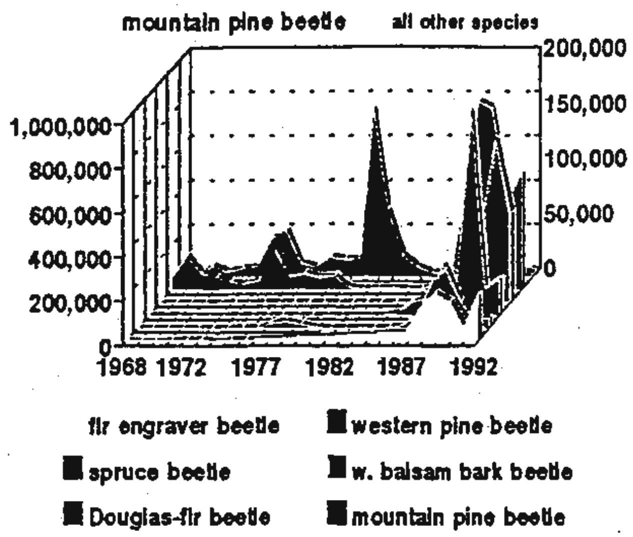


Trees Killed by Bark Beetles on
National Forests of Southern Idaho 1968 - 1992



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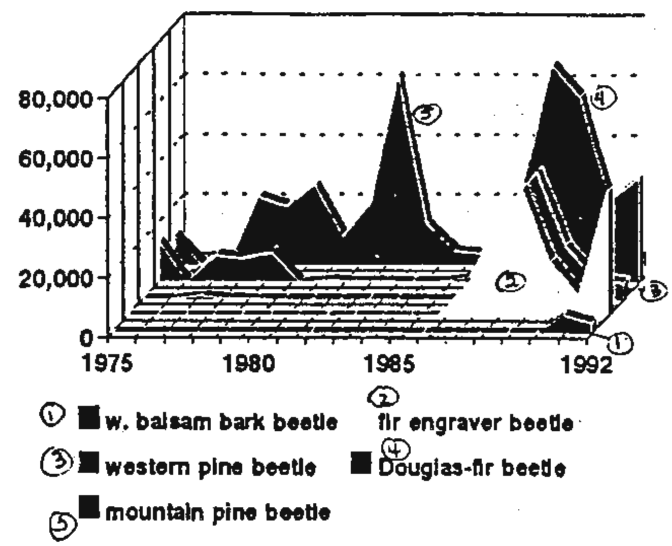
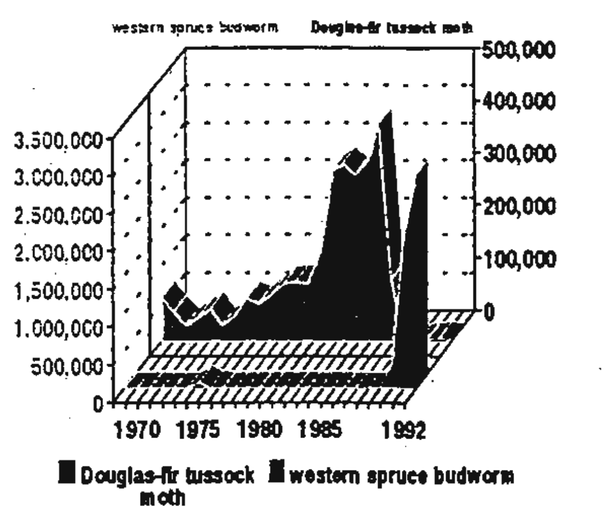


Acres Defoliated by
Western Spruce Budworm and Douglas-fir Tussock Moth
on National Forests of Southern Idaho 1968 - 1992



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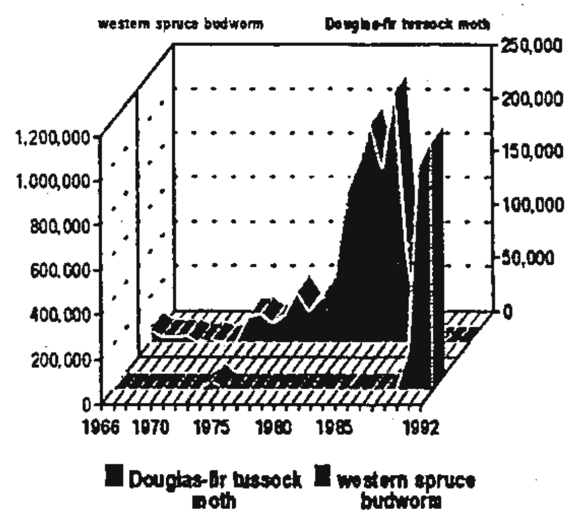
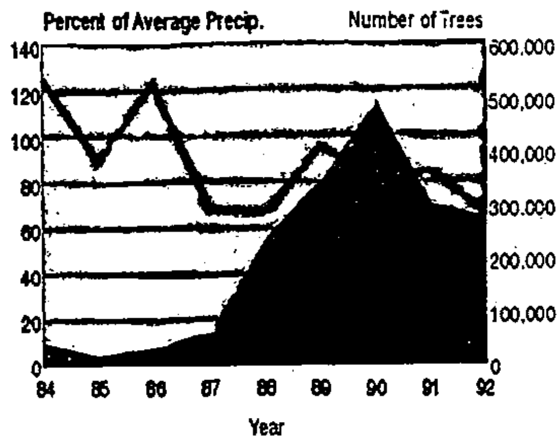
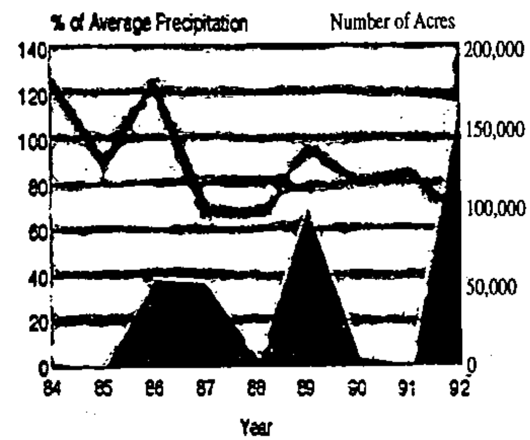


Trees Killed by Bark Beetles & Percent of Average Precipitation in Southern Idaho 1984 - 1992*



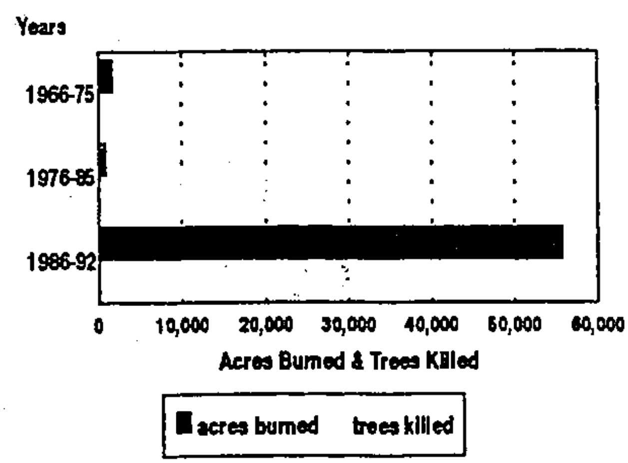
*1992 Precip. #'s estimated

Acres Burned & Percent of Average Precipitation on Boise National Forest 1984 - 1992*



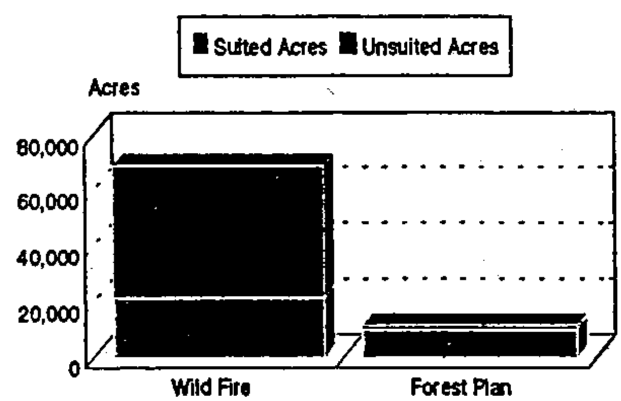
*1992 Precip. #'s estimated

Average Annual Acres Burned and Trees Killed* Boise National Forest 1966 - 1992



*Trees killed by bark beetles

Average Annual Acres Burned vs. Estimated Harvest Acres FY 90 - 92 Boise National Forest



"Departure" Through Wildfires

Forest Health Strategy

Boise National Forest

Boise National Forest Forest Health Strategy

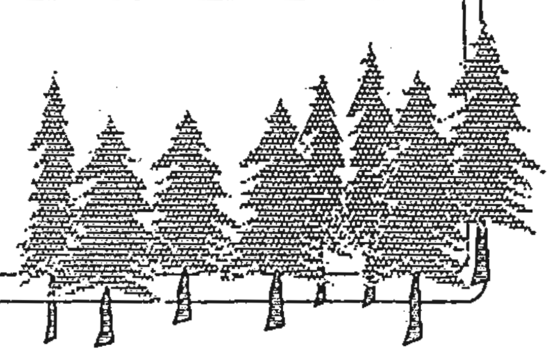
Forest Health is the top management challenge

The Boise National Forest has developed a three part strategy to deal with the Forest Health issue.

1. Salvage Dead and Dying trees to recover their economic value, reforest infested areas, and reduce wildfire risk.

2. Restore resilience, including thinning trees to reduce the number per acre, increasing the use of prescribed fire. Simulate nature with management activities.

3. Share our understanding of Forest health. Including studies, symposiums, public meetings. Currently participating in a Study with American Forests, FS Research, University of Idaho, Idaho Department of Lands, and Boise Cascade Corp.



Salvage
Dead and Dying Trees

Salvage volume:

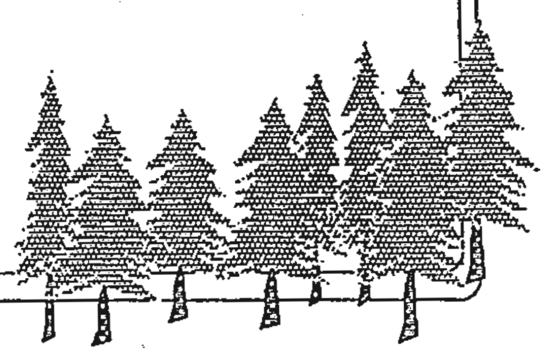
1991	32.0 MMBF
1992	85.0 MMBF
1993	183.5 MMBF
1994	26.0 MMBF
1995	15.0 MMBF
1996	10.0 MMBF

Reforest areas understocked as a result of insect mortality.

Reduce fuel loading to decrease risk of wildfires.

Bait trees, trap insects and remove trees to reduce insect populations.

Exempt sales from appeals.



Thin Green Stands

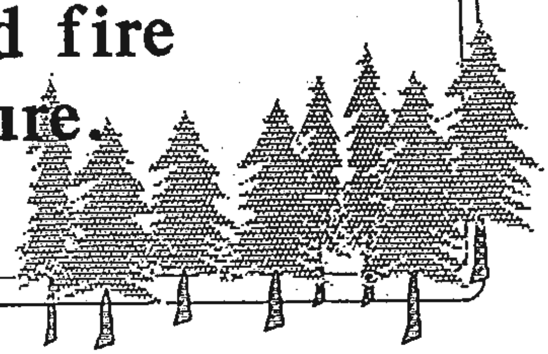
Density control is a major tool in reducing stress from drought.

Shift Species composition towards seral species (pines)

Precommercial thinning is needed.

Chase resilience, not volume, treatments are ecosystem based.

Use silviculture and fire to approximate nature.



