

# **PROCEEDINGS OF THE 46th ANNUAL WESTERN INTERNATIONAL FOREST DISEASE WORK CONFERENCE**

**Reno, Nevada  
September 28-October 2, 1998**



# **Proceedings of the 46th Annual Western International Forest Disease Work Conference**

**Reno, Nevada  
September 28-October 2, 1998**

**Compiled by:  
Lori Trummer  
USDA Forest Service  
Forest Health Protection, Alaska Region  
Anchorage, Alaska**

Compiled by Lori Trummer  
TABLE OF CONTENTS

Page

- 1 Program  
6 Chairperson's Opening Remarks Bob Edmonds  
8 Keynote Address : Holocene Paleoecology of Central Nevada - Implications for Management  
Robin Tausch

PANEL : ASPEN ECOLOGY, PATHOLOGY AND MANAGEMENT

- 10 Aspen Decline Panel, Moderator Notes John Guyon  
13 The Current Status of Aspen in the Western United States Dale L. Bartos  
18 Monitoring Aspen Regeneration in Northern Arizona Mary Lou Fairweather and Borys Tkacz  
24 Aspen Regeneration Failure Studies in Colorado William R. Jacobi

SPECIAL PAPERS

- 26 Wildlife Use of Dwarf Mistletoe Brooms  
Catherine G. Parks, Evelyn L. Bull, Robert O. Tinnin, Jay F. Shepherd and Arlene K. Blumton  
28 The Impact of Hard Pine Rusts on the Timber Supply in the Central Interior of British Columbia  
Alex Woods, Albert Nussbaum and Bill Goulding  
36 Occurrence of Stem Rusts of Lodgepole Pine in a Site Preparation Trial at Bednesti,  
British Columbia John Muir  
37 Development of the Understory Enhancement for the Dwarf Mistletoe Spread and Intensification  
Model Helen Maffei, Jim Stone, Lance David, Tom Gregg, Judy Adams and Brian Geils  
47 Rare Hybrids of *Heterobasidion annosum* Provide Insights on Mechanisms of Fungal Speciation:  
Potential Effects of Environmental Alteration on the Speciation of a Forest Pathogen  
M. Garbellotto, W. Otrosina and I. Chapela  
57 The Great Debate: Swiss Needle Cast in Coastal Oregon - Pathology or Mythology Gregory M. Filip  
59 Swiss Needle Cast on Douglas-Fir in Coastal Oregon: Is it Time to Reexamine the Paradigm?  
Charles G. "Terry" Shaw III  
61 *Armillaria* Root Disease in California Kendra Baumgartner and David M. Rizzo  
65 Investigation of the *Laetiporus sulphureus* Species Complex in North America  
Harold H. Burdsall Jr. and Mark T. Banik  
72 Filling Missing Values for Multivariate Data Required by a Landscape Forest Pest Model  
Shaoang Zhang, Matthew J. Oberle and Judy A. Adams  
85 Preliminary Report on the Ecology of *Armillaria* in Utah and the Inland West Geral I. McDonald  
93 Reflections on the Epidemiology and Damage Caused by *Elytroderma deformans* in the  
South Lake Tahoe Basin, California, 1971-1998 Robert F. Scharpf

PANEL WOOD DECAY, SOIL ORGANISMS, AND THEIR ROLE IN FORESTED ECOSYSTEMS

- 95 Decay Mechanisms of Basidiomycetes Barbara Illman  
97 Heart Rot and Other Causes of Small-Scale Disturbance in the Temperate Rain Forests of  
Southeast Alaska Paul E. Hennon and Mike H. McClellan

- <sup>1E</sup> 106 Wildlife and Wood Decay Interactions Catherine Parks  
 108 Can We Harness Biological Decomposition to Offset the Effects of Fire as a Primary Carbon  
 Recycling Agent Alan E. Harvey, Michael J. Larsen and Russel T. Graham  
 119 Brown Versus White Rot in Forest Ecosystems : Does it Matter?  
 Robert L. Edmonds and Michelle Isaacson

PANEL - FOREST DISEASE MODELS: WHO IS USING THEM AND WHO IS NOT?

- 125 Summary of Panel Ellen Michaels Goheen

POSTERS

- 129 Dothistroma Needle Blight of Limber Pine in Montana Jane E. Taylor and John W. Schwandt  
 130 Screening for Blister Rust Resistance in British Columbia Yields Western White Pine Seed  
 Orchards R.S. Hunt and G.D. Jensen  
 131 Detection of a Chitinase-Like Protein in the Roots of Douglas-Fir Trees Infected with Armillaria ostoyae  
 and Phellinus weirii Richard Robinson, Rona Sturrock, Joanne Davidson,  
 Abul Ekramoddoullah and Duncan Morrison  
 132 Screening Coastal Douglas-Fir for Resistance to the Laminated Root Rot Pathogen, Phellinus  
 weirii: Interim Results Rona Sturrock, Alvin Yanchuk and Jack Woods  
 133 Computer Demonstration of Preliminary Work on a Mathematical Description of Root Disease  
 Spread Through Root Contact and Fungus Transfer  
 F.G. Peet, R.S. Hunt, R.N. Sturrock, D. M. Morrison and M. Cruickshank  
 134 Causes of Decline in Pacific Madrone (Arbutus menziesii Pursh)  
 Marianne Elliott and Robert L. Edmonds

COMMITTEE REPORTS

- 137 Dwarf Mistletoe Committee  
 143 Hazard Tree Committee  
 144 Rust Committee  
 145 Root Disease Committee  
 149 Disease Control Committee  
 150 Regional New, Continuing and Terminated Project Reports  
 156 Business Meeting Minutes with Bylaws and Treasurer's Report

MEMORIAL STATEMENTS

- 165 Charles Gardner Shaw  
 167 Toby Childs  
 176 Reed Miller

**Western International Forest Disease Work Conference**  
46th Meeting - September 28 to October 2, 1998  
Reno, NV

**Program**

**Monday - September 28**

- 4:00 - 7:00 pm Registration, University Inn, Watts Room  
4:00 - 8:00 pm Social and hospitality, University Inn, Watts Room and adjoining patio

**Tuesday - September 29**

- 6:45 am Rust Committee Breakfast, University Inn, Watts Room  
7:30 - 4:00 pm Registration and Poster set-up, University Inn, Watts and Sierra Room  
8:30 am Chair's Welcome - Bob Edmonds, (University of Washington, Seattle, WA)  
Local information - Jim Hoffman, (USDA - FHP, Boise, ID), Judicial Hall  
9:00 am Keynote Address - Dr. Robin Tausch, (USDA Rocky Mtn. Res. Sta., Reno)  
10:00 am Coffee Break  
10:30 am Brief Regional, University, Provincial, and State Reports  
11:30 am Hazard Tree Committee Lunch, University Inn, Watts Rm.  
1:00 pm **Panel: Aspen Ecology, Pathology, & Management.** Moderator - John Guyon (USDA-FHP, Ogden, UT)  
The Current Status of Aspen in the Western U.S. Dale Bartos (Rocky Mountain Research Station, Logan, UT)  
Monitoring aspen cuts in Arizona. MaryLou Fairweather (USDA-FHP, Flagstaff, AZ)  
Aspen Regeneration Failure Studies in Colorado. Bill Jacobi (Colorado State University, Fort Collins, CO)  
3:00 pm Coffee Break  
3:30 pm **Special Papers.** Moderator - Greg Filip (Oregon State University, Corvallis, OR)  
Dwarf Mistletoe and Wildlife Interactions. Catherine Parks (PNW Res. Sta., La Grande, OR)  
Impacts of Pine Stem Rusts on Lodgepole Pine in the Central Interior of British Columbia. Alex Woods (B.C. Ministry of Forests, Smithers, B.C.)  
Incidence and Effects of Lodgepole Pine Stem Rusts in a Ten-year Experimental Study of Site Preparation Treatments in Central British Columbia. John Muir, Q. Liang, L. Bedford, and M. Grismer (B.C. Ministry of Forests, Victoria, B.C.)  
5:00 pm Adjourn. Hospitality Suite 501.  
7:00 pm Poster Session and Ice Cream Social, University Inn, Watts and Sierra Rooms.

**Wednesday - September 30**

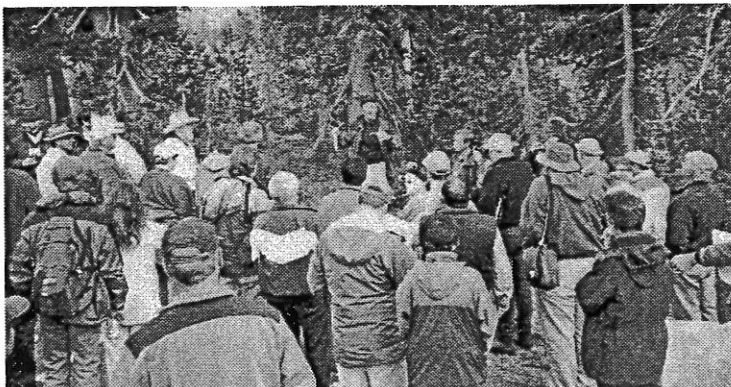
- 6:45 am Disease Control Committee Breakfast, University Inn, Watts Room.  
8:00 am Field Trip to the Lake Tahoe Basin.  
6:00 pm Return to Reno. Dinner on your own.

**Thursday - October 1**

- 6:45 am Root Disease Committee Breakfast, University Inn, Cafe Ten-O-One  
8:30 am **Panel: Wood Decays, Soil Organisms, and Their Role in Forested Ecosystems.**  
Moderator - Bob Edmonds (University of Washington, Seattle, WA), Conference Hall  
Decay Mechanisms of Basidiomycetes. Barbara Illman (Forest Products Lab, Madison, WI)  
Heart Rots as Agents of Small Scale Disturbance in the Rain Forests of Coastal Alaska  
Paul Hennon (USDA-FHP, Juneau, AK), Mike McClellan (PNW Res. Sta, Juneau, AK)  
Decay and Wildlife Interactions. Catherine Parks (PNW Research Sta., La Grande, OR)  
Can We Harness Biological Decomposition to Offset Fire as a Primary Carbon Recycler?  
Al Harvey (USDA-Forest Sciences Laboratory, Moscow, ID)  
Brown vs. White Rot in Forest Ecosystems: Does It Matter? Bob Edmonds (University of  
Washington, Seattle, WA)  
10:30 am **Special Papers.** Moderator - Greg Filip (Oregon State University, Corvallis, OR)  
Development of an Understory Sub-model for the Dwarf Mistletoe Spread and Intensification  
Model. Jim Stone (USDA-Forest Service, Bend, OR)  
Potential Effects of Altered Ecosystems on the Forest Pathogen *Heterobasidion annosum*.  
Matteo Garbellotto (University of California, Berkeley, CA)  
11:30 am Dwarf Mistletoe Committee Lunch, University Inn, Cafe Ten-O-One  
1:00 pm **Special papers.** Moderator - Greg Filip (Oregon State University, Corvallis, OR)  
Swiss Needle Cast in Coastal Oregon: Pathology or Mythology ? Terry Shaw (PNW Research  
Station, Juneau, AK) vs. Greg Filip (Oregon State University, Corvallis, OR)  
Armillaria Root Disease in California. Kendra Baumgartner (Univer. of California, Davis, CA)  
3:00 pm Coffee Break  
3:30 pm **Special papers.** Moderator - Greg Filip (Oregon State University, Corvallis, OR)  
Potential Approaches to Fill Missing Data for Landscape-based Forest Pest Models.  
Shaoang Zhang (INTECS International, Inc.)  
Stumpmaster Video Demonstration. Rich Hunt (Pacific Forest Centre, Victoria, B.C.)  
Ecology of Armillaria in Utah. Geral McDonald (USDA Forest Sciences Lab., Moscow, ID)  
5:00 pm Adjourn  
6:00 pm Banquet: National Automobile Museum, 10 Lake Street S, Reno, NV

**Friday - October 2:**

- 8:00 am      **Panel: Forest Disease Models: Who is Using Them and Who is Not?** Moderator - Ellen Goheen (USDA -FHP, Central Point, OR) Conference Hall.
- Introduction and Results of WIFDWC Survey. Ellen Goheen (USDA -FHP, Medford, OR)
- Models for Whom and What? An Overview of the State of the Art. Judy Adams (USDA Forest Health Technology Enterprise Team, Fort Collins, CO)
- Douglas-fir Dwarf Mistletoe and Northern Spotted Owl Nesting, Resting, and Foraging Habitat: Using the Dwarf Mistletoe Model to Compare Treatment Alternatives. Jim Stone (USDA Forest Service, Bend, OR) and Helen Maffei (USDA-FHP, Bend, OR)
- Using FVS and the Root Disease Model in Broadscale Assessments. Blakey Lockman (USDA FHP, Missoula, MT)
- Forest Disease Models, Who is Using Them, Who is Not, and Why Not? Richard Teck (USDA -Forest Management Service Center, Fort Collins, CO)
- 10:00 am      Coffee Break
- 10:30 am      Business Meeting



## CHAIRPERSON'S OPENING REMARKS

Bob Edmonds  
College of Forest Resources  
University of Washington,  
Seattle, WA

It is a pleasure to welcome you to the 46th Annual Western International Forest Disease Work Conference in Reno. I note that we have quite a few retired members present, and it is a particular pleasure to welcome you. On a sad note, several of our retired members passed away last year, including Charles Gardner Shaw, Toby Childs, and Reed Miller and we will miss them.

I would like to thank the members of the organizing committee of this meeting for their hard work; Jim Hoffman and John Guyon for local arrangements, Greg Filip as program chair, Lori Trummer as Secretary and John Schwandt as Treasurer. I think they have put together a very good program and field trip.

As WIFDWC chair it is typical to look back to the time when you first attended WIFDWC. My first meeting was in 1968 at Couer D'Alene, Idaho when I was fresh young graduate student from Australia. I haven't attended every meeting in the 30 years since then, but this will be my 19th WIFDWC. I thought it might be interesting to compare the program in 1968 to that this year to see how things have changed or stayed the same. Of course I couldn't remember the details of the 1968 program so I had to go back to the proceedings on my shelf. The panels in 1968 were pretty traditional for the time

- Diseases of trees in the Inland Empire, moderated by Don Leaphart and including an interesting paper by Art Partridge (Inland Rots and Tommy Rots),
- Root diseases and intensive forest management, moderated by Charlie Driver, with a paper by Earl Nelson entitled *Poria weirii*: Is there hope for control?, and
- Factors governing the distribution of dwarf mistletoes, moderated by Dick Smith. In this panel Ed Wicker gave a paper on the absence of Douglas-fir dwarf mistletoe from western Oregon and Washington.

There were also workshops on air pollution, remote sensing, cost/benefit ratios, modern techniques of pathogen identification, and, interestingly, managing stands for other than timber values.

We are still considering many of these topics in 1998 and federal public land management in particular now tends to focus on managing stands for other than timber values. New subjects have been introduced since 1968 such as the concept of ecosystem management. We are now studying how pathogens and saprophytes function in ecosystems, not just host/pathogens interactions. At this meeting we have a panel on wood decays and soil organisms and their role in forest ecosystems. Our approach is now more holistic and this has led to forest health monitoring and examination of the interaction of insects, diseases, fire, wind and wildlife in forest ecosystems. Forest pathologists can contribute greatly to forest management decisions, particularly with respect to how wildlife is managed. There are strong relationships between stem decays, dwarf mistletoes and wildlife.

Computers have strongly influenced forest pathology in recent years, and we have come a long way since we used punch cards in 1968. They have particularly enhanced our ability to model diseases and computer assisted aerial photography now enables us to detect differences between bear-killed and root-disease-killed Douglas-fir trees. This technology allows us examine the influence of diseases at the landscape level and the City of Bremerton for example is currently managing its watershed relative

to the distribution of *Phellinus weirii*. Molecular techniques have also been introduced into forest pathology allowing us to better identify new species and strains of pathogens.

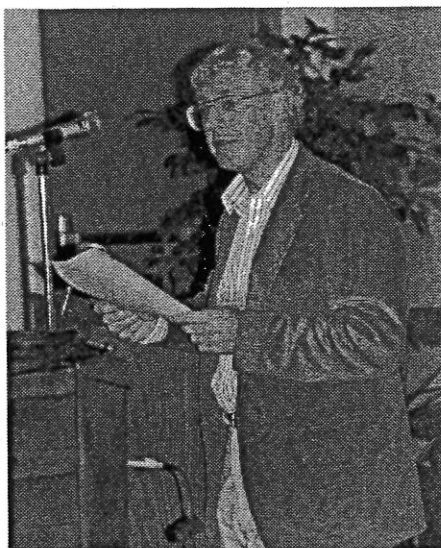
Perhaps one of our greatest new concerns is the introduction of exotic pathogens and insects into North America due to the movement of logs around the world. Many of members feel very strongly about this and suggest that the risk is too high. Hazard trees have also received a lot of attention from our members in recent years.

Many western forest pathologists have been actively involved in education, particularly in the production of videos, compact discs and web sites. Hopefully, after this meeting we will be able to develop a permanent WIFDWC world wide web site to foster this.

These days there are strong concerns about the viability of small organizations like WIFDWC. We all seem to be busier and busier with less and less time to attend meetings. However, WIFDWC still is healthy. Our attendance has fluctuated from 33 at our first meeting to 80 or so and attendance is strong at this meeting (more than 80). The diversity of people attending WIFDWC has also increased; e.g., there were no women at the 1968 meeting, but now women make up as much as one quarter of the attendance. To be viable new members must be recruited and there must be strong student participation. It is encouraging to see so many students here.

One of things that we like to encourage at WIFDWC is the exchange of ideas and we hope that the audience will actively participate in the panel discussions here. We also have a new format to encourage this exchange of ideas represented by the debate between Terry Shaw and Greg Filip about Swiss Needle Cast. I am sure you are as interested as I am in how this debate will turn out.

Thanks for nominating me as the meeting chairperson for 1998. I know we are going to have an excellent meeting.



Bob Edmonds

## KEYNOTE ADDRESS

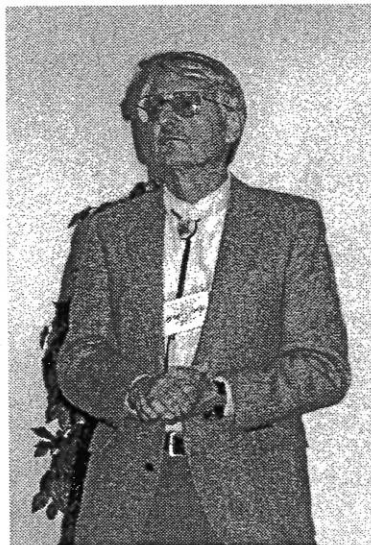
### Holocene Paleoecology of Central Nevada--Implications for Management

Dr. Robin Tausch  
USDA Forest Service  
Rocky Mountain Research Station, Reno, Nevada

References to ecosystem health, including forest and range condition and trend, are widely applied to plant communities and whole ecosystems. Despite their importance, the interpretation or understanding of terms such as good or poor ecosystem health vary greatly, are the subject of scientific, social, and political debate, and often do not supply answers to management questions.