Ecosystem Management

Deeply committed

Use Habitat types

Historic Range of Variability
- Species composition & density
- risk ratings and sediment

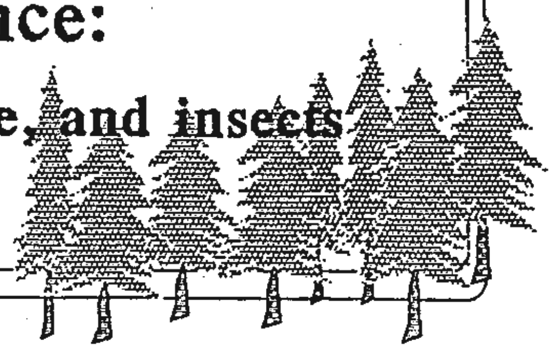
Landscape level management
- Landscape Patterns
- Successional stages
- Viable Pop. of Plants and animals

Long-term forest health problems

won't improve until we thin the forest

and improve its **Resilience:**

resistance to fire, disease, and insects



Partnerships to Improve Forest Health

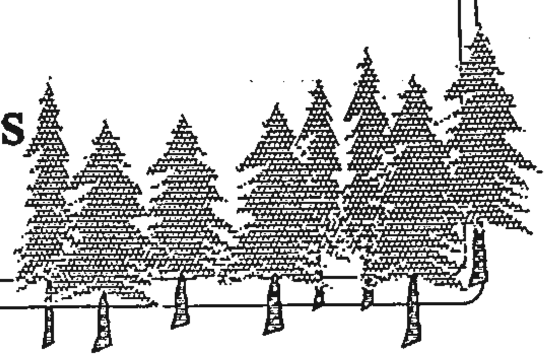
Partners in Forest Health

- American Forests
- University of Idaho
- State of Idaho
- Research Station
- Boise Cascade Corporation

To improve understanding of forest health, sponsor: Workshops, Policy Analysis, risk ratings, and symposiums.

Include:

- Research
- Universities
- Interested Groups
- Citizens



AXENIC CULTURE OF PINE STEM RUST FUNGI

James A. Walla
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Western Gall Rust

Western gall rust (*Peridermium harknessii* J.P. Moore) (WGR) damages pines in plantations and native stands in the northern Great Plains region of the United States and poses arguably the greatest disease threat to pines in agroforestry plantings of the future. As tree improvement activities progress, a narrower germplasm is being used for agroforestry trees. Individual seed sources of several tree species, including pines, are being identified for widespread planting. Because WGR is currently widespread in the Great Plains, significant damage is likely to occur if the pine seed sources selected for future plantings are highly susceptible to WGR. A greater understanding of WGR resistance is needed to avoid serious damage.

Several pine stem rust fungi, including WGR, have been grown in axenic culture (Pei, 1990). At North Dakota State University, work has been done with WGR axenic cultures in conjunction with ponderosa pine tissue culture in attempts to develop an *in vitro* disease resistance screening system. Maintenance of ponderosa pine callus tissue for the time periods needed was not achieved, so an *in vitro* screening system was not developed. However, once developed, axenic culture of WGR offered other opportunities and has been continued.

Growth of *P. harknessii* in axenic culture has been characterized (Lundquist et al, 1991). Two culture types develop; first an orange callus-like mycelium (OC) grows from pine gall explants and then a fluffy white mycelium (WM) develops from OC. The conversion from OC to WM in culture appears to be basically the same as the germination process in aeciospores. The OC type appears similar to aeciospores and the WM type appears to correspond to mycelium in the gall.

Axenic cultures could be useful to examine the nuclear cycle of the fungus; that is, is it "*Endocronartium*" or "*Peridermium*?" The nuclear condition of cells in axenic cultures has been observed in preliminary studies by using a DNA specific fluorescent stain. Nuclei in callus-like cells generally appear to be dikaryotic. Large diameter hyphae growing from callus-like cells and small diameter hyphae growing from large diameter hyphae appear to contain one nucleus per cell. Because the cell walls of the callus-like cells are thinner than those of spores, the axenic cultures may allow observation of how this fungus changes from a dikaryon to a monokaryon. Understanding of this mechanism is important to development of sustainable resistance to WGR.

Axenic culture may allow artificial crosses between isolates. One difficulty in resistance studies with WGR is that in order to understand virulence, crosses between isolates need to be made. However, there is no known crossing in WGR. In preliminary studies, blocks of mycelium were paired on media. There was considerable variation in growth of the isolates toward each other, ranging from no growth toward each other to normal growth together to form a common colony. These differences could be due to differences in compatibility between the isolates. Before further work was done, a more diverse culture collection was needed and characterization of the isolates was needed so the results of crosses could be assessed. About 55 isolates from several north-central states and several pine hosts have now been established in stock culture. Isozyme phenotypes of these isolates have been determined.

Additionally, isolation from white-spored WGR from ND yielded callus-like mycelium that was white rather than the normal orange, providing a color marker for crosses.

Axenic isolates are also being used for host inoculations. Spore collections from single galls become old or depleted by the time they are characterized. These problems might be overcome with inoculations using cultures. Such inoculations have worked to some extent with other pine rusts, but not with WGR. With WGR, galls are consistently obtained by placing spores in various types of wounds on ponderosa pine seedlings but have not been obtained in inoculations with mycelium. Nevertheless, more work will be done in this area due the control over inoculum that such a method could provide.

Eastern Gall Rust and Comandra Blister Rust

Eastern gall rust [*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp *banksianae*] (EGR) is morphologically similar to WGR and isozyme systems in the two fungi are similar (Tuskan & Walla, 1989). Because of this similarity, study of EGR in axenic culture may allow a better understanding of WGR axenic culture. Comandra blister rust (*Cronartium comandrae* Pk.) (CBR) was recently found in ND on lodgepole pine in a windbreak planting. CBR is very different than WGR both in morphology and in isozyme systems, so comparison of axenic cultures between the two rusts may provide a good contrast.

EGR collected from northwest MN and CBR from ND were readily grown in axenic culture using the same methods as for WGR. Two culture types of both fungi were found and have been established in stock culture for over one year. Previous reports of axenic culture of EGR have not been found, although *C. q. fusiforme* from the southern U.S. and *C. quercuum* from Japan have been grown in axenic culture (Pei, 1990). Previous reports of axenic culture of CBR have not been found.

Citations

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PEST MANAGEMENT PRESCRIPTION FOR BALD EAGLE HABITAT

Willis Littke

Doak Mountain

Management Plan for Forest Health and Eagle Habitat

September 1992

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Introduction

The Oregon forest lands managed by Weyerhaeuser Company support a wide variety of wildlife species, including the Bald Eagle *(Haliaectus leucocephalus)*. In 1967 (11 years before the Bald Eagle was listed as threatened under the federal Endangered Species Act), Weyerhaeuser established an eagle management policy to protect and maintain eagle habitat on company lands in conjunction with active forest management. An area of particular interest to Weyerhaeuser's biologists and foresters is the Klamath Basin in southcentral Oregon.

One of the largest Bald Eagle winter roosting areas in the country is located in the Klamath Basin (Stalmaster 1987). Weyerhaeuser lands support two winter roosting areas as well as one of the highest concentrations of resident nesting Bald Eagles in the lower 48 states. Weyerhaeuser has taken an active role in protecting these roost and nest areas and the eagles that inhabit them by developing specific protection plans for each nesting territory.

The Doak Mountain area northwest of Klamath Falls, where about 20 percent of the local eagle population resides, has been severely affected by seven consecutive years of drought. The combination of abnormally low precipitation, competition for moisture and insect infestation, has caused an accelerated rate of tree mortality throughout the area. Species that are not drought-tolerant, such as white fir *(Abies concolor)*, Douglas-fir *(Pseudotsuga menziesii)* and incense cedar *(Libocedrus decurrens)*, are particularly susceptible. Due to the severity of the drought, pines *(Pinus spp)* also have become stressed to the point where secondary pest agents (fungi and bark beetles) are increasing mortality rates among trees that are normally drought-tolerant.

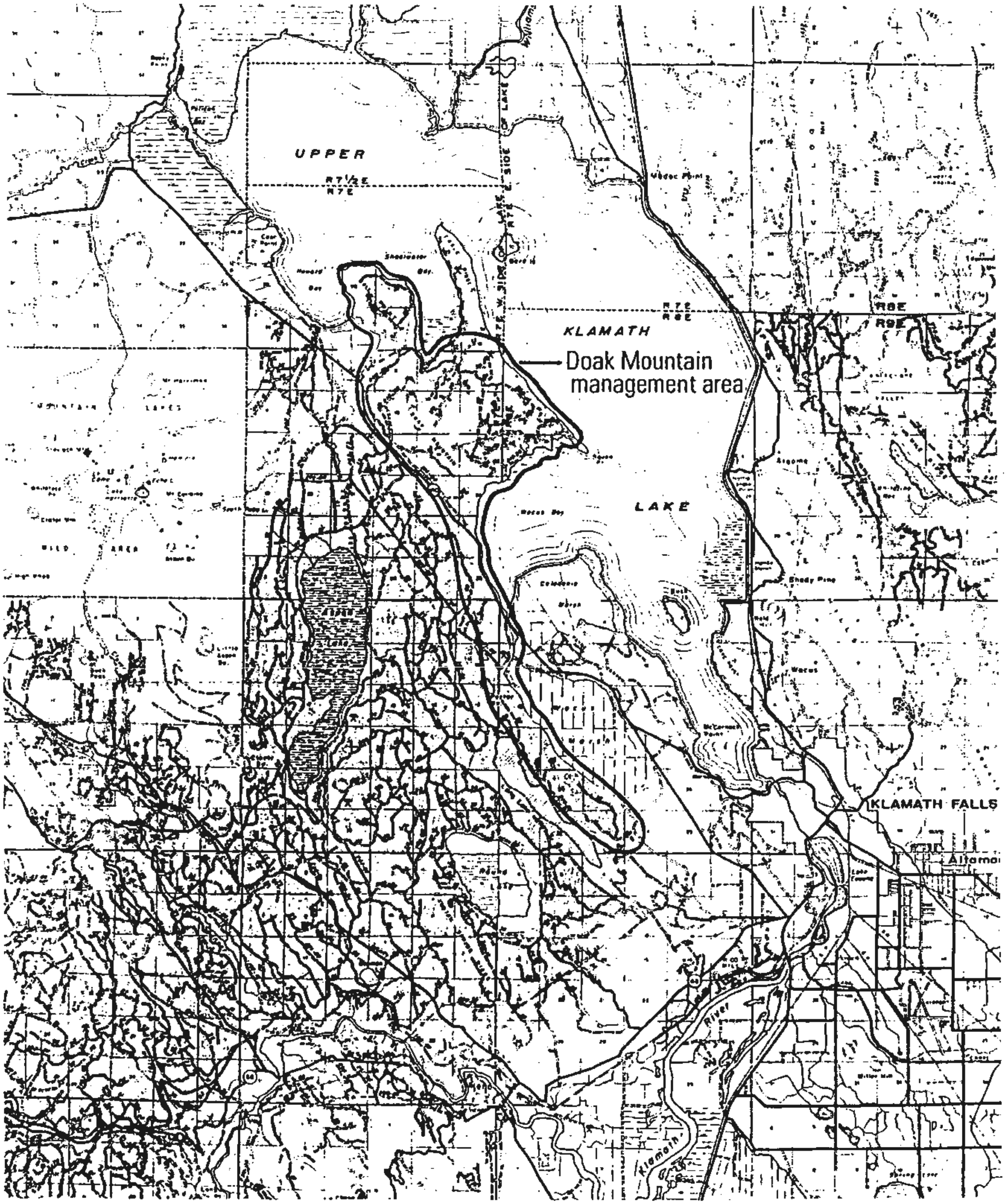
In addition to its desire to continuously grow and maintain healthy stands of timber on Doak Mountain, Weyerhaeuser is concerned particularly about the future of the Bald Eagle nests in the area. Most nests are in live, dominant trees that are normally resistant to drought and insect infestation, but some of the nest trees are already dead and several more are threatened. Therefore this management plan was prepared by Weyerhaeuser Company to protect existing Bald Eagle nest trees on Doak Mountain and to enhance the production of potential nest trees in a manner that maintains the level of Bald Eagle nesting productivity seen in the past.