Usually ecosystem health is determined by reference to a standard. This standard varies, but it is based on judgement of what represents healthy or unhealthy condition from community composition. This paradigm has created problems for the interpretation and understanding of the present and future states of the structure, function, and resilience of ecosystems. First, since the late 1950's, plant communities have been known to potentially have multiple endpoints. Second, accumulated information from the past shows that the climate has continually changed during the last 2-million years. Third, other information is demonstrating the potential impacts from the past, present, and future human activities altering ecosystem dynamics. Finally, there is a general failure to keep the concepts of health or condition separate from the ecological data and theories used or applied in making those assessments.

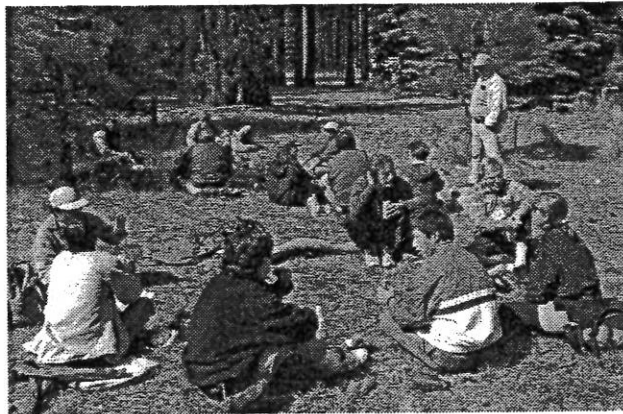
For instance, to understand the dynamics of Great Basin woodlands, knowledge of their development is necessary. At the core of current and historic woodland development is climate. Through the control of energy and water, climate is the most important factor in the occurrence and distribution of plant communities and ecosystems. Land form is the major modifier of climate. Climate change and its topographic modifications influence key ecological processes, driving both local and regional vegetation changes up and down the scales of space and time. Thus far about all we really can predict about climate is that it will change.



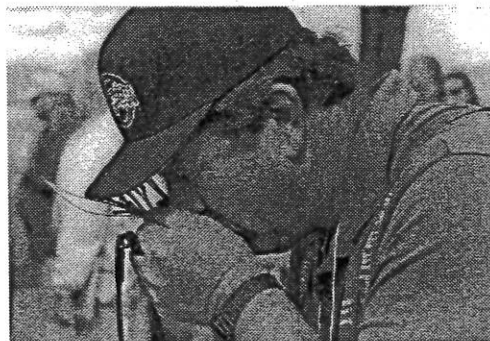
Robin Tausch

On geologic time scales, most of the Great Basin is a region or zone of transition between northern coniferous forests and southern deserts that has shifted hundreds of miles north and south during each glacial cycle. As community composition has continually changed, both between and within glacial cycles, these changes were modified by the topography of the region. There have been major shifts through time in the trees' location, their abundance, and their relative contribution to plant communities. It is apparent that each vegetation change interacting with the environment sets the conditions for the next vegetation change.

Currently, multiple successional stages of plant communities occur in repetitive, but constantly changing mosaics across the landscape. However, dramatic expansion of the pinyon-juniper plant community over the last 150-years has set up the conditions for possible decline in these woodland areas from large fires.



Tod Ramsfield



Will Littke

## PANEL: ASPEN ECOLOGY, PATHOLOGY, AND MANAGEMENT

**John Guyon - Moderator**

USDA Forest Service

Ogden, Utah

A paper by Dr. Charles Kay published in the *Journal of Forestry* (97) coined the term "aspen decline" to describe a reduction in trembling aspen, *Populus tremuloides*, acreage in the western United States. This "decline" appears to be taking place throughout the west. Bartos and Campbell (98) recently reported a 60 percent decline in aspen acreage in Utah. For several years prior to either of these publications many land managers in the USDA Forest Service have voiced their concerns about the declining vigor of aspen clones in Utah, Idaho, and western Wyoming. This phenomenon is not new, with various authors reporting declining aspen clones since 1954 (Elison 1954, Krebil 1972, and Schier 75). The reduction in aspen acreage has become acute in some areas. For example, a 90 percent decrease in aspen acreage was recently reported from the Targhee National Forest in one drainage (Monte 96).

An excellent review of aspen ecology, and management is provided in DeByle and Winokur (85). My purpose here is not to examine biological and physical factors associated with this "decline", but rather to examine the roles that forest diseases play in this decline. One definition for forest decline is, "a disease with multiple interchangeable, specifically ordered abiotic and biotic factors producing a gradual, general deterioration often leading to the death of trees" (Manion 81). Does aspen decline described by Kay fit in this definition? If you accept that the fundamental unit of aspen regeneration is the clone, and that multiple interacting factors involved in the decline are fire exclusion, heavy grazing pressure, and an invasion of aspen sites by other forms of vegetation, then perhaps this decline does fit the description. I prefer to think of this decline as primarily an ecological phenomenon in which humans have played a major role by excluding fire, introducing a large number of domestic grazing animals, and eliminating the predators of wild herbivores. The end result is that the "natural" disturbance pattern in many, if not most, aspen clones has been altered, making it difficult for clones to regenerate. Forest insects and diseases may have an impact on this process, but the role has been largely unexamined. For critical review, I would like to postulate a generalized model of roles that forest insects and diseases might play in this ecological phenomenon.

### Possible Roles Of Forest Insects and Diseases in Aspen Clone Decline

1. Stress indicators. Some diseases such as Cytospora canker, *Cytospora chrysosperma*, have a definite relationship with stress caused by biotic and abiotic factors (Guyon et al. 96). Others such as Poplar borer, *Saperda calcarata*, play similar roles (Jones et al. 85). It may be possible to use the presence of insects and diseases of this type as indicators of stress, perhaps shedding some light on the overall health of a clone.

2. Recycling Agents - Stem decays and/or root diseases may be indicators of advanced stem age. In a biological evaluation conducted by Forest Health Protection, (Guyon 93) less than five percent of the trees under 80 years old on the Fishlake National Forest had visible signs of decay. Twenty-two percent of the trees in the 80-90 year old age class had conks and although difficult to determine precise ages on most trees over 90 years, 38 percent of these trees had some external evidence of decay. Ganoderma root disease, *Ganoderma applanatum*, also appears to increase in incidence within older stands in the Intermountain Region (Richard Krebill, personal communication). It seems logical to assume that as disease incidence increases, it signifies prolonged intervals between disturbance events.

3. Foliar Insects and Diseases. Defoliation causes stress in trees by reducing the amount of photosynthate available to the tree. Large scale outbreaks of foliar insects and pathogens have occurred in the Intermountain Region, particularly Marssonina leaf blight, *Marssonina* spp. (Harniss and Nelson, 1984). Aspen defoliation is mapped by Intermountain Region Forest Health Protection aerial surveys every year. A recent peak in heavy defoliation over 14,000 acres occurred in 1997 (unpublished data). I have personally observed trees with heavy defoliation on the Wasatch-Cache National Forest that have experienced three consecutive years of heavy defoliation. After the first year, I could see little or no tree mortality or branch dieback. After the second year of heavy defoliation, some branch dieback was evident, and less one percent of the trees died. After three years of heavy defoliation, branch dieback, topkill and tree mortality were common. These observations correspond with similar damage observed by Dr. William Jacobi in Colorado (personal communication). Interestingly, many of these clones are now producing root suckers. This may indicate that consecutive years of defoliation can act as a large scale disturbance agent, similar to wildfire events or silvicultural treatments. Presumably, this premature loss of foliage may also contribute to the slow decline of clones by exhausting carbohydrate reserves.

4. Thinning agents. Regeneration of 20-30,000 stems per acre is not excessive in many western aspen stands (Schier et al 1985). A reduction in stems per acre occurs sharply during the first five years of regeneration and more slowly afterwards. In the early stages of regeneration shoot blight, *Venturia* spp. and Cytospora canker are the most commonly encountered diseases (Jacobi and Shepperd 91). Insects and diseases play a vital role in thinning aspen clones throughout their life-span. All categories of aspen disease act as thinning agents under the right circumstances.

5. Agents causing regeneration failure. In this panel Dr. William Jacobi discussed several examples of regeneration failures. In the Intermountain Region, I have observed at least 10 regeneration failures in aspen, and heavy grazing pressure was associated with all but one of them.

In summary, I would like challenge all WIFDWC members to use their experience and build upon the framework I have outlined above to increase our understanding of role played by insects and diseases in aspen decline. In his opening statement, Dr. Tausch talked about ecological thresholds, past which it is difficult to alter the trajectory of ecological change. I believe that we may be quickly approaching one of these thresholds with aspen in the western U.S., if we have not already surpassed it. If Dr. Kay's ideas discussed in his paper are correct, we are indeed approaching a critical junction in the natural history of aspen as a species. Increasing the awareness of all land stewards in the west of the altered state of our aspen forests is essential.

#### References

- Bartos, D. L. and Robert Campbell. 1998. Decline of quaking aspen in the interior west-Examples from Utah. *Rangelands* 20:17-24.
- DeByle, Norbert V., and Robert P. Winokur, editors. 1985. Aspen: Ecology and management in the Western United States. USDA Forest Service GTR RM-119, 283 p.
- Elison, Lincoln. 1954. Subalpine vegetation of the Wasatch Plateau. *Ecological Monographs* 24:86-96.
- Guyon, John C. 1994. A Forest-wide survey to assess the effects of diseases and insects on the Bridger-Teton National Forest. USDA Forest Service, Forest Pest Management Publication R4-94-03. 29 p.
- Guyon, John C., William R. Jacobi and Gary A. McIntynre. 1996. Effects of environmental stress on the development of Cytospora canker of aspen. *Plant Disease* 80:1320-1326
- Harniss R. O. and D. L. Nelson. 1984. A severe epidemic of Marssonina leaf blight on quaking aspen in northern Utah. USDA Forest Service Research Note INT 339. 6 p.

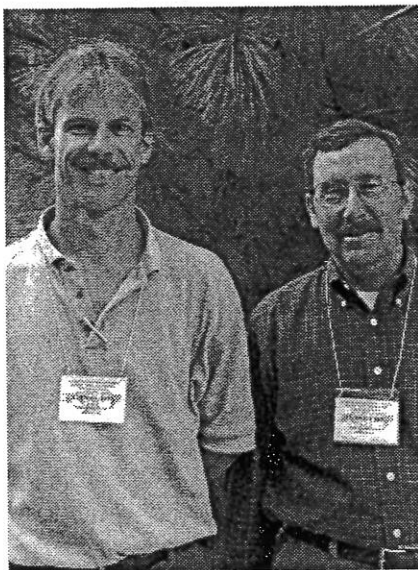
Jacobi, W. R. and Wayne D Shepperd. 1991. Fungi associated with sprout mortality in aspen clearcuts in Colorado and Arizona, USDA Forest Service, Rocky Mtn Forest and Range Experiment Station, Research Note RM-513. 5p

Kay, Charles E. 1997. Is aspen doomed? Journal of Forestry 95: 4-11.

Krebill, R. G. 1972. Mortality of aspen on the Gros Ventre elk winter range. USDA Forest Service Research Paper INT-129. 16 p.

Monte, Duane R. 1996. Aspen Ecosystem Recovery plan. Targhee National Forest. 12 p.

Schier, G. A. 1977. Deterioration of aspen clones in the middle Rocky Mountains. USDA Forest Service Research Paper INT-170.



John Guyon and Jim Hoffman



Bill Jacobi

## The Current Status of Aspen in the Western U.S.

Dale L. Bartos  
USDA Forest Service  
Rocky Mountain Research Station, Logan, UT

Quaking aspen (*Populus tremuloides*) is widely distributed across the North American continent (Little 1971, Sargent 1890). The aspen type extends from Labrador on the east coast to Alaska on the north to Mexico on the south. In its eastern range, aspen is relatively continuously distributed. However, in the western U.S., it occurs on the more suitable sites of mountains and high plateaus (Jones 1985), and in the driest climates it is confined to riparian zones. Most western aspen occurs on public lands and exists either as pure clones or successional to conifer (some are replaced by sagebrush). It can occur as extensive stands or as small scattered groves. Generally, aspen communities in the western United States are second only to riparian areas in species diversity and abundance. Aspen is a keystone species in the West and one of the best integrators of overall ecosystem health.

It is commonly recognized that aspen ecosystems in the West produce numerous products and benefits some of which include: (1) favored wildlife habitat for big-game and non-game species, (2) forage for livestock, (3) water for downstream users, (4) watershed protection, (5) esthetics, (6) sites for recreational opportunities, (7) wood fiber, and (8) landscape diversity. Loss, or potential loss, of aspen on these lands can be attributed primarily to the successional process that occurs with the reduction (or elimination) of fire and by excessive use by ungulates.

An aspen clone contains numerous genetically identical stems (ramets) that propagated vegetatively from a single seedling which germinated at some time in the past. These stems may or may not be interconnected via the root system. Shepperd and Smith (1993) reported that by approximately 25 years of age aspen stems have established independent root systems with few stems still connected by the original root system. Unlike other tree species, aspen lost from the landscape generally will not return through natural seeding processes.

Because western aspen reproduces primarily by self-regeneration, the elimination (or major modification) of fire and extensive overuse of the reproduction has caused many aspen dominated sites to convert to other vegetation types. For millennia, aspen communities in the West regenerated as clones with suckers arising from parent root systems that survived frequent wildfires. Barnes (1975) speculates that many of these clones have been present on sites since the last ice age while Knight (1994) states some clones may have persisted since Pleistocene times. Therefore, clones that have persisted for thousands if not hundred of thousands of years have been eliminated in as little as 150 years (since European settlement).

Successful sexual reproduction is extremely rare in western aspen forests (Mitton and Grant 1996). Jelinski and Cheliak (1992) describe "windows of opportunity" that allow seedling establishment at intervals of 200-400 years. Numerous aspen seedlings occurred after the 1988 fires in the Greater Yellowstone Ecosystem, however little of this regeneration survived because of heavy use by wild ungulates or other factors (Kay 1993). Generally, vegetative reproduction requires a disturbance or die-back which alters the hormonal balance (Schier, et al. 1985; Bancroft 1989). Basically, when the tree is killed or stressed this disrupts the flow of auxin down to the root system and allows cytokinins (that is produced in the roots) to stimulate suckering. One major stressing factor is caused by disease, e.g. *Marssonina* leaf blight, which occurs periodically (Harniss and Nelson 1984).

Fire has been a critical part in defining the spatial and temporal variability of western aspen landscapes. In recent years, fire has been recognized as a critical tool for the resource manager. Pyne (1995) said it very succinctly that "fire and humans coevolved". It has long been thought that inhabitants of the North American continent were natural conservationist living in harmony with the

environment; however, it is becoming clear that they had a profound influence on the landscape, particularly with respect to the use of fire. When European man settled the western U.S. about 1850, they found a mosaic of vegetation that had been profoundly influenced by native American (Kay 1997). These "pristine" landscapes were in a continual state of flux as a result of both natural and man caused burning. Furthermore, early settlers impacted the land by removing the fine fuels by grazing domestic livestock. In the early part of the twentieth century, the land managers instigated a very vigorous campaign of fire control. The absence of fires on these landscapes, coupled with excessive browsing of young aspen trees by livestock and wildlife, has led to rapid displacement of aspen communities by conifer forests throughout the West.

I believe that knowing more about the fire history is absolutely essential to understanding the dynamics of the aspen ecosystem. Ongoing fire history work in southern Utah indicates that during the ~ 400 years prior to settlement fire free cycles varied from 20 to 60 years (L. Chappell, unpublished data).

Given a continuation of conditions (e.g., lack of fire, wildlife use, grazing by livestock) that have prevailed for the past 100-150 years in the Interior West, most aspen stands will eventually be replaced by conifers, sagebrush, or possibly other shrub communities. Numerous areas throughout the West which were once dominated by aspen are in a late successional stage, and if treatment is going to be successful, something needs to be done soon. Many treatment alternatives (fire, cutting, fencing, spraying [Bartos and Harniss, 1990; Bartos and Lester, 1984], ripping, chaining, etc.) exist that can be used by land managers to rejuvenate aspen. In certain areas, treatments need to be pursued with caution. Excessive animal pressure (Shepperd and Fairweather 1994) must be considered in certain parts of the West. Clones treated by burning and then repeatedly browsed usually only hasten their demise (Bartos et al., 1994; Kay 1990). Therefore, treatments that induce suckering must not be initiated before relief from excessive browsing is obtained (Southwest Region 1994).

Currently, there are more precise data on aspen occurrence and distribution than at any time in the past. Rocky Mountain Research Station's Forest Inventory and Analysis Project (FIA) has compiled data on aspen in the Interior West. Their data represent the current abundance of aspen and can be used to suggest the historical acreage of aspen. Historical data result from summing all acres that currently contains at least one aspen (either living or dead) which implies that these acres were once occupied by aspen. Bartos and Campbell (1998) report that for the state of Utah, FIA data shows that there has been at least a 50% decrease in aspen dominated lands since the arrival of European man. Similar losses have been reported for other aspen producing States in the west (Table 1). These losses range from 40% in Colorado to 95% in Arizona. Conifer trees transpire more water than aspen and have sparse undergrowth with relatively few species. Therefore, this loss of aspen from western landscapes translates to a decrease in water, forage, and biodiversity as well as other benefits.

Lachowski, et al. (1996) and Wirth et al. (1996) studied the extent of aspen decline in the Gravelly Mountain landscape in southwestern Montana. They used remote sensing and geographic information systems (GIS) to evaluate the loss of aspen. They reported that aspen decreased by ~47% over the 45-year period (1947-1992) and that the biggest change was due to succession to conifer species. Brown (1995) in a review article, states that the deterioration of aspen in Oregon and Washington does not seem substantially different from the decline of aspen in other parts of the west.

Bartos and Campbell (1998) have identified five risk factors to help resource managers prioritize critical areas in need of treatment. If any of these factors exist then it is incumbent on the manager to consider treatment---particularly if their objective is to maintain aspen on the landscape. Following are the five risk factors:

- (1) conifer understory and overstory cover >25%
- (2) aspen canopy cover <40%
- (3) dominant aspen trees >100 years of age
- (4) aspen regeneration <500 stems/acre (5-15 feet tall)
- (5) sagebrush cover >10%.

If any of these factors exist, then the landscape is not in a properly functioning condition.

Aspen are susceptible to many diseases, however, few kill or seriously injure living trees (Hinds 1984). Disease becomes more prevalent in these over mature aspen stands (either climax or successional) and can cause a decrease in merchantable logs.

Table 1. Current and Historical Acres of Aspen for Various States and percent Decline.

State	Historical Aspen acres	Current Aspen acres	Acres Lost	Decline %
Arizona	720,880	29,009	691,871	96
Colorado	2,188,003	1,110,764	1,077,239	49
Idaho	1,609,547	621,520	988,027	61
Montana	590,674	211,046	379,628	64
Nevada	-----	118,768		
New Mexico	1,141,677	140,227	1,001,450	88
Utah	2,930,684	1,427,973	1,502,711	51
Wyoming	436,460	203,965	232,495	53
Total	9,617,925	3,863,272	5,754,653	60

#### Literature Cited

- Barnes, B. V. 1975. Phenotypic variation of trembling aspen in Western North America. *Forest Science* 22(3):319-328.
- Bancroft, B. 1989. Response of aspen suckering to pre-harvest stem treatments: A literature Review. Forestry Canada and B.C. Ministry of Forests, Research Branch, Victoria, B.C. 55 p.
- Bartos, D. L. and R. B. Campbell, Jr. 1998. Decline of quaking aspen in the Interior West--- examples from Utah. *Rangelands*. 20(1):17-24.
- Bartos, D. L. and R. O. Harniss. 1990. Pine Hollow Exclosures: Effect of Browsing on a Aspen Community Sprayed with 2,4-D. Res. Note INT-393. Ogden UT. USDA For. Serv., Intermountain Research Station. 9 p.
- Bartos, D. L., and J. E. Lester. 1984. Effects of 2,4-D on a *Populus tremuloides* community in the Western United States--22 years after treatment. *Great Basin Naturalist* 44(3):459-467.
- Bartos, D. L., J. K. Brown, and G. D. Booth. 1994. Twelve years biomass response in aspen communities following fire. *J. Range Management*. 47:79-83.
- Brown, M. 1995. Aspen decline in the inland Northwest: a review of some relevant literature. Unpublished manuscript. 28 p. PNW.