Current Situation

Bald Eagle nest occupancy and productivity in the Doak Mountain area are monitored annually by helicopter. Nest occupancy is checked in April of each year and chick production (productivity) is monitored in June. Tree mortality also is noted during these flights. A significant increase in tree mortality was apparent between the June 1991 and April 1992 flights, and also between April

(Reference To Figures And Tables Come From The Larger Report)

District map of Doak Mountain Management Unit and vicinity.



Scale: 1/4" = 1 mi

and June of 1992. Color infrared photography was taken after the June 1992 nest check to aid in identifying areas of mortality and stress within the area. Field inspection then identified the extent of the damage and the causal agents (Littke and Figueroa 1992).

Tree mortality in the Doak Mountain area is related to several factors that have been aggravated by prolonged drought. Foremost is the competition for moisture caused by an abundance of understory conifer regeneration and shrubs (Figure 1). The absence of fire as a natural thinning factor over the past 60 years, coupled with dense conifer regeneration and lack of thinning, has reduced tree vigor and lowered resistance to pest agents. Conifers stressed by drought are being killed by various insect infestations:

- Fir engraver beetles *(Scolytus ventralis)* are killing white fir and Douglas-fir.
- Mountain pine beetles *(Dendroctonus ponderosae)*, western pine beetles *(Dendroctonus brevicomis)* and pine engraver beetle *(Ips pini)* are associated with mortality of pine species.
- Incense cedar is dying, primarily from drought, but insects are believed to be involved as well.

This mortality greatly adds to previous woody debris on the site and has caused high fuel loads, which in turn increase the potential for catastrophic fires.

All of these factors threaten the survival of eagle nest trees and future replacement trees. Even if the drought ended this year, reductions in growth and crown vigor, as well as lowered resistance to disease and insects, could not be immediately reversed. The proposed management options are a continuation of the current Bald Eagle management strategy, and reflect the critical attention required to respond to severe forest conditions brought on by the drought.

Objective

The objective of this plan is to describe silvicultural and integrated pest management strategies that will be implemented to 1) protect the future supply of eagle nest trees, and 2) promote forest health; in response to the drought conditions that exist now and that may continue.

Short-Term Goals

The short-term goal is to maintain the health of current nest trees, to improve the chances for their survival, and to reduce fuel loads that could support catastrophic fires. To do this, immediate treatments will be designed to improve the health of specific nest trees, replacement trees, and the general forest. Areas are prioritized according to: 1) designated zones of eagle use, 2) current stand health and 3) potential hazards.

Pest Agents

A complex of insect and disease agents occur sporadically across the Doak Mountain area. This patchy distribution is related to forest type, host species abundance, site factors, fires and previous management. Insect outbreaks in the area are part of a larger regionwide increase in bark beetle populations in response to the prolonged drought. A few pest groups are described below, along with how they relate to the forest management objectives.

Dwarf Mistletoe

Dwarf mistletoe (*Arceuthobium* spp.) is a common component of multi-age (uneven-age) forest stands. The disease is passed from infected overstory trees to like-species regeneration below. Douglas-fir dwarf mistletoe (*A. pseudotsuga)* and ponderosa pine dwarf mistletoe (*A. douglasi*) occur with high frequency at the Doak Mountain area. Infections by this disease deform and weaken trees and make them susceptible to drought and pest agents (Parmeter and Scharpf 1982). Witches brooms, caused by the parasite, can reach the ground, forming fuel ladders by which fire can climb into the forest canopy (crown). However, mistletoe-infected trees serve important functions in the forest for wildlife (such as providing a food source or nesting site).

The intensity of dwarf mistletoe infection is measured by estimating the proportion of the tree crown infected, using the six-point system developed by Hawksworth (1977). The crown is divided into thirds and rated as follows: 0 = not infected; 1 = moderate; 2 = severe. The ratings from each third are added together to develop a dwarf mistletoe rating (DMR) for each tree, and averaged together for a stand DMR rating. Trees with a DMR rating of 5 to 6 are considered high-risk trees for subsequent stand infection, fire and beetle attack.

Bole Decay and Root Disease

The signs and symptoms of bole decay and root disease fungi can be found in most conifer species in the Doak Mountain area. Annosus root disease caused by *Heterobasidion (Fomes) annosum* occurs sporadically throughout the area. This disease weakens the trees' ability to withstand wind and also predisposes them to bark beetles (Cobb et al. 1974, Hertert et al. 1975).

Numerous decay fungi often associated with fire scars may be present on the site (Littke and Gara 1986). Bole decay established in this manner decreases host tree vigor over several decades and contributes to tree decline and future bark beetle outbreaks (Gara et al. 1984, Geiszler et al. 1980).

Bark Beetles

Beetles observed at the site include the mountain pine beetle, western pine beetle, pine engraver beetle, turpentine beetle (*Dendroctonus valens*) and fir engraver beetle. There is evidence of increasing mountain pine beetle infestation, with substantial attacks and brood production occurring. As success rates of insect attack and brood production increase, bark beetle populations may rise to epidemic levels and overcome pines, regardless of their size and vigor (Thomson et al. 1983).

Windthrow

Windthrow, the potential for trees to be blown over by wind, is a minor problem in this area. Soil types are categorized as windfirm and much of the area is protected by Spence Ridge on the west. Ponderosa pine is fairly resistant to uprooting by wind, although older trees may break from high winds if previously weakened by decay or fire scars (Barrett et al. 1983). On the exposed escarpments, trees remain standing for many years, as evidenced by the many eagle nest trees that protrude above the canopy. There also are many gray snags scattered throughout the Doak Mountain area. An examination of the few downed trees that were detected showed no distinctive pattern of windthrow in the area.

History of Other Resources

Other Species

There is a rookery near Squaw Point, with a history of use by both Great Blue Herons and Great Egrets. The rookery has ranged in size from two trees of 40 nests in 1978 to 117 nests in eight trees in 1986. The rookery has continued to be used through 1992, although the number of nests have not been counted since 1987.

Over the years of monitoring the herons and eagles, several western pond turtle nests were discovered along Squaw Marsh. Incidental sightings of white-headed woodpeckers have been reported in the Shoalwater and Howard Bay areas. Historically, Doak Mountain is also a winter range for black-tailed deer *(Odocoileus hemionus columbianus).*

Recreational Use

This area is popular for big- and small-game hunting, woodcutting and fishing. Public use generally increases the risk of fire. There is a seasonal road closure program, administered in cooperation with the Oregon Department of Fish and Wildlife, to reduce disturbance to nesting Bald Eagles.

Hazard and Risk Assessment

The biotic and abiotic agents of mortality in forest stands are termed *hazards*. These include diseases, insects, drought stress, wind, fire and the combination of two or more agents. The probability that a hazard will result in tree mortality over some specified time period is termed *risk*. The two principal hazards now affecting the Doak Mountain area are direct mortality from drought stress and mortality from the combination of drought and insect attack. Fire is also a serious hazard, but is beyond the scope of this plan. Hazard ratings for drought and insects were developed separately for each forest stand using information from the Weyerhaeuser Forest Inventory System (FIRS) and field examinations.

Drought Susceptibility Hazard

The hazard of drought stress in a forest stand is determined by four influencing factors: competition, tree species, slope and aspect (exposure).

Competition

Competition from understory vegetation and neighboring trees affects availability of water. Basal area (BA) per acre of all tree species was used as a measure of competition within forested stands. Since understory vegetation cannot be quantified in the FIRS and since the clumped distribution of tree stems in many units is therefore not taken into account by the inventory system, these figures actually underestimate the amount of competition in portions of those stands.

The relationship between basal area and drought susceptibility hazard is shown below:

Least Susceptible →			→ Most Susceptible
0-50 sq.ft. BA	51-100 sq.ft. BA	101-150 sq.ft. BA	150+ sq.ft. BA

Species Type

The drought susceptibility hazard rating assumes that the potential for mortality due to drought is also a function of drought tolerance (species). The FIRS has 10 categories of species types for forest stand classification. Stands were classified as follows:

- A stand containing 25 to 50 percent by volume of a single tree species is identified by that species.
- A stand with two species, each comprising 25 to 50 percent of the volume has both species listed in the name of the stand type.
- A stand that contains less than 25 percent of any single species is classified as "mixed conifer."

The relationship between species and the potential for drought-caused mortality is assumed to be:

Least Susceptible ————► Most Susceptible

ponderosa pine → Douglas-fir → incense cedar → white fir

Slope and Aspect

The final two variables that were given ratings for affecting stand susceptibility to drought were position on slope and aspect. These two site characteristics influence the intensity and duration of direct solar radiation and the levels of soil and air temperatures (Cleary et al. 1978). Sites with steep slopes tend to have shallow soils and a large rock component. Steep slopes were rated as most susceptible to drought (rated 4). All other sites were rated 2. Sites on south aspects are subject to higher radiation loads and temperatures. These sites are most susceptible to drought (rated 4), compared to those on north aspects (rated 2).

Each stand's ratings were summed and represented on a map (Figures 6a and 6b), according to the cutoff points indicated below. The map was developed as a guide for prioritizing areas for treatment. As the drought continues, stand condition changes will cause the ratings to change. For example, some areas will move into a higher risk category and some of the extreme risk areas will drop to lower risk as the stand characteristics change through mortality or treatment. The acreage in each hazard class is shown in Figure 7.

Least Susceptible ————► Most Susceptible

Low	Medium	High	Extreme
<7	8-10	11-12	13+

Pine Beetle Hazard

Five factors were used to develop the second hazard map, identifying forest stands with risk of mortality due to pine beetles: slope, aspect, basal area, percentage of basal area in ponderosa pine, and the quadratic mean diameter of the pine component.

Pines are more susceptible to insect attack when stressed by drought (Barrett 1983), so factors that contribute to drought stress on pine (i.e., slope, aspect and basal area of all tree species) were included in this assessment as they were for the drought hazard rating. There is also strong evidence that tree spacing affects stand susceptibility to pine beetles (Sartwell and Stevens 1975, Schmid and Mata 1992); the most susceptible pure pine stands contain more than 120 square feet in basal area per acre. Most of the Doak Mountain stands are not pure pine, so 150 square feet was designated as the cutoff for the most susceptible rating value to account for the greater basal area usually achieved in mixed-species stands.

Pine beetles only attack pine species, so the percentage of ponderosa pine (by basal area) was factored in. Although sugar pine *(Pinus lambertiana)* is present incidentally on Doak Mountain, it comprises less than five percent of the volume in a stand, so the influences on the hazard ratings are negligible.

Pine beetles prefer large-diameter trees for optimal production and survival of the brood, so the quadratic mean diameter of the ponderosa pine component of each stand was rated. The FIRS uses the quadratic mean diameter, which is calculated according to the average basal area from cruise inventory diameters.

The pine beetle mortality hazard ratings for specific stand areas, generated from FIRS databases are shown in Figures 8a and 8b. The acreage in each hazard class is shown in Figure 9. In some cases, especially on steep slopes, the stand type maps show Douglas-fir as the prevalent species, yet the pine hazard map shows the stand to be a high risk for pine mortality. Although the pine may be a smaller component of the stand, the average diameter of the pine may be fairly large; this, in combination with the site characteristics, produced a high rating.

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Rifle and shotgun delivered inoculum for inoculating trees with wood decay fungi

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ABSTRACT:

Forest managers are challenged to provide suitable snags for cavity nesting wildlife. Most such trees have internal decay columns. Inoculation with decay fungi could facilitate the development of decay. However, inoculating trees with decay fungi is time-consuming, often hazardous, and thus expensive. We developed several rifle and shotgun loads for shooting fungal inoculum into trees. A lever-action rifle in .45-70 Government caliber was chosen because of its relatively slow velocity and large bullet. The nose of 300- and 400 grain bullets was drilled to provide space for the inoculum. Wooden dowels colonized for 11 weeks with either *Phellinus pini* or *Fomitopsis cajanderi* were inserted into openings in the bullets and covered with wax or silicone sealant. Bullets were fired into freshly cut bolts of Douglas-fir. The average depth of penetration was 6.1 cm for the 300 grain bullets, and 8.1 cm for the 400 grain bullets. About half of the 300 grain bullets reached the heartwood; all of the 400 grain bullets penetrated to the heartwood. The decay fungi were recovered from 13 of 30 attempts. Two of 3 12 gauge shotgun slugs with stained sawdust inserted behind them penetrated to the heartwood. Firearms can provide a low cost and convenient method for delivering viable inoculum to the heartwood of Douglas-fir from distances of at least 25m.

INTRODUCTION

Wildlife which nest in cavities often select trees with internal decay (Shigo and Kilham 1968, Conner et al 1976, Miller et al 1979). Most woodpeckers excavate cavities in dead trees because they contain wood softened by decay fungi, which makes excavation easier. Woodpeckers excavate several cavities each year for nesting and roosting. After woodpeckers abandon these cavities, other mammals that cannot excavate for themselves use the cavities.

Managing for cavity-dependent wildlife is a major issue for State and National Forest resource managers who have difficulty maintaining dead standing trees, which are often harvested for fiber and firewood or felled for safety. Public lands managers are now required to retain habitat for snag-dependent wildlife in timber sales or other intensive management activities. We do not have effective methods to create suitable trees where these are lacking. Herbicides and girdling have been used to produce snags for cavity nesting birds (Conner et al 1981, McComb and Rumsey 1983, Bull and Partridge 1986), but these trees fall sooner than trees killed by natural causes and are rarely used by cavity nesters. Trees that are limbed and topped by an explosive charge are most frequently used by nesting woodpeckers and stand the longest (Bull and Partridge 1986). This technique is used throughout the West by forest managers actively recruiting snags by killing trees. Unfortunately, the technique is expensive, requires highly skilled personnel, and often does not produce suitably decayed wood.

Although dead trees are the most common nest sites for cavity dwellers, live trees may also accommodate nesters if the boles contain decayed wood. Studies are being done to inoculate trees with decay fungi in order to predictably produce trees suitable for cavity excavation (Conner et al 1983, Parks et al 1990). The fungi used are usually associated with trees that have been damaged by lightning, logging or some other wounding event. Trees are climbed and inoculated at nest height; climbing is time consuming, hazardous, and costly.

Shooting the inoculum into trees with rifles and shotguns would be considerably faster and less expensive. Perhaps more important, bulky safety equipment need not be carried into the woods, permitting inoculations at greater distances from roads. The challenge is in developing loads that can place the inoculum in the heartwood, the optimum location for colonization success, without destroying the inoculum. This study was initiated to determine the feasibility of ballistic inoculation.

METHODS

Preparation of inoculum. Cultures of *P. pini* (Thore.:Fr.) A. Ames and *F. cajanderi* (Karst.) Kotl. et Pouz. were grown on malt extract agar. Hardwood dowels 0.64 cm (0.25 in) diameter were cut to 0.64 cm or .89 cm, autoclaved in malt extract broth for 40 min, and inoculated with one of the test fungi. Inoculum was grown for 11 weeks at 20C in the dark.

Preparation of ammunition. We chose the .45-70 cartridge firing .458 caliber 300 grain Hornaday hollow point bullets and 400 grain Speer flat nose bullets. This choice was based on our belief that a bullet of large mass traveling at a relatively slow velocity was needed to achieve penetration without "shattering" the inoculum. The front of each bullet was drilled to a depth of 0.8cm on a drill press with a 19/64" bit to create a cavity for the inoculated dowel. New Federal brass cases were then reloaded with CCI 200 primers. Cases were filled with 45 grains of Dupont IMR 4320 powder and 300 grain bullets or 48 grains of IMR 4320 powder and 400 grain bullets[1]. Powder was measured with a Redding BR-3 powder measure and bullets were seated with RCBS dies.

The colonized dowels were cleaned of any surface mycelium, and then stained with red food coloring. After removing excess food coloring, dowels were inserted into the hollow point of the bullet. Dowels were held in place with candle wax or silicone sealant. The prepared ammunition was then stored at room temperature overnight.

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[1]The loading data contained in this report yielded loads that were safe in the authors' firearms. These loads may be excessive in other firearms, particularly in older firearms.

We had initially hoped to insert colonized dowels into factory loaded 12 gauge shotgun slugs, but preliminary testing showed that this was not effective. We then cast 12 gauge slugs from pure lead using a Lyman 2654012 mold. These 475 grain hollow base slugs were then loaded into Winchester Super X cases, with Winchester 209 primers, 37.0 grains of DuPont SR 4756 powder, the basal portion of a Winchester WAA12 wad, and 2 - 12 gauge 0.125" cards according to data in the Lyman Shotshell Handbook (Ramage 1987). Sawdust stained with red food coloring was inserted into the slug and held in place with several drops of candle wax. This slug was placed in the case over the wad column, and was then roll crimped (Lyman 8898902).

Inoculation. Freshly cut bolts of Douglas-fir 30-40 cm in diameter were cut to 1.5m lengths the day prior to shooting. At the rifle range, these bolts were cut again to 0.3-0.5m for ease in retrieving bullets. Bolts were placed on end, and 2-3 rounds of ammunition were fired into each. Test firearms were a lever action Model 1886 Winchester in .45-70, and a Holiday Birdwing 12 gauge semi-automatic shotgun. An Oehler Model 43 chronograph was used to measure velocity of the loads. We also used this chronograph to measure chamber pressure for the shotgun loads.

Evaluation of inoculation. After shooting, each bolt was split to expose the bullet path. Depth of penetration, including bark, was measured for each direct hit. We also determined whether each bullet reached the heartwood. Cultures were made from the largest pieces of stained wood recovered onto either Kuhlman's medium (Kuhlman and Hendrix 1966) or 2% malt extract agar. Inoculum fragments large enough were flamed. Subcultures were made as necessary.

RESULTS

Both *P. pini* and *F. cajanderi* were recovered from 2 randomly selected unfired rounds of ammunition loaded with each fungus, although contaminant fungi were present in 3 of 8 plates. After firing into the bole sections, *P. pini* was recovered from 7 of 19 (37%) culture attempts, and *F. cajanderi* was recovered from 6 of 11 (55%) attempts (Table 1). The 400 grain bullets with an average muzzle velocity of 1439 $\pm$ 38 feet per second penetrated 8.1 cm and all of them reached the heartwood. The 300 grain with an average muzzle velocity of 1403 $\pm$ 92 feet per second bullets penetrated an average of 6.1 cm.

The 12 gauge slugs, with an average muzzle velocity of 1169 feet per second, penetrated an average of 5.8 cm, with 2 of 3 reaching the heartwood. Abundant stained sawdust was delivered to the heartwood. Peak chamber pressure from these loads was 251 PSI(M43), compared with 218 PSI(M43) from Winchester factory loads. While the 12 gauge slugs did not carry viable inoculum, the amount of sawdust in the heartwood suggests that these loads would effectively deliver inoculum.

DISCUSSION

Both *P. pini* and *F. cajanderi* survived shooting into trees. Survival of the fungi might have been greater than our recovery rate suggests because it was often difficult to find relatively large pieces of inoculum for culturing. Red food coloring was used to stain inoculum because it was assumed to be non-toxic to the fungus. However, red food coloring is water soluble, and often moved from the inoculum to the adjacent tissue, making it difficult to distinguish inoculum from host tissue. A subsequent trial showed that immersing the fungal colonized inoculum in 1% safranin O in 50% ethanol for as long as 25 minutes had no effect on these fungi. A less mobile stain could certainly help to improve inoculum recovery and is recommended for future studies.

In many cases the inoculum was recovered only from the sapwood. However, we suspect that the damage to the sapwood caused by the bullet was sufficient to permit the decay fungi to colonize that tissue and ultimately the adjacent heartwood.

While we did not extensively test the accuracy of these loads, they were sufficiently accurate from a distance of 25 m to hit the bolts, which were approximately 40cm in dia. Misses occasionally occurred as a result of aiming at the edge of the bolts, trying to space 3 rounds in the bolt. When bullets did not hit squarely, they tended to glance and not penetrate. Some glancing bullets, however, skimmed along the heartwood, expanding the area exposed to the inoculated fungus. The variation in accuracy and penetration could easily be overcome by firing 2-3 shots per tree.

Recoil might cause concern to some shooters. The .45-70 had little felt recoil, and someone inoculating trees would not be hampered by the recoil if they were familiar with firearms. The 12 gauge slugs, however, produced substantial recoil. The test firearms did not have a recoil pad. With such a device installed, or one of the external recoil pads (eg. Past Inc.), a shooter should be able to avoid great pain. While there were no signs of excessive pressure during firing or upon examination of the fired hulls, our reloaded slugs produced greater chamber pressures than factory loads. This suggests that it may be possible to reduce recoil by reducing the powder in this load.

While testing the .45-70 Government loads, we experienced two misfires. These were probably due to relatively light loads in relation to the weight of the bullet, and no crimp on the case to hold the bullet tightly. Reduced loads require a heavy crimp on the case to hold the bullet tightly enough to completely burn the powder and provide enough pressure to propel the bullet out of the barrel.

The 400 grain .45-70 Government loads used in this study all reached the heartwood, and viable inoculum was recovered from about half the inoculations. More of the bullets may have delivered viable inoculum, but our recovery may not have been effective. Regardless, inoculating trees at least twice should increase the probability of inoculation with viable inoculum. Loads using the 300 grain bullet were less effective at reaching the heartwood, perhaps because too much of the bullet's mass was removed to make room for the inoculum, or because the combined high velocity and low bullet weight produced more bullet expansion and less penetration.

We have shown that viable inoculum can be delivered into trees with a rifle. It must now be determined whether the amount of inoculum delivered can initiate a decay column. The 12 gauge shotgun also appears able to deliver inoculum to the heartwood, and offers a chance to deliver more inoculum, but with less accuracy and greater recoil. Properly equipping a shotgun with a rifled barrel and a recoil pad should reduce these concerns.

Another opportunity to improve inoculum delivery into the heartwood would be to use custom .458 caliber bullets designed for modern rifles (Simpson 1993). Conventional bullets are designed to mushroom at the slower velocities that are maximum in older rifles, and these bullets often came apart in our studies. Custom bullets are designed to mushroom at the greater velocities obtainable in modern rifles. Such bullets delivered at "slower" velocities should retain their integrity longer in the wood, and penetrate more deeply than conventional bullets, perhaps delivering the inoculum more deeply. It remains to be seen if the inoculum would be released into the wood or would remain inside these less fragile bullets.

RECOMMENDATIONS

Decay studies should be done using inoculated dowels in 400 grain bullets loaded in the .45-70 Government cartridge. Inoculum should be stained with safranin for later detection. These tests should also examine the performance of modern .458 bullets. Inoculations should also be made using 12 gauge shotgun slugs loaded with colonized sawdust.