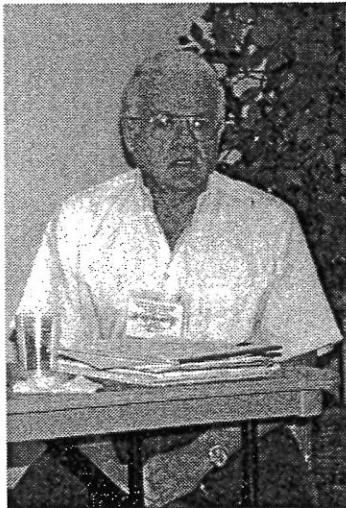
- Hinds, T. E. 1985. Diseases p. 87-106. IN: DeByle, N.F., and R. P. Winokur, (eds). Aspen: Ecology and Management in the western United States. USDA Forest Ser. Gen. Tech. Rep. RM-119.
- Harniss, R. O. and D. L. Nelson. 1984. A severe epidemic of *Marssonina* leaf blight on quaking aspen in northern Utah. Res. Note INT-339. Ogden UT. USDA For. Serv. Intermountain Research Station. 6 p.
- Jelinski, D. E., and W. M. Cheliak. 1992. Genetic diversity and spatial subdivision of *Populus tremuloides* (Salicaceae) in a heterogeneous landscape. Amer.J.Bot 79(7):728-736
- Jones, J. 1985. Distribution p. 9-10. IN: DeByle, N.F., and R. P. Winokur, (eds). Aspen: Ecology and Management in the western United States. USDA Forest Ser. Gen. Tech. Rep. RM-119.
- Kay, C. E. 1990. Yellowstone's northern elk herd: A critical evaluation of the "natural regulation" paradigm. PhD. Dissertation Utah State University, Logan, UT. 490 pp.
- Kay, C. E. 1993. Aspen seedlings in recently burned areas in Grand Teton and Yellowstone National Parks. Northwest Science 67:94-104.
- Kay, C. E. 1997. Is aspen doomed? J. For. 95(5):4-11.
- Knight, D. H. 1994. Mountains and Plains The Ecology of Wyoming Landscapes. Yale University Press, New Haven. 338 p.
- Lachowski, H.; J. Powell; T. Wirth; P. Maus; K. Suzuki; J. McNamara; P. Riordan; and R. Brohman. 1996. Monitoring aspen decline using remote sensing and GIS---Gravelly Mountain Landscape, southwestern Montana. Report prepared for Remote Sensing Steering Committee, USDA Forest Service. 15 p.
- Little, E. L. Jr. 1971. Atlas of United States trees: Vol. 1 Conifers and important hardwoods. Misc. Pub. 1146. USDA Forest Service, Washington, D.C. 211 pp.
- Mitton, B. J. and M.C. Grant. 1996. Genetic variation and the natural history of quaking aspen. Bioscience 46:25-31.
- Pyne, S. J. 1995. World fire---the culture of fire on earth. Henry Holt and Co. New York. 379 p.
- Sargent, C. S. 1890. The silva of North America. Vol. 9, Cupuliferae---Salicaceae. 190 p. Arnold Arboretum, Harvard University. [Reprinted by Peter Smith, N.E., 1947.]
- Schier, G.A.; J. R. Jones; and R. P. Winokur. 1985. Vegetative Regeneration p. 29-33. IN: DeByle, N. F., and R. P. Winokur, (eds). Aspen: Ecology and Management in the western United States. USDA Forest Ser. Gen. Tech. Rep. RM-119.

Shepperd, W. D. and M. L. Fairweather. 1994. Impact of large ungulates in restoration of aspen communities in a southwestern ponderosa pine ecosystem. In: Conference on Sustainable Ecosystems: Implementing an Ecological Approach to Land Management. July 12-15, 1993, Northern AZ Univ. GTR-RM-247. Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station. 344-347.

Shepperd, W. D. and F.W. Smith. 1993. The role of near-surface lateral roots in the life cycle of aspen in the central Rocky Mountains. *Forest Ecology and Management* 61:157-170.

Southwestern Region and Rocky Mountain Forest and Range Experiment Station. 1994. Sustaining our aspen heritage into the twenty-first century. *USDA For. Ser.* 6 p.

Wirth, T.; P. Maus; J. Powell; H. Lachowski; K. Suzuki; J. McNamara; P. Riordan; and R. Brohman. 1996. Monitoring aspen decline using remote sensing and GIS---Gravelly Mountain Landscape, Southwestern Montana. Report prepared for Remote Sensing Steering Committee, USDA Forest Service. 14 p.



Dale Bartos



Mary Lou Fairweather

## **Monitoring Aspen Regeneration in Northern Arizona.**

Mary Lou Fairweather and Borys Tkacz  
Forestry and Forest Health  
Arizona Zone of Entomology and Pathology  
Flagstaff, Arizona

### **Abstract**

This study was setup in northern Arizona in 1990 to monitor the causes of mortality in aspen regeneration, which had been protected from the impacts of ungulates. In 1997, ungulates were browsing 6 of the 10 sites even though the fence had only been removed intentionally from 2 sites. The biological agents responsible for the original dieback became insignificant compared to the damage caused by ungulates, especially elk.

### **Introduction**

The decline of aspen in the Southwest has concerned resource managers for several decades. A recent comparison of forest inventories revealed rapid changes in only 25 years (Anonymous 1993). Aspen dominated forests decreased from 5.9% to 3.6% in New Mexico, and from 2.0% to 0.7% in Arizona, representing a 39% and 65% loss, respectively. This decline has been confirmed by visual observation and comparison of old photographs and is considered to be due to changes in forest structure and composition as a result of fire suppression, overgrazing, logging practices, and browsing of sprouts by ungulates.

In northern Arizona, aspen stands are generally much smaller than stands characteristically found throughout the Rocky Mountains. Most aspen groves are single storied with a conifer component of ponderosa pine or mixed conifer species that are in the process of shading out the aspen.

On the Peaks Ranger District (RD), Coconino National Forest, in northern Arizona, several attempts to regenerate aspen in the 1970's and early 1980's failed. This was not from lack of initial suckering of the root systems, but from subsequent sucker mortality due to incessant browsing from large ungulates. Since the mid-80's, over 20 areas have been clearfelled followed by fencing. The fences are about seven feet high in order to exclude elk and deer, in addition to cows. These areas range from about 5 acres to 40 acres in size. In 1990, personnel from the AZ-Zone office of Entomology and Pathology were requested to determine causes of mortality occurring within some of these regenerated and fenced areas. These dieback areas were approximately 2-4 acres in size. This paper presents the results of this study.

### **Methods**

Monitoring began in 1990 with the selection of seven aspen regeneration sites (645, 5489, 5466, 3937, 4631, 4648, and 4634). Most sites were harvested between 1986 to 1988, and fenced immediately afterward. Sites 4631, 4648, and 4634 had 2-4 acre patches of recent mortality in 1990. Site 645, harvested in 1980 and not fenced until 1987, was showing overall regeneration problems in 1990.

Survey design was as follows: 10 plots on a 2 X 2-chain grid were established in each site. However, two sets of 10 plots were established in the three sites having patches of mortality, one set in each of the "good" and "poor" regenerated areas. The plots were 5' X 5'. Information collected included number of live and dead trees. The following measurements were collected for the three largest live and three largest dead trees in each plot: diameter at root crown (drc); height; % live crown; age (destructive sampling of 3 largest live and dead trees outside plot), and presence of pathogens and insects. Remeasurement occurred in 1992, 1994, and 1997.

### Results

In September of 1990, the average stocking of all sites ranged from 1600 to 3600 live trees per acre (TPA) and 3000 to 68000 dead TPA (Figure 1). Site 645, which was fenced 7 years after harvest, had the lowest stocking of live trees and was the only site where sprouting occurred right out of stumps. As previously mentioned, sites 4631, 4648, and 4634 were divided into two survey areas, poor (P) and good (G). The number of dead trees nearly equaled the number of live trees in site 4631, but dead trees far exceeded the live trees in sites 4648 and 4634. Since we determined that small dead stems typically fell over after a year or two, it was assumed the mortality had occurred all at once.

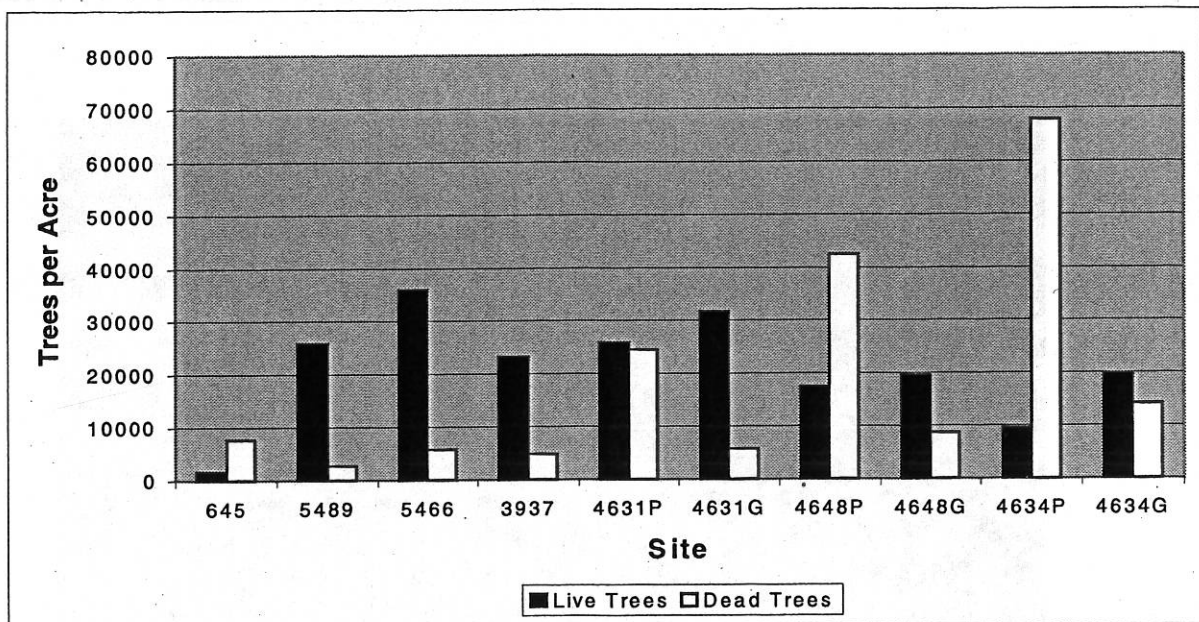


Figure 1. --Trees per acre for all aspen sites, 1990.

Table 1. --Disease and insects affecting aspen sites on the Coconino National Forest. All records are from live trees except for the canker category, which was tallied from dead trees in 1990 only.

Disease and Insect Categories	# Sites, 1990	% Trees, 1990.	# Sites, 1992	% Trees, 1992	# Sites, 1994	% Trees, 1994	# Sites, 1997	% Tre 1997
Foliage Diseases	10	4-100	10	21-100	1	11	4	4-9
Cankers	10	40-88	NA	NA	NA	NA	NA	NA
Frost Damage	4	6-16	0	0	0	0	0	0
Aphids	6	14-43	0	0	1	43	0	0
Basal Wounds	4	4-63	0	0	1	11	1	4
Ungulate Browsing	0	0	2	63-70	6	4-100	6	9-10
Antler Rubbing	0	0	0	0	0	0	4	30

Incidence of the major insects and diseases is presented in Table 1. The foliage diseases, *Marssonina populi* and *Melampsora medusae*, occurred to some degree in all sites in 1990 and 1992, and tapered off during the drier years of 1994 and 1997. Although the canker-causing disease, *Cytospora chrysosperma*, was only tallied on dead trees in 1990, it was associated with mortality every year. Frost damage was only evident in 1990. Aphids were active in six sites in 1990 and one site in 1994, causing stunted leaves. Rodents and snowbend probably caused the basal wounding. *Armillaria sp.* root disease was found during off-plot sampling on recently killed trees in sites 5466 and 4634P.

Damage from ungulates was included when it became an important cause of mortality. Ungulate browsing and barking increased over the years for a couple of reasons. In the fall of 1991, Peaks RD personnel removed the fence from part of site 4634, which contained both the 4634P and 4634G plots. It was thought the 5-year-old trees were tall enough to survive elk browsing. However, the elk actually reached up and grabbed the tops of many trees to get at the succulent foliage, snapping off the top of the tree on their way down (Figure 2). The lower portions of these trees did not survive over time due to both *C. chrysosperma* infection and continued browsing of foliage, which sprouted from dormant buds. By 1997, there were no live trees left in the plots of 4634P and the number of trees in 4634G was severely reduced (Figure 3). Later, the bark started getting stripped off trees that were used for rubbing antlers. This bark stripping exposes wood to decay organisms.



**Figure 2. –Elk damaged aspen regeneration. A seven-foot tall fence had protected these suckers for 5 years. This shot was taken one year after removal.**

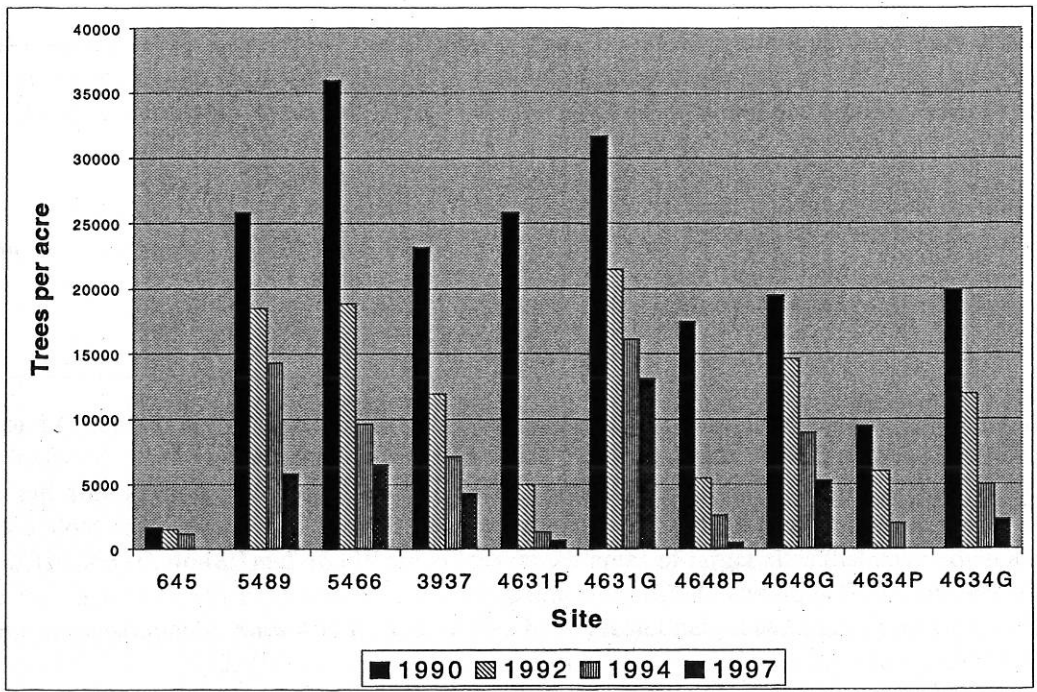


Figure 3. -Change in density (trees per acre) for all sites from 1990-1997.

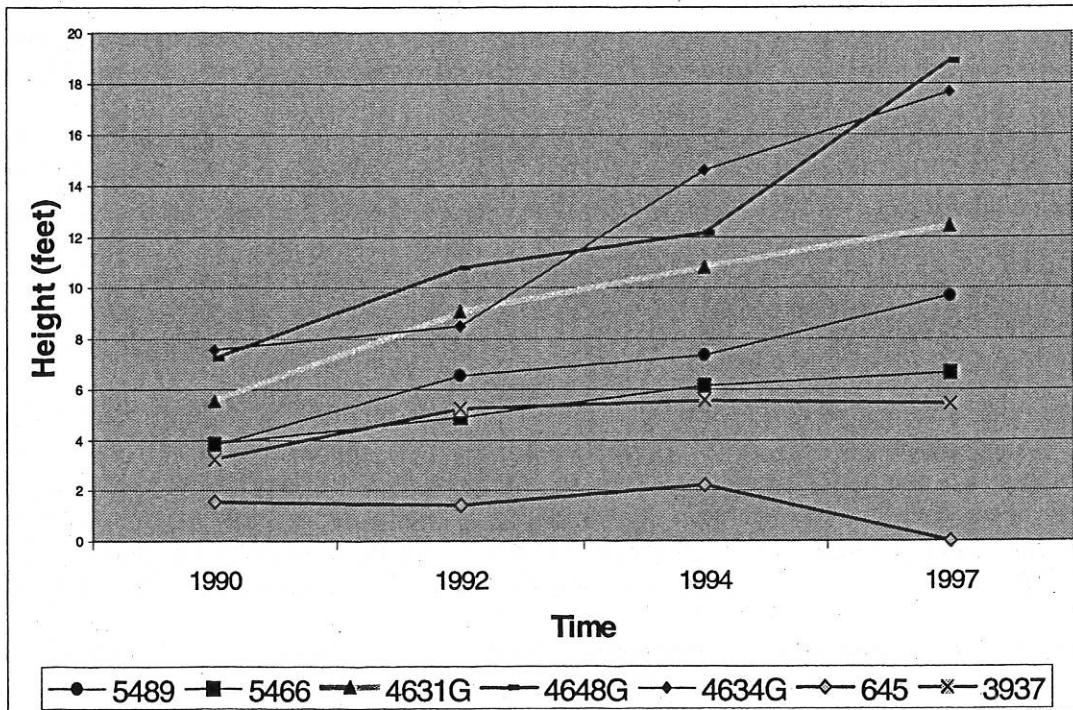


Figure 4. -Average height of aspen trees in selected sites, over time.

Although no other fences were removed, there were 4 other sites (4648P, 4648G, 5489, and 5466) affected by ungulate activity. The fences started sagging in these areas, allowing elk and/or deer to jump into these sites. Interestingly, sites 4634G and 4648G, the “Good” sites most affected by the ungulates, had the greatest average heights in 1997 (Figure 4).

Sites 645, 4631P, 4631G, and 3937 had no sign of ungulate activity, although there were other problems. No live stems were seen inside or outside the established plots of site 645 in 1997, it is now a protected area of grasses and forbes. Apparently, the aspen sprouts were browsed too heavily before this area was fenced.