This research required modifying bullets and creating highly customized ammunition. This level of complexity - especially the structural modifications to bullets - requires careful control, adequate equipment, and above-average expertise. Neither the authors, Utah State University, or the USDA Forest Service assume any liability for anyone attempting to duplicate these methods.

ACKNOWLEDGEMENTS

We thank the staff at Oregon State University Forest for the bolts of Douglas-fir, and the Albany (Oregon) Rifle and Pistol Range for use of their range. This research was supported in part by funds provided by the US. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

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Table 1. Depth of penetration, proportion of bullets reaching heartwood, and fungal recovery from .45-70 bullets. See text for load data.

Bullet Weight (gr)	Fungus	Penetration Depth (cm)	Penetration to Heartwood	Fungus recov-ered
300	None	2.3	1/4	0/4
	P. pini	2.3	5/11	3/9
	F. cajanderi	2.5	6/14	3/6
400	None	2.2	1/2	0/2
	P.Pini	3.1	10/10	4/10
	F. cajanderi	3.3	9/9	3/5

SITE AND ENVIRONMENTAL RELATIONSHIPS OF ASPEN REGENERATION FAILURE

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Introduction

Throughout Colorado, disease-induced regeneration failure occurs in part or all of an aspen stand within 3-8 years following harvesting. About 10% of the region's stands are impacted. Two canker fungi (Cytospora chrysosperma, Dothiora polyspora) rapidly girdle and kill the aspen sprouts within a few months. C. chrysosperma is the predominant pathogen. Both fungi damage stressed trees. Regeneration has not occurred in affected areas even after 10 years, leaving large treeless patches. This project's aim was to identify the interacting environmental conditions that predisposed aspen sprouts to infection by these canker fungi. Thus, the research objectives were to determine the weather conditions related to the temporal occurrence of aspen mortality and the site, soil, and soil moisture factors related to the spatial occurrence of aspen mortality.

Materials and Methods

Seven study sites in Colorado were utilized. Each site consisted of a pair of plots. A plot with 95% sprout mortality was paired with a plot within the stand or within 2 miles where at least 50 % of the sprouts survived. Data were collected on sprout number, size and health, radial growth rates of surviving trees, previous stand tree size, density, basal area, slope, aspect, habitat, surface soil density and soil moisture. Soil pits were used to describe soil morphology, density, texture/particle size, structure and nutrient content. Neutron probes determined soil moisture throughout two growing seasons to a depth of 1.8 m. Nine soil-moisture access tubes were used on each plot. Meteorological data (April and May snow pack, monthly mean temperatures, monthly total precipitation etc.) were obtained from NOAA stations near research sites.

Results

The occurrence of canker-induced aspen mortality at five of the seven study sites, apparently was caused by stress induced by excess soil moisture induced by late spring snow pack and cool temperatures. At two sites, stress resulted from limited spring snow pack and summer drought. These meteorological events, mediated by subtle soil differences predisposed aspen sprouts to infection by canker fungi. The deep snow pack did not melt till early summer the year trees died at the wet sites because of abnormally high snow pack and below normal temperatures in May and June. Snow pack was low and limited summer precipitation induced drought at dry sites.

On the five sites with excess soil moisture, the areas with tree mortality apparently had poor drainage. These wet sites had significantly lower soil moisture depletion rates at 2-4 ft than areas with trees surviving. These features restricted moisture depletion, thus stressing trees by flooding roots. Areas with aspen mortality had depletion rates that did not relate to tree biomass so low depletion rates were apparently soil driven and not vegetation driven.

On sites with drought induced stress, the areas with good aspen survival apparently had better moisture holding capacity. Thus, trees on soil with better-drainage in the upper 2 ft were more stressed than trees on the better moisture holding soil, when drought conditions were imposed. Unfortunately at the time of this presentation detailed soil data was not available.

It was not possible to predict soil features from previous stand characteristics; stem density, tree size or basal area, habitat types, or surface soil density. No root diseases were found associated with sprout mortality. In some sites topography and configuration played a role in accentuating excess soil moisture. Predicting where mortality will occur is difficult since many of the predictors are relative soil and moisture depletion factors and not easily measured. Predicting when mortality may occur can be derived from meteorological data.

Conclusions

1. Excess soil moisture from deep and late spring snow packs on soils that did not drain well predisposed aspen trees to infection by canker pathogens.

2. Drought conditions from low spring snow packs and reduced summer precipitation on soils with poor water holding capacity and soils with poor lower depth drainage also predisposed aspen trees to infection by canker pathogens.

3. Predicting where mortality will occur is difficult since previous stand characteristics were not predictive and soil characteristics are difficult to obtain.

4. Predicting when mortality will occur is feasible based on meteorological data.

RELATIONSHIP OF ENVIRONMENTAL STRESS AND CYTOSPORA CANKER OF ASPEN

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POSTER SUMMARY

Cytospora canker (Cytospora chrysosperma (Pers.) Fries) is one of the most important diseases of urban and forest grown aspen (Populus tremuloides Michx.) in Colorado. Canker incidence is suspected to be related to predisposing environmental stresses. Our research is aimed at determining these stresses and the degree of stress needed to increase susceptibility of aspen.

The research was completed over the last 6 years in nursery and greenhouse experiments. One to 5-year-old aspen seedlings were used in greenhouse studies and 10 to 12-year-old trees in nurseries. The following stresses were assessed as to their effect on canker initiation and expansion: drought, flooding of roots, defoliation, and nitrogen deficiencies and excesses. Pressure bombs were used to measure tree water potentials during drought studies. Drought was induced 7 days before inoculation by withholding water until tree water potentials reached 1.5 to 2.0 MPa. Then a small amount of water was added to prevent death. Thus, a cyclic drought stress was applied. Flooding was simulated by putting potted aspen in tanks of water 2 days before inoculation. Trees were defoliated at levels of 0, 50, 75 and 100% by removal of leaves for 4 weeks before inoculation. Nitrogen was applied to greenhouse trees at 0, 66, 185, and 360 ppm 6 weeks before inoculation. Trees were treated with these nitrogen concentrations a second year. All experiments utilized at least two C. chrysosperma isolates and were repeated at least twice. Canker size (length and width) was recorded weekly for 4 to 6 weeks after inoculation.

Drought affected host/pathogen relationships in various ways. In the spring, the duration wounds remained susceptible to infection increased from 2 or 4 days on watered trees to at least 10 days on drought stressed trees. Resistance, based on the number of successful infections, started on watered trees two days after wounding and after 6 to 8 days on drought stressed trees. In greenhouse studies, trees under drought stress had significantly ($P=0.5$) larger cankers than non-stressed trees. The number of successful infections on field grown aspen increased from 16 to 100% as water potentials increased from 0.7 to 2.0 MPa during the growing season. Increased water potential at or above 1.0 MPa using polyethylene glycol in the growing medium induced a significant growth decrease in the pathogen. Thus, fungal growth is not favored by low water protentials in the host but by reduced host resistance.

Flooding of root systems did not affect aspen water potential or size of cankers, but did cause partial defoliation after 3-6 weeks. Trees with defoliation amounts of 75 and 100% had significantly larger cankers than non defoliated trees. Aspens receiving no nitrogen had significantly larger cankers after one and two growing seasons.

POSTER TITLE:
IDENTIFICATION AND ASSOCIATIONS OF ARMILLARIA SPECIES WITH YOUNG CONIFERS IN CALIFORNIA SIERRA NEVADA FORESTS

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ABSTRACT

Armillaria spp. isolates were collected from 12 sites and two plantations in Sierra Nevada forests. Associations of host vigor, tree size, and root deformities with Armillaria spp. were examined by surveying mortality centers in the 6 and 11 year old conifer plantations. Root systems of 161 trees were excavated to examine root development and possible Armillaria spp. infections. The isolates were grouped into similar genets by vegetative compatibility tests. The confrontation zone of the test isolates was treated with a %5 L-DOPA solution to verify the presence of a "black line" and to help distinguish intra- from interspecific tests. Each genet was tested with diploid North American biological species to identify the species. Chi-square and odds ratio test statistics verified that Armillaria spp. is associated with dead and declining vigor, smaller (dbh ≤ 2.5 cm) trees, and root deformities due to improper planting. A. mellea, and A. gallica were found in the plantations and A. mellea was found at the 12 other locations. The plantations' genets appeared to be saprophytic because of the strong association of the fungus with dead trees. However, the A. mellea plantations' genets may have acted as weak facultative pathogens, and contributed to the mortality on these sites since it was found on a few severely declining trees.

DWARF MISTLETOE COMMITTEE REPORT - 1993

ROCKY MOUNTAIN REGION

1. CONTROL - CHEMICAL

Evaluation of field tests of the plant growth regulator, ethephon, has shown that significant abscission of dwarf mistletoe shoots occurs within a few weeks after application. Tests conducted in the Black Forest north of Colorado Springs, Colorado in 1988 on ponderosa pine dwarf mistletoe showed abscission rates of 73 to 98 percent with mid-June, mid-July and mid-August applications of the chemical at rates of 2200 and 2700 ppm ethephon in water with a spreader-sticker.

Examination of trees four years following treatment showed development of immature shoots on all treatments and some development of mature shoots with fruits. It is also interesting to note that 32 percent of the original branch infections have died as a result of breakage, girdling by rodents, and other natural agents during this time (D. Johnson, USFS, R-2).

2. CONTROL - SILVICULTURAL

Plans are to treat 1,470 acres of dwarf mistletoe infested stands on the Arapaho and Roosevelt; Grand Mesa, Uncompahgre and Gunnison; Medicine Bow; Pike and San Isabel; and White River National Forests (P. Angwin, D. Johnson, USFS, R-2).

3. DWARF MISTLETOE SURVEYS

Presuppression surveys for dwarf mistletoe are planned for 30,398 acres on the Arapaho and Roosevelt; Medicine Bow; Pike and San Isabel; Routt; and White River National Forests (P. Angwin, D. Johnson, USFS, R-2).

DWARF MISTLETOE COMMITTEE REPORT - 1993

REGION 5

Region 5 has six dwarf mistletoe projects, two in the Southern Sierra and four in Southern California recreation areas.

1. Stanislaus NF, Groveland RD. Presuppression surveys were completed on 15,045 acres that were part of the 1987 Stanislaus Complex Wildfire. Survey data will help the District decide on treatments in areas already replanted and areas yet to be planted.

2. Inyo NF, Mammoth RD. 20 acres in the Twin Lakes Campground were treated for control of lodgepole pine dwarf mistletoe. Infections in the treatment area were light to moderate. 590 trees were either broom or branch pruned, and 73 trees were removed. Pines ranged from 10-14 inches dbh. This was the first dwarf mistletoe suppression project involving lodgepole pine in a R-5 recreation area.

3. Angeles NF, Mt. Baldy RD. 33 acres in the Crystal Lake Recreation Area were treated for control of western dwarf mistletoe in Jeffrey pine. 280 trees were pruned and 20 trees were removed.

4. Cleveland NF, Descanso RD. 89 acres in the Burnt Rancheris, Wooded Hill, and Horse Heaven campgrounds were treated for control of western dwarf mistletoe in Jeffrey pine. 250 trees were pruned and 133 trees were removed.

5. Los Padres NF, Mt. Pinos RD. 70 acres in the Mt. Pinos Campground and Organizational sites were treated for control of western dwarf mistletoe in Jeffrey pine. 600 trees were pruned and 200 trees were removed.

6. San Bernardino NF, Arrowhead, Big Bear, and San Gorgonio RDs. 196 acres in developed recreation areas were treated for control of western dwarf mistletoe in Jeffrey pine. 500 trees were broom-pruned or removed.