The trees in site 4631P continued to decline. It was the only site with continuous aphid populations, but the aphids are not known to kill trees.

### Discussion

Bartos and Campbell (1998) outlined five risk factors for aspen dominated landscapes. One of these risk factors included aspen regeneration that is at less than 500 stems/acre (5-15 feet tall). Sites 645, 4631P, 4648P, and 4634P, classified "poor" at the beginning of our study, have 0, 660, 500, and 0, trees per acre left in the plots, respectively. All four of these sites would be considered at risk or, obviously, completely failed. Sites 4631P, 4648P and 4634P are at least small areas of larger sites that have adequate stocking (Figure 3). However, since elk and deer are impacting sites 4648G and 4634G, the success of these sites over time is questionable. Sites 4648G and 4634G have greater height averages compared to the other sites (Figure 4). This is likely due to the elk damage since the smaller trees are more easily killed and the residual trees have reduced competition.

In 1990, this study was setup to monitor the causes of mortality in aspen regeneration, which had been protected from the impacts of ungulates. In 1997, ungulates were browsing 6 of the 10 sites even though the fence had only been removed intentionally from 2 sites. The biological agents responsible for the original dieback became insignificant compared to the damage caused by ungulates, especially elk.

In studies dealing with the impacts of elk on aspen in Wyoming, Colorado and Northern Utah, elk occupy aspen stands as their winter range (Romme et. al. 1995; Krebill 1972; Packard 1942). In Arizona, elk along with deer and domestic livestock occupy and impact aspen sites during the growing season, and nearly always move down to lower elevations for the winter. In the north, browsing of sprouts occurs above snowline giving them a chance to survive but never grow past a certain height. In Arizona, new sprouts are browsed all the way to the ground, year after year, until the resources are depleted and they stop sprouting altogether.

The lack of aspen sprouts in Northern Arizona is not new. Martin (1965) monitored a site, very close to our study areas, where a commercial cutting had taken place in 1942. He sampled the site right after harvest, and again in 1952 and 1962. In 1942, the smallest aspen sucker found was 2 inches in diameter at root crown (drc). No aspen sprout smaller than 2 inches was ever recorded on the site during the 20 year span of sampling, indicating no regeneration occurred during this time. Typically, ponderosa pine or mixed conifer species are regenerating beneath an aspen overstory.

Romme et.al. (1995) studied the temporal patterns of aspen regeneration in northern Yellowstone National Park (YNP). Most stands of trembling aspen in northern YNP appear to have become established between 1870 and 1890, with little regeneration since. They suggest that a complex interaction, involving herbivore abundance (especially elk), climatic variation, fire, and predators, controls the dynamics of aspen tree regeneration there. Perhaps the same can be speculated about aspen in Arizona, but the temporal pattern of aspen regeneration has not been determined here. Since there is so little aspen in Arizona it would be well worth investigating before more is lost.

### Literature Cited

Anonymous. 1993. Forest Health Restoration Initiative. USDA, Forest Service, Southwestern Region. Regional Publication. 19 pp.

Krebill, R. G. 1972. Mortality of aspen on the Gros Ventre elk winter range. USDA, Forest Service, Intermountain Forest and Range Experiment Station. Research Paper INT-129, 16 p.

Martin, E. C. 1965. Growth and Change in Structure of an Aspen Stand After a Harvest Cutting. USDA, Forest Service, Rocky Mountain Research Station. RM-45. 2 pp.

Packard, F. M. 1942. Wildlife and Aspen in Rocky Mountain National Park, Colorado. Ecology 23: 478-482.

Romme, W. H., M. G. Turner, L. L. Wallace, J. S. Walker. 1995. Aspen, Elk, and Fire in Northern Yellowstone National Park. Ecology 76 (7): 2097-2106.

## Aspen Regeneration Failure Studies in Colorado

Dr. William R. Jacobi  
Colorado State University  
Fort Collins, CO

Several studies have looked at aspen regeneration problems after clearcutting. Crouch (1986) reported the first disease related sprout failure after a wet spring. In a survey of aspen stands with sprout mortality in Wyoming, South Dakota and Colorado, Hildebrand and Jacobi (1990) reported that no site or plant indicators were found that could predict aspen sprout failure. Hinds and Shepperd (1987) reported many abiotic and biotic damages on sprouts but did not relate any specific damage to regeneration failure. Jacobi and Shepperd (1991) found two fungi killing aspen sprouts in sites with regeneration failure. To determine site and environmental conditions related to sprout mortality by these two cankers a study of seven aspen failures sites in Colorado was under taken.

Seven study sites were established on the San Juan, Grand Mesa, Uncompahgre and Gunnison National Forests and State lands near the Routt National Forest to determine what environmental conditions predisposed aspen sprouts to infection by two canker causing fungi (*Cytospora chrysosperma*, *Dothiora polyspora*). Each site was located where >95% aspen sprout mortality occurred in 1983, 1987 or 1990 and consisted of whole stands or portion of stands that ranged from 2-10 acres. At each site, 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. Measurements of past meteorological conditions, current soil conditions, soil hydrologic factors, and current and previous stand conditions were taken during the summers of 1990-93.

Two scenarios explain the aspen regeneration failure at the seven study sites. On wet sites, excess soil moisture resulting from deep and late spring snow packs on poorly drained soils, predisposed aspen trees to infection by canker pathogens. Root mortality from soil flooding and drought in mid summer may have caused drought stress. On dry sites, drought conditions from low spring snow packs and reduced summer precipitation on soils with poor water holding capacity predisposed aspen trees to infection by canker pathogens. In addition, shallow rooting induced by a high water table appears to be related to potential drought on dry sites.

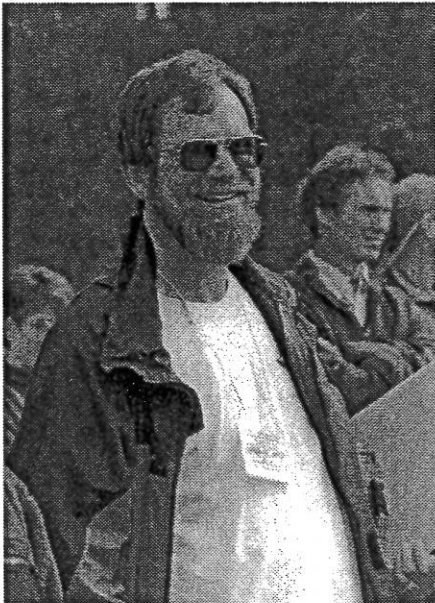
Predicting where mortality will occur is difficult because previous stand characteristics were not different between areas with or without sprout mortality and soil differences were specific to a site and thus the soil conditions were not similar on all sites. Predicting when mortality will occur may be feasible with additional research that relates sprout health to the amount of water in spring snow packs, summer precipitation and Palmer Drought Index data. Failure of aspen regeneration will probably continue to occur. Based on 8-60 years of meteorological data, deep May snow packs occur about 26% and shallow snow packs occur 8% of the years at the study sites.

### References

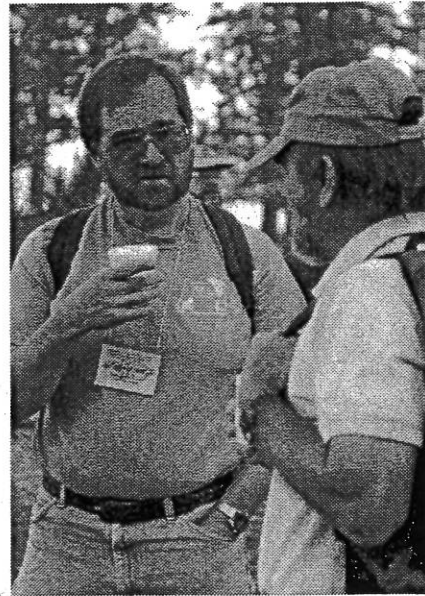
- Crouch, G. L. 1986. Aspen regeneration in 6 to 10 year-old clearcuts in southwestern Colorado. U.S. Department of Agriculture, Forest Service, Res. Note RM-407. 4 p.
- Hildebrand, D. M., Jacobi, W. R. 1990. Comparisons between aspen harvest units with and without adequate resprouting in the Rocky Mountain Region. U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Tech. Rep. R2-46. 38 p.

Hinds, T. E., Shepperd, W. D. 1987. Aspen sucker damage and defect in Colorado clearcut areas. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Res. Pap. RM-278. 12 p.

Jacobi, W.R. and Shepperd, W. D. 1991. Fungi associated with sprout mortality in aspen clearcuts in Colorado and Arizona. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Res. Note RM-513. 5 p.



Bill Jacobi



Greg Filip and Hal Burdsall

## SPECIAL PAPERS

Greg Filip - Moderator

### Wildlife Use of Dwarf Mistletoe Brooms

Catherine G. Parks,<sup>1</sup> Evelyn L. Bull,<sup>1</sup> Robert O. Tinnin,<sup>2</sup>  
Jay F. Shepherd,<sup>1</sup> and Arlene K. Blumton<sup>3</sup>

<sup>1</sup>USDA Forest Service, Pacific Northwest Research Station, La Grande, Oregon 97850, USA

<sup>2</sup>Department of Biology, Portland State University, Portland, Oregon 97207, USA

<sup>3</sup>USDA Forest Service, La Grande Ranger District, La Grande, Oregon 97850, USA

#### Introduction

There is great interest in maintaining and improving habitat for wildlife in managed forest. It has been well documented that many species of wildlife use dwarf mistletoe plants and seeds directly for food and use the structure provided by dwarf mistletoe brooms for resting and nesting sites. However, few quantitative data are available on the frequency of broom use by wildlife, characteristics of utilized brooms, or broom locations in trees and stands. This information could be used by resource managers to retain trees with brooms that have a high probability of being used by wildlife.