ROOT DISEASE COMMITTEE REPORT - 1993

Gregory M. Filip

The root disease committee met and discussed several topics relating to root disease biology and management. The following reports were submitted this year.

PROJECT TITLE: Pest Trend Impact Plots In The West- Rocky Mountain Region

INVESTIGATORS: Pete Angwin, Dave Johnson, Jenny Holah and Bernard Benton, Forest Health Management, Rocky Mountain Region

COOPERATORS: Bov Eav, Renee Platz, Judy Adams, FPM Methods Application Group; Jim Friedley, BIA Southern Ute Agency; Don Brake, BLM Gunnison Resource Area Office; Lee Christiansen, Joy Towbridge, Elizabeth Stiller, Randy Rick, Jim Allen and Steve Pische, Black Hills NF; Sam Schroeder, White River NF; Gary Roper, Mike Morrison and Mike Westfahl, Routt NF; Paul Langowski and Steve Johnson, Roosevelt NF; Phil Kemp and Bob Vermillion, San Juan NF.

YEARS: Begun- 1990; End- indeterminate

PROJECT DESCRIPTION: The objective of the project is to establish a series of permanent plots to provide data for the validation and calibration of the western root disease model for the range of stand conditions in Region 2. Permanent plots to monitor spread characteristics of Armillaria and Heterobasidion root diseases were established according to the cluster design developed and implemented in Region 1. In 1991, permanent plots were installed in six mixed conifer stands on the Southern Ute Reservation and six ponderosa pine stands on the Black Hills National Forest. The 1991 plots were remeasured in 1993. In 1993, additional plots were installed in seven lodgepole pine stands on the Arapaho and Roosevelt NFs and on BLM land west of Gunnison, as well as in six white spruce stands on the Black Hills NF. Installation of the Pest Trend-Impact Plot System (PTIPS) database, together with data entry will be done this winter. The database will be housed at the R2 Regional Office. Additional permanent plots will be installed in spruce/fir stands in Colorado.

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PROJECT TITLE: Survey of biological species of Armillaria and Heterobasidion in Region 2

INVESTIGATORS: Pete Angwin, Dave Johnson, Jenny Holah and Yun Wu, Forest Health Management, Rocky Mountain Region

COOPERATORS: Terry Shaw, Dan Omdal and John Lundquist, Rocky Mountain Forest and Range Experiment Station; Geral McDonald, Intermountain Research Station; Alice Ratcliff, Pacific Southwest Forest and Range Experiment Station; various Forest and Ranger District personnel.

YEARS: Begun- 1993; End- indeterminate

PROJECT DESCRIPTION: The objective is to determine the biological species of Armillaria and Heterobasidion root diseases in various hosts and ecosystems in the Rocky Mountain Region. This information will then be used to develop better root disease management strategies for our various customers. Starting in 1993, diseased wood samples containing Armillaria and Heterobasidion, collected from throughout Region 2, are sent to the diagnostic lab at the FHM Lakewood Service Center. The pathogens are isolated from the host material and identified to biological species using heterokaryon x heterokaryon (somatic) and heterokaryon x homokaryon (di-mon) pairing techniques. The fungal isolates are then catalogued and kept in cold storage (along with the various tester strains) as part of the Region's new fungal reference collection.

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PROJECT TITLE: Black Hills National Forest Armillaria Root Disease Surveys

INVESTIGATORS: Jenny Holah, Forest Health Management, Rocky Mountain Region

COOPERATORS: Spearfish Ranger District, Harney Ranger District, and Custer Ranger District, Black Hills National Forest.

YEARS: Begun - 7/92, End - 9/93.

PROJECT DESCRIPTION: The project objectives were to determine 1) if Armillaria root disease in the Black HIlls NF has an impact on ponderosa pine stands, 2) what association, if any, there is between Armillaria and mountain pine beetle presence, and 3) if Armillaria prevalence differs between recent intensively managed stands and those that have not been recently managed.

Recent studies that are primarily qualitative (Lundquist, 1991) have shown Armillaria to be widespread throughout this national forest, but few studies have examined quantitative stand impacts. Three of the nine districts in the Black Hills National Forest were extensively surveyed for Armillaria: Spearfish, Harney, and Custer districts. The districts were contiguous and comprise nearly one-half million acres of forested land. Over 54 half-mile transect lines were walked between 200 and 260 feet in width throughout this large area. Survey methods were based on Bloomberg's line-transect technique.

Approximately 11% of the ponderosa pine stand acreage surveyed in the Spearfish district, the northernmost district, was occupied by Armillaria centers. In contrast, the Custer district, the southernmost district surveyed, had less than 1% of the land area affected by root disease. Results for the Harney district, which falls between the Custer and Spearfish districts, have not been fully analyzed, but acreage affected by root disease will probably approach the 10% level. The numbers reported here are conservative because allowances were not made for root disease presence beyond symptomatic trees. Also, centers were only recorded where mycelial fans and/or rhizomorphs were found on living trees, which resulted in many probable disease areas not being included in the survey. Most Armillaria centers were characterized by dead and dying pines of all ages, a patchy open canopy, very poor ponderosa regeneration, and, often, an increase in hardwood species, especially birch. These surveys provide sound evidence that the disease is occupying a significant percent of stand acreage within most areas surveyed north of Custer. Land managers need to start recognizing Armillaria in their stand inventories, as well as impacts on stand regeneration and future volume projections. This will require future training and assistance in disease recognition from the Rapid City Service Center.

Mountain pine beetle presence was recorded throughout the transect surveys. On the Spearfish district, 78% of all mountain pine beetle areas were found in or near Armillaria centers. Similarly on the Harney district, 77% of all small mountain pine beetle areas were associated with disease centers. A few transect lines were run in areas experiencing epidemic levels of beetle activity and there was no association with disease evident. (If epidemic areas are included in the survey results, the association drops to 67%.) The percent of Armillaria centers surveyed that were associated with mountain pine beetle was 48% on the Spearfish District and 44% on the Harney District. Custer district also had negligible beetle activity in addition to the negligible Armillaria presence. Results indicate that small areas of mountain pine beetle activity (generally comprising of 5 or fewer trees) are strongly associated with Armillaria centers. However, the presence of Armillaria does not necessarily imply a correlation with mountain pine beetle. Recognition that endemic levels of mountain pine beetle are correlated with Armillaria centers in the Black Hills could prove a valuable tool, not utilized yet, in the ongoing attempts to predict future probability of attack in epidemic periods of beetle activity.

Results are difficult to clearly interpret, especially for the Harney district, regarding disease impact in recently managed vs. less recently managed because nearly all stands surveyed had multiple intensive entries and quantifying management level was difficult. The Spearfish district had a similar number of Armillaria centers found in both stand types, but the acreage occupied by Armillaria was twice as great in areas that had been recently managed. Results suggest an increase in severity of root disease with intensive management, but further, more detailed studies need to address this issue for the region.

A series of biological evaluations will be available soon from Forest Health Management, Rocky Mountain Regional Office regarding this series of surveys.

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PROJECT TITLE: Possible New Root Staining Disease Complex in the Nebraska National Forest, Bessey Ranger District

INVESTIGATORS: Jenny Holah and Bill Schaupp, Forest Health Management, Rocky Mountain Region

COOPERATORS: Mack Deveraux, District Ranger, Bessey District, Nebraska National Forest; Clark Fleege, Nursery Manager, Bessey Nursery; Tom Harrington, Plant Pathology Department Chair, Iowa State University.

YEARS: Begun - 8/92, End - 9/93.

PROJECT DESCRIPTION: The objectives of this project were to determine the cause of extensive mortality in advanced jack pine regeneration and in adjacent mature jack pine following a series of harvests beginning in the early 1980's.

A stain in the roots, extensive turpentine beetle and (probably) Hylastes sp. activity, and extensive resinosus were consistently found in symptomatic trees. The stain has been identified as Leptographium terebrantis, though other related fungi may be involved as well. A series of pitfall trappings in affected areas revealed large numbers of turpentine beetles and root feeding beetles, probably Hylastes sp. and/or Hylurgops sp. L. terebrantis was isolated from the probable Hylastes species and fruiting Leptographium was seen several times within turpentine beetle galleries.

In order to determine the pathogenicity of L. terebrantis on its jack pine host, inoculations were made in 2-0 jack pine seedlings planted under natural field conditions at Bessey nursery. Seedlings were inoculated with toothpicks, either colonized by L. terebrantis or sterile, by sliding the toothpick under the bark at the soil collar and wrapping with parafilm. Inoculated seedlings had either wounding or non-wounding treatments, treatments which attempted to simulate the extensive insect feeding found on affected trees. Nine percent of the seedlings inoculated (99 seedlings total) died and all dead seedlings had been inoculated with the fungus, with the exception of two controls. Six percent of the seedlings were symptomatic when the experiment ended, approximately two months after the initial inoculation, and all had been inoculated with the fungus. Nearly all seedlings that had been inoculated with L. terebrantis exhibited a resinous canker at the point of inoculation, seedlings inoculated with sterile toothpicks did not exhibit such a reaction. L. terebrantis was reisolated from two symptomatic seedlings. Isolations from dead seedlings were unsuccessful even though the wood was extensively stained, probably because these seedlings had died quite a few weeks before reisolations were attempted and the fungus died out. There were not any significant differences between wounding and non-wounding treatments.

Evidence suggests the large populations of root feeding beetles, perhaps reaching epidemic proportions after a harvesting period, which are able to vector a potentially pathogenic Leptographium, are playing a large role in the dynamics of this new disease complex in the area. Whether or not this disease situation is related to complexes in other areas, such as the red pine decline in Wisconsin, remains to be seen. This disease complex is occurring a very unique area - a forest planted in the Nebraska sandhills in the 1890's. The population dynamics of the beetle vectors, and perhaps the associated fungi, may be quite different from we would consider "normal". It may be possible that epidemic levels of root feeding beetles are able to sustain themselves for prolonged periods of time due to lack of natural enemies and/or a combination of environmental and host factors. It seems likely that the jack pine stands throughout this area may not be able to sustain themselves over long periods of time due to this complex. This disease complex appears to present throughout much of the jack pine stands, albeit at low levels, and attempts at cutting and future regeneration may prove quite difficult. Suggestions for management include restricted harvests, push-over logging and/or stump sanitation procedures, and, perhaps the most feasible option, replanting with other species, such as ponderosa pine and junipers.

ROOT DISEASE COMMITTEE REPORT - 1993
ROCKY MOUNTAIN REGION

PROJECT TITLE: Pest Trend Impact Plots In The West- Rocky Mountain Region

INVESTIGATORS: Pete Angwin, Dave Johnson, Jenny Holah and Bernard Benton, Forest Health Management, Rocky Mountain Region

COOPERATORS: Bov Eav, Renee Platz, Judy Adams, FPM Methods Application Group; Jim Friedley, BIA Southern Ute Agency; Don Brake, BLM Gunnison Resource Area Office; Elizabeth Stiller, Randy Rick, Jim Allen and Steve Pische, Black Hills NF; Sam Schroeder, White River NF; Gary Roper, Mike Morrison and Mike Westfahl, Routt NF; Paul Langowski and Steve Johnson, Roosevelt NF; Phil Kemp and Bob Vermillion, San Juan NF.

YEARS: Begun- 1990; End- indeterminate

PROJECT DESCRIPTION: The objective of the project is to establish a series of permanent plots to provide data for the validation and calibration of the western root disease model for the range of stand conditions in Region 2. Permanent plots to monitor spread characteristics of *Armillaria* and *Heterobasidion* root diseases were established according to the cluster design developed and implemented in Region 1. In 1991, permanent plots were installed in six mixed conifer stands on the Southern Ute Reservation and six ponderosa pine stands on the Black Hills National Forest. The 1991 plots were remeasured in 1993. In 1993, additional plots were installed in seven lodgepole pine stands on the Arapaho and Roosevelt NFs and on BLM land west of Gunnison, as well as in six white spruce stands on the Black Hills NF. Installation of the Pest Trend-Impact Plot System (PTIPS) database, together with data entry will be done this winter. The database will be housed at the R2 Regional Office. Additional permanent plots will be installed in spruce/fir stands in Colorado.

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PROJECT TITLE: Survey of biological species of *Armillaria* and *Heterobasidion* in Region 2

INVESTIGATORS: Pete Angwin, Dave Johnson, Jenny Holah and Yun Wu, Forest Health Management, Rocky Mountain Region

COOPERATORS: Terry Shaw, Dan Omdal and John Lundquist, Rocky Mountain Forest and Range Experiment Station; Geral McDonald, Intermountain Research Station; Alice Ratcliff, Pacific Southwest Forest and Range Experiment Station; various Forest and Ranger District personnel.

YEARS: Begun- 1993; End- indeterminate

PROJECT DESCRIPTION: The objective is to determine the biological species of *Armillaria* and *Heterobasidion* root diseases in various hosts and ecosystems in the Rocky Mountain Region. This information will then be used to develop better root disease management strategies for our various customers. Starting in 1993, diseased wood samples containing Armillaria and Heterobasidion, collected from throughout Region 2, are sent to the diagnostic lab at the FHM Lakewood Service Center. The pathogens are isolated from the host material and identified to biological species using heterokaryon x heterokaryon (somatic) and heterokaryon x homokaryon (di-mon) pairing techniques. The fungal isolates are then catalogued and kept in cold storage (along with the various tester strains) as part of the Region's new fungal reference collection.

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PROJECT TITLE: Black Hills National Forest Armillaria Root Disease Surveys

INVESTIGATORS: Jenny Holah, Forest Health Management, Rocky Mountain Region

COOPERATORS: Spearfish Ranger District, Harney Ranger District, and Custer Ranger District, Black Hills National Forest.

YEARS: Begun - 7/92, End - 9/93.

PROJECT DESCRIPTION: The project objectives were to determine 1) if Armillaria root disease in the Black HIlls NF has an impact on ponderosa pine stands, 2) what association, if any, there is between Armillaria and mountain pine beetle presence, and 3) if Armillaria prevalence differs between recent intensively managed stands and those that have not been recently managed.

Recent studies that are primarily qualitative (Lundquist, 1991) have shown Armillaria to be widespread throughout this national forest, but few studies have examined quantitative stand impacts. Three of the nine districts in the Black Hills National Forest were extensively surveyed for Armillaria: Spearfish, Harney, and Custer Ranger Districts. The districts were contiguous and comprise nearly one-half million acres of forested land. Over 54 half-mile transect lines were walked between 200 and 260 feet in width throughout this large area. Survey methods were based on Bloomberg's line-transect technique.

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DISEASE CONTROL COMMITTEE MEETING
WIFDWC - 1993
BOISE, IDAHO

Meeting held Sept. 16, 1993

Attendees:

R. L. James, Alan Kanaskie, John Muir, Will Littke, Art McCain, Borys Tkacz, Greg Filip, Catherine Parks, Rich Dorsett, Walt Thies, Ken Russell, Mike McWilliams.

Littke: discussed grey mold control problems, especially on sequoia. Chemical controls include chipco, ornalin, and daconil. Also discussed Pythium problems.

Muir: discussed a root ripper and stump remover; a tree puller capable of extracting 14" trees are available from Sweden. The puller is used in pre-commercial thinnings, works on slopes like excavators. A video is available describing this tool.

Russell: discussed the "Tree Max" excavator.

Muir: discussed standard tree harvesting using a pusher; this produces undesirable site disturbance problems.

Parks: discussed Peniophora gigantea used in biocontrol and applied operationally in Finland after mechanical harvesting. Being produced by Kimera from Helsinki. In the United States, EPA and APHIS have approved its use as a stump decay treatment. It is being tested on grand fir to control root disease organisms. It was suggested that a panel be conducted on Peniophora at next years' WIFDWC.

Muir: discussed problems associated with seedling export from British Columbia. Forest nursery certification is needed to make sure stock is disease-free. Certifications are done by visual inspection.

Several members discussed control of Fusarium root disease using chipco and Cleary's fungicides.

BLISTER RUST COMMITTEE MEETING

The blister rust committee meeting was held during lunch on 9/16. In the absence of chairman Rich Hunt, John Muir started the meeting off by briefing the group on some Canadian genetics work dealing with lodgepole pine. Cheng Ying is evaluating lodgepole pine families in provenance tests for differences in insect, disease, and animal damage. He has found significant family differences with stem rusts (western gall rust and stalactiform rust). He is also involved in developing a benefit/cost analysis to make a case for more intensive management of white pine.

This was followed by a short discussion dealing with the interaction of insects on white pine. John Schwandt reported that one Forest Service District on the Clearwater National Forest had 40% of pruned and thinned white pine attacked by the red turpentine beetle (Dendroctonus valens) which resulted in 10% mortality. A small follow-up study has been initiated to monitor this problem in conjunction with severe pruning (pruning white pine to the top whorl). Fifteen of 38 trees pruned in May were attacked by September, and the beetles seemed to prefer the most severely pruned trees. John plans further evaluations on other Districts.

Hadrian Merler reported finding a small bark beetle had been found associated with some of the Canadian pruning operations. Alan Kanaski also reported finding some insects associated with pruning and blister rust cankers.

Dick Krebill initiated a discussion about the potential loss of some of the high elevation pines due to blister rust. Several members reported heavy damage from the Cascades in Oregon to the Rockies, and north through Idaho, Montana, and British Columbia. In the southwest, there may be a potential concern about losing bristlecone pine.

Most of these species are marginally commercial at best, so management activities raise questions about non-timber values. In addition, many of these species occur primarily in unroaded or wilderness areas, so management activities may be difficult or impossible to implement.

There was also some discussion about inoculation work being conducted by Yasu Hiratsuka. There was some concern expressed that some of his techniques which wound trees may be by-passing natural resistance mechanisms. He is also studying aeciospore eating insects.

A discussion about managing for western gall rust was jeered at by the group, since there was a general consensus of opinion that it was acting as a natural thinning agent, and rarely killed enough trees to create a management concern. Det Volger reported that he knew of areas with 1000 radiata pine per acre with lots of rust infections, but they were still a well stocked stand (many of the cankers were out on branches so were non-lethal).

Respectfully submitted....John Schwandt.

9/09/93

WIFDWC - 1993
ROCKY MOUNTAIN REGION REPORT

1. New and Continuing Projects

A. Forest Disease Surveys-General

88-A-1 Evaluation of site factors involved with aspen sprout mortality (P. Angwin, W. Jacobi).

C. Cone, Seed, and Seedling Diseases

Evaluation of Basamid and methyl bromide fumigants, Bessey Nursery, Halsey, NE (J. Holah, C. Fleege, J. Gleason).

Evaluation of black walnut storage rot, Bessey Nursery, Halsey, NE (J. Holah, C. Fleege).

D. Root and Soil Diseases or Relationships (including Mycorrhizae)

Surveys of Armillaria root disease in the Black Hills to determine impacts on timber productivity, association with mountain pine beetle, incidence in recently versus less recently managed stands, and geographic distribution (J. Holah).

Evaluation of a root disease complex of jack pine, Bessey Ranger District, Nebraska NF (J. Holah, W. Schaupp).

Survey of biological species of Armillaria and Heterobasidion in Region 2 (P. Angwin, D. Johnson, J. Holah, Y. Wu).

90-D-2 Root disease impact monitoring (P. Angwin, D. Johnson, J. Holah)

79-D-1 Surveys of root diseases in managed conifer stands in R-2 (P. Angwin).

79-D-5 Spread of Armillaria spp. disease centers in managed pine stands (P. Angwin).

D. Stem Diseases: Malformations, Witches'-Brooms, Dwarf Mistletoes, Etc.

85-F-5 Silvicultural control of dwarf mistletoe in young lodgepole pine stands (B. Geils, D. Johnson).

86-F-1 Evaluation of ethephon as a control of dwarf mistletoes in high use recreation forests (D. Johnson).

E. Miscellaneous Studies

92-K- Effectiveness of fire for site preparation in seral aspen in western Colorado (P. Angwin, W. Shepperd).

90-K-1 Vegetation management planning in developed recreation sites (D. Johnson, P. Angwin, M. Sharon).

2. Terminated Projects

A. Forest Disease Surveys-General

92-A- Forest Health Monitoring plot installation (D. Johnson, Mike Schomaker).

RECENT PUBLICATIONS (as of August 1993)

Angwin, P.A., and E.M. Hansen. 1993. Pairing tests to determine mating compatability in Phellinus weirii. Mycol. Res. (In press).

Haines, A.L., and P.A. Angwin. 1992. Campground vegetation management and silvicultural prescription summary - Taylor Canyon and Taylor Park project. Silvicultural Prescription, USDA Forest Service, Grand Mesa, Uncompahgre and Gunnison National Forests, Taylor River Ranger District. 128 p.

Hawksworth, F.G., and D.W. Johnson. 1993. You can save your trees from dwarf mistletoe. USDA For. Serv., Rocky Mountain Forest and Range Exp. Sta. GTR RM-225. 11 p.

Johnson, D.W. 1992. Effects of application rate and timing of ethephon treatments on abscission of ponderosa pine dwarf mistletoe 4 years following treatment. USDA For. Serv., Renewable Resources, Rocky Mountain Region Tech. Rep. R-2-54. 9 p.

Johnson, D.W., C.G. Shaw, III, and M. Schomaker. 1992. Forest Health Monitoring Plan for Colorado. USDA For. Serv., Renewable Resources, Rocky Mountain Region Tech. Rep. R2-53. 25 p.

Lundquist, J.E. 1992. Pest conditions and potential hazard trees in campgrounds along the North Fork Shoshone River corridor, Wapiti District, Shoshone National Forest. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-92-1. 34 p.

Lundquist, J.E. 1992. An evaluation of a disorder of black walnut seedlings associated with cold storage at Bessey Nursery. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-92-3. 4 p.

Lundquist, J.E., B.W. Geils, and D.W. Johnson. 1992. White pine blister rust on limber pine in South Dakota. Plant Disease 76:538.

O'Neil, C.G. 1993. Forest Pest Conditions in the Rocky Mountain Region 1991. USDA For. Serv., Renewable Resources, Rocky Mountain Region, Forest Health Mgmt. 31 p.

Pasek, J.E., and W.C. Schaupp, Jr. 1992. Populations of Douglas-fir beetle in District, Shoshone National Forest, Wyoming. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-92-01. 13 p.

Pasek, J.E., and W.C. Schaupp. 1992. Status and trends of mountain pine beetle populations in the Bear Mountain and White House Gulch areas on the Harney Ranger District, Black Hills National Forest, South Dakota. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-92-04. 17 p.

Pasek, J.E., and W.C. Schaupp. 1992. Trends in overwintering egg populations of a pine sawfly, Neodiprion autumnalis, on ponderosa pine sampled in January and December 1991 near Ft. Meade in South Dakota. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-92-05. 12 p.

Raimo, B.J. 1993. Western spruce budworm - Creede and Del Norte Districts, Rio Grande National Forest. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-92-4. 32 p.

Schaupp, W.C., Jr., J.E. Pasek, J.M. Schmid, S.A. Mata, and C.K. Lister. 1993. Mountain pine beetle emergence from infested logs during hauling. USDA For. Serv., Rocky Mountain Forest and Range Exp. Sta. Research Note 522. 4 p.