We conducted a study last year on the Starkey Experimental Forest located in the Blue Mountains of Northeastern Oregon. Our objectives were to determine (1) wildlife species that use dwarf mistletoe brooms in Douglas-fir in northeast Oregon; (2) characteristics of dwarf mistletoe brooms associated with use by birds and mammals; (3) the relation between wildlife use and tree age, tree size, broom age, and broom size; and (4) wildlife use of Douglas-fir without dwarf mistletoe brooms.

#### Summary

Douglas-fir (*Pseudotsuga menziesii*) trees with and without dwarf mistletoe (*Arceuthobium douglasii*) brooms were examined for evidence of use by wildlife (Table 1). Evidence of foraging occurred in 51% of the broomed trees and in 29% of the trees without brooms. Evidence of nesting by mammals, primarily tree squirrels, occurred in 18% of the broomed trees and in none of the trees without brooms. Brooms used and those not used by wildlife were significantly different in type and volume. These findings suggest that retaining mistletoe brooms in stands may be important to provide nesting, foraging, resting, and roosting habitat for mammals and birds. A full manuscript will be published in Western Journal of Applied Forestry in Spring of 1999.

Additional research is planned to determine what structures are used by tree squirrels when brooms are not available, that is, when brooms are systematically removed from a stand. This research will also evaluate the comparative value to wildlife of leaving patches of broomed trees versus scattered individuals, and the development of small brooms left on the edges of logged openings. The study has begun; this year with pre-treatment monitoring, stands will be treated in 2000, and results will be available in 2002.

Table 1. Percentage of 117 broomed trees and 42 nonbroomed trees with mammalian and avian wildlife use in northeast Oregon, 1997.

Use	Broomed trees	Nonbroomed trees
Mammal use		
Foraging		
Douglas-fir cones-scales	44	28
Ponderosa pine cones-scales	43	4
Mushrooms	6	0
Nesting		
Grass	10	0
Lichen	7	0
Grass and lichen	20	0
Resting <sup>a</sup>	47	0
Avian use		
Nesting <sup>b</sup>	0	2
Roosting		
Grouse pellets	6	0
Owl pellets	1	0

<sup>a</sup>Includes droppings, cached bones, and wads of hair.

<sup>b</sup>Passerine nest.



Greg Filip and Catherine Parks enjoying evening festivities.

## The Impact of Hard Pine Rusts on the Timber Supply in the Central Interior of British Columbia

Alex Woods<sup>1</sup>, Albert Nussbaum<sup>2</sup>, and Bill Goulding<sup>3</sup>

<sup>1</sup> BC Ministry of Forests, Prince Rupert Forest Region, Smithers, BC

<sup>2</sup> BC Ministry of Forests, Research Branch, Victoria, BC

<sup>3</sup> Silvicon Services Inc. Smithers, BC

### Introduction:

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is one of the most economically important tree species in B.C. It makes up 25 % of the total harvest and 35 % of total planting in the province (B.C. Ministry of Forests 1992). The species can grow over a wide variety of site conditions and produce quality wood over a relatively short rotation. Lodgepole pine, however, is susceptible to a wider array of pathogens than any other managed timber species in B.C. Among these pathogens, the hard pine stem rusts such as comandra blister rust (*Cronartium comandrae* Peck), stalactiform blister rust (*Cronartium coleosporioides* Arth) and western gall rust (*Endocronartium harknessii* (J.P. Moore) Hirat.) are responsible for a considerable amount of damage in juvenile stands throughout the interior of British Columbia.

There are few estimates of impacts due to hard pine rusts in the literature. Bella and Navratil (1988) estimated that 15 % of total lodgepole pine volume was lost to western gall rust over a 20 year period in a sample of stands in west-central Alberta. van der Kamp (1981) estimated the volume losses to western gall rust and stalactiform blister rust at 5 % and 0.5 % respectively for B.C. The damage caused by hard pine rusts, however, is not evenly distributed throughout the province. Juvenile lodgepole pine stands in some Timber Supply Areas (TSAs) such as the Lakes and the Mackenzie TSA (R. Reich pers. comm.) in the central interior of B.C. are particularly heavily infested. An assessment of the impact due to rusts for timber supply projections in the Lakes TSA was the objective of this study.

### Methods:

#### Study Location

We conducted this study in the Lakes Timber Supply Area (Figure 1). Lodgepole pine is the dominant commercial tree species in the Lakes TSA covering over 490 000 ha, or 77 % of the timber harvesting land base. The remainder of this landbase is covered in interior spruce (*Picea engelmanni* x *Picea glauca*) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) at 21 % and 2 % respectively. The majority of the lodgepole pine is in the mature (> 100 years) age class with only approximately 77 000 ha of stands < 20 years.



Figure 1. Map of British Columbia showing the location of the Lakes TSA.

### **Landscape Level Hard Pine Rust Incidence Survey**

The first requirement of this project was an estimate of the incidence of hard pine rusts throughout the Lakes TSA. I selected a random sample of 67 juvenile lodgepole pine stands out of the population of 339 for the Lakes TSA. The requirements for the sample stands were as follows; the stands were between the ages of 10-25 years, > 80 % lodgepole pine and < 5000 stems/ha.

We used a low intensity survey of each of the selected blocks to determine the incidence of rust. This survey consisted of a series of connected 3 m wide, 100 m long transects up to a survey intensity of 0.4 % of the total block area. Based on the results of the survey, the stands were grouped into three rust incidence classes; low 0-10 %, moderate 10-20 % and high > 20 %. These rust incidence classes correspond to the incidence classes outlined in the Forest Practices Code, Pine Stem Rust Management Guidebook (BC Ministry of Forests 1996). The rust incidence estimates were based on those rust infections that would deem a tree unacceptable based on the Free Growing Damage Standards as found in the Forest Practices of BC Establishment to Free Growing Guidebook, Prince Rupert Forest Region (BC Ministry of Forests, 1995). These standards state that a tree is unacceptable if a branch has a comandra or stalactiform infection closer than 60 cm to the stem or a gall rust infection closer than 10 cm to the stem. Stem infections of all three rusts were considered lethal.

### **Stem Mapping**

We randomly selected ten sample stands from the low, moderate and high rust incidence classes. We then randomly located a 100 m x 100 m (1 ha) plot in each of these stands.

We recorded the location of each tree greater than 1.5 m in height by taking a minimum 30 second GPS (Global Positioning System) reading using two Trimbol Pro XL GPS units per two person crew. All GPS data were differentially corrected. Microstation-95 was used to encode the data digitally. At each tree the plot number, subplot number and tree species was recorded on the GPS recording unit. For lodgepole pine trees we also recorded the following specific tree attributes:

- live pine with no rust
- live pine with stalactiform rust \*
- live pine with comandra rust\*
- live pine with western gall rust\*
- dead pine (due to other causes)

\* Note: dead trees where the cause of death was obviously a rust were recorded as rust infected

If a tree was infected by more than one rust only the most lethal infection was recorded. This was done based on the following ranking from most to least lethal; comandra, stalactiform, western gall rust. We painted each tallied tree with either "glow orange" for rust infected trees or blue for uninfected trees. The primary purpose of the paint was to avoid double tallying trees. The tree painting also provided a means by which I could check the accuracy of the field crew determinations of disease.

We established ten site index plots (5.64 m radius) in a systematic pattern immediately adjacent to each one hectare stem map installation. The 'best tree' in each of these plots was selected as a sample tree in order to determine site index. The 'best' tree is defined as the largest diameter tree within each plot that is free from rust or other pathological indicators. We recorded the location of each site index tree using a minimum 30 second GPS reading. All site index determinations were made using destructive sampling in order to obtain the most accurate site index measurements.

### Stand Growth Projection Modelling

We used the GPS data to determine the x - y co-ordinates of every tree in the one hectare stem mapped areas. Trees of all species were included so that the competition from species other than lodgepole pine was represented. The stem mapped stand data was entered into the Tree and Stand Simulator (TASS) model. TASS is a computer model that simulates the growth of individual trees and stands in three dimensions. In this model the crowns of individual trees grow asymmetrically as branch extension responds to internal growth processes, physical restrictions imposed by the crowns of competitors, environmental factors and silvicultural practices (Mitchell 1975). In addition to the stem mapped data the model also required the site index for each individual stand. We modelled merchantable volume using a 12.5 cm minimum diameter at breast height, and a minimum top diameter of 10.0 cm.

In order for us to model the affects of hard pine rusts on the lodgepole pine stands using TASS, we had to provide answers the following questions:

- (1) how long do rust infected trees take to die?,
- (2) which rust infections are lethal?, and
- (3) do the voids created by rust persist?

While rust infected trees are still alive they are competing for the limited resources of the site with the neighbouring uninfected trees and are thereby reducing the potential productivity of these trees. If the rust infected trees are killed quickly then the remaining trees may capitalize on the lack of competition. If the infected trees remain on site for a prolonged period of time, the neighbouring uninfected trees may not be able to take full advantage of the increase in resources even when the infected trees finally die. We first made the assumption that all rust infected trees will die by age 40. This assumption is quite safe for the trees infected with comandra blister rust but is less so for those trees infected with western gall rust and the few infected with stalactiform blister rust. Gall rust infected trees may die from a number of different indirect causes such as snow breakage, rodent girdling, or blow-down. In some cases, particularly on small trees, the rust infection itself may kill the tree. It is also possible for a gall rust infected tree to live as long as a typical rotation age of 80 years. Trees with stalactiform infections could also live this long in some cases. There were very few stalactiform infections observed in either the landscape level survey or the stem mapped stands. For the sake of simplicity these infections were considered equivalent to gall rust infections. To see how critical this time to death assumption was we also ran the model killing all rust infected trees by age 30 and 50.

The answer to the second question concerns the lethality of individual rust infections. As