Sharon, M. 1992. Tree failures: can we reduce the risk? Park & Grounds Management. Jan. 1992:4-7.

Sumpter, C.W. and B.J. Raimo. 1992. The use of GPS, GIS and remote sensing in a stratified forest survey. In: Remote Sensing and Natural Resource Management. Proceedings of the Fourth Forest Service Remote Sensing Applications Conference. Orlando, Florida, April 6-11, 1992.

A LINE OFFICER'S VIEW OF FOREST PEST MANAGEMENT

With notes on the future of ecosystem management

Ed Wood
District Ranger
Red River Ranger District, Nez Perce National Forest

Nothing I am going to say to you is either very original or very startling, so those who visited the brewpub last night are free to rest their eyeballs. It always appeared to me that the main reason for Friday sessions at WIFDWC was to allow the senior members to recover from the night before.

I transferred out of Forest Pest Management and into the National Forest system ten years ago. Although I was no longer a pathologist, for the first eight of those years, I was interested in and involved with pest management on an almost daily basis, as a forest planner, public affairs officer, timber staff, and fire staff, in various combinations.

When I was a planner, my forest was one of the first to incorporate comprehensive pest management guidelines into a forest plan. In fact, I delivered a paper on the subject at the 1985 WIFDWC in Olympia. I also furnished enough homebrew for a couple of parties of the whole. Most of you will no doubt remember the parties better than the paper.

As a public affairs officer, I talked a lot about diseases and insects, and their effects on a forest. While a timber staff, white pine blister rust was discovered on my forest, the Lincoln, but not by me. I hate to admit it, but it was that old warhorse, Frank Hawksworth, who came up with it.

Finally, as a fire staff, I completed several large-scale dwarf mistletoe control projects by erradicating the parasite, and its host species, from large areas of the forest.

My attitude toward forest pests has undergone a gradual change in the last ten years. I am no longer dedicated to saving the world from the dreaded root rots, or the insidious mistletoes, or the other things that lurk in the forest, ready and willing to exploit the fragile armor of our most important product, trees.

But then, the Forest Service itself has changed over the same span of time, in its attitude toward forest pests, and in a lot of other ways. I submit to you that the changes have only started, that we are going to see much greater ones in the future.

Rather than stand up there and tell you what I as a district ranger want from you as pathologists, let me describe to you some of the changes taking place on a district level, using Red River as an example, and suggest some places where you might make a contribution to the future.

I want to say that most of what you are doing is right on track. I would like to see some things changed, and I hope I stimulate your thoughts in those directions.

The Forest Service has been talking ecosystem management for several years now. Long enough to know what it is, but not long enough to have developed all the tools and changed all the attitudes to make it work smoothly. Simply put, we know where to go, but not how to get there.

Four years ago, I was one of a group of Forest-level timber staff officers in the Southwest who decided that ecosystem management would never work until the Forest Service was no longer bound to timber targets measured in board feet. We proposed instead that our targets be acres under prescription. Under our scenario, the volume of timber produced would be a result of, or dependent upon, integrated resource management of the land, rather than being the object of land management.

I remember well the reaction to our proposal. To say that it was a resounding "Hell, No! is putting it mildly. We were told that the Forest Service leaders would not accept such a change, and that even if we could convince them that it was the proper course of action, Congress could not be made to understand any target other than bushels or boards.

I think a reaction to such a proposal made today would be neutral, hopefully even positive. I firmly believe that before ten more years have past, many of our targets will be expressed in units related to the ecosystem rather than commodities.

Another example of changed attitudes involves a rather insignificant plant that grows in a few places in the Northwest. The Red River District botanist spends all summer looking for this plant in proposed project areas, including timber sales, mines, trails, and the like. In areas where it is discovered, we have moved cutting units, changed mining plans, and rerouted trails and roads.

So what? Doesn't the Forest Service protect many valuable, rare plants and animals? Of course it does, but only in the last few years would we have even considered protecting a plant like Allotropa virgata (candystick), which parasitizes several species of mycorrhizal fungi, including Cenococum and Rhizopogon, let alone redesigning major projects around it.

On the subject of botany, the district's botanist is attached to the silviculture section. All of our data bases are managed by the same shop. In the near future, we expect to get permission to change the name of the section to better reflect its leadership role in ecosystem management. The process is going slowly because we have to operate within the comfort zones of so many people, but before too many years, I believe that all the resource specialties will be gathered into an ecosystem management unit.

Speaking of silviculturists, I have seen some great changes there in the last few years. Two of our district silviculturists underwent certification or recertification this last year. As I perused the prescriptions they wrote, which were much like theses, I was impressed at the ease with which they integrated pest management into stand management. In fact, they went further and discussed the roles of pests in management of landscapes. Although they struggled with the concept, the need to manage on a landscape basis, rather than by individual stands, was recognized.

In the next few years, I believe that we will see an expansion of the principles of landscape management by silviculturists, and that their title will be changed to reflect the increasing interest in management of all vegetative resources.

Now to the doomsday prophesy. We have been learning to do more with less, but the slope of the learning curve is going to have to increase. To put it in context, Red River District has lost five permanent positions in the last three years, or about fifteen percent of our work force. Now we are facing a further reductions in positions in timber and NEPA coordination, both of which are about as sacred as any in the Forest Service.

The listing of the chinook salmon as threatened involved almost half of the District's workforce last summer, to one degree or another. Although the workload was less this past summer, it was still a major impact on our human resources.

The analysis of effects of projects was possible only because much of the needed information was in exiting data bases, but at the same time, the effort was hampered by the need to validate and upgrade the information.

How are we getting around all this? Far more than at any time in the past, we are using zoning and interdistrict cooperation. People and teams are moving around the forest from project to project, rather than being assigned to specific districts. However, no real solutions have been developed. As a result, stresses are building, and people are burning out.

How can pathologists help? Pest management practicioners have traditionally been closely allied to silviculturists. I submit that you need to adapt, just as your fellow-travellers are adapting, to a larger horizon, the landscape. Become ecosystem managers. Many of you in the field are already doing this, at least in your minds. Examples include the recent symposium on forest health, Jim Byler's article in the Journal of Forestry, and Willis Litke's paper here at WIFDWC. For the rest of you, don't wait to be brought along, there are too many slowdown points as it is. Be out in front!

Abandon your turf. Doing so actually frees you up. As we redefine the role of government, and our agencies, there are opportunities to move out, to be more creative. I have been interested in the recent discussion in the SAF pest management group relating to a name change. Many perceive a name change, and all that it stands for, to be a threat. Some are just not comfortable operating outside traditional areas. True, a change in name might be just eyewash, but I encourage you to look beyond the rhetoric to the mission.

Well, I have probably belabored the point enough. Let me leave you with a story that might put things in perspective. About three miles from the Red River Ranger Station is a hillside which is riddled with root rot. I haven't actually climbed the slope, pulaski in hand, and confirmed this. However, my nose twitches each time I drive by, so that I know in my heart that it is so. Am I worried? Do I feel guilty because two or three hundred acres of the district are not producing the timber of which they are capable?

Not at all. You see, this south-facing slope is valuable mild-winter and early spring habitat for large ungulates (deer and elk), a resource which is lacking in this part of the district. I have shed my pathologist/timber beast mindset, and now look at the pathogens as the agents for accomplishing a management objective. Besides, the area is the primary source of firewood for those who live on the station's grounds.

Business Meeting Minutes

Prepared by James R. Allison

Chairperson Will Littke convened the WIFDWC business meeting September 16, 1993 in Boise, Idaho.

The minutes of the business meeting of the 1992 WIFDWC were accepted as read.

Five new honorary life members were recognized: John "Dick" Parmeter, Earl Nelson, Fields Cobb, Robert "Bob" Scharpf, and Arthur McCain.

Ken Russell presented the Treasurer's Report. A detailed version of the report is included in these proceedings. There was a mistake in the cost of the history and proceedings. The reported cost was $2,000, but the actual cost was $3,316.16. We had a June 18, 1994 balance of $2477.03. The total left after $500.00 wsa provided to Jim Hoffman was about $1500.00 for the next meeting. Ken reported that we are in good financial shape. He also said the History Books are for sale for $10.00. We collected $215 in interest and sold $190 in proceedings. Old proceedings are still for sale. Members gave Ken a hand for the great job he has done as treasurer and approved the Treasurer's Report as read.

John Muir made a motion for Ken Russell to remain as Treasurer. It was moved and seconded. A discussion followed. Out of the discussion came the following decision, Ken Russell will remain as Treasurer, but in addition to Ken, Walt Thies, and Dave Shaw can also sign checks.

Leon Lamadeleine asks folks to consider taking over Ken's job in the future, if they have time to do 3-6 transactions per year. A request went out for volunteers to help Ken this year. John Schwandt volunteered to help Ken.

Charles "Terry" Shaw made a motion to have Secretary send a letter to all honorary life members telling them that they can have a copy of History free of charge if they write and request it. This motion was seconded and passed. Terry also made a motion that Walt Thies make up a list of persons to be added to the list of honorary life members and that a committee should be appointed to draw up criteria for persons to be added to honorary life category. This motion was seconded and passed.

John Pronos made a motion that we reinstitute the "Tree Hazards" Committee that was active between 1966 and 1977. The motion was seconded and passed. John also requested that a sign-up sheet be sent around to find out who is interested in providing input to the functioning of the committee. The chair agreed to this and the list was sent around for signatures.

Charles Gardner Shaw make a motion that in memory of all deceased members of WIFDWC, an amount not to exceed $1,000 be donated by WIFDWC to the Frank

Hawksworth Memorial Fund at Colorado State University. The motion was moved, seconded, and passed. Further discussion explained that a person could chack the box in the letter sent out by WIFDWC so the amount you contribute can be include in Scholarship Fund or make contributions on your own to reduce IRS problems.

WIFDWC Officers elected for 1994: WIFDWC Chairperson- Charles "Terry" Shaw; Secretary- Greg Filip; and Program Chairperson- Mark Schultz.

WIFDWC Conference will be held in Kalispell, Mont. In 1995. The location of the Conference in 1996 and 1997 were discussed at some length. The decision was made to hold the 1996 WIFDWC in the Hood River Gorge Area of Wash./Ore. and the 1997 WIFDWC in Victoria, B.C., Canada.

Special thanks went out to Jim Hoffman for the excellent job he did in the local arrangements.

Treasurer's Report, 41st WIFDWC

Balance recorded at close of fortieth meeting in Durango.		$3680.66
Adjustment for 40th Proceedings plus WIFDWC History: Printed as a package. (Total cost of proceedings plus history = $3031.16. Original estimate was $2000 as shown in 39th treasurer's report for proceedings only.)		(1031.16)
Interest paid to the account from July 1, 1992 through June 30, 1993.		180.05
Miscellaneous: Proceedings sales (25), History sales (6) from 1/1/93 to 12/31/93. (All publications sold @ $10 each.)		310.00
Sub-total		3139.55
WIFDWC transactions at Durango meeting.		
Net Receipts:		6669.00
Meeting Participants		
Regular	60	
Students	14	
Retirees	6	
Spouses/Guests	10	
Total	90	
Expenses: $500 advance sent to Owyhee Hotel 3/23/93 to reserve meeting date subtracted from this total.		(5758.00)
Travel expenses: guest speaker Richard Mueller		(311.00)
Travel expenses: guest speaker Joe Zaerr		(308.00)
Proceedings printing estimate for 160 copies.		(2000.00)
Balance at close of fortieth meeting in Boise		1431.55

Funds held in account 936258-3, Washington State Employee's Credit Union. PO Box WSECU, Olympia, WA 98507. Phone (206) 943-7911. Official signatures for withdrawing funds are Walt Thies, Ken Russell, and David Shaw.

Ken Russell, Treasurer, August 10, 1994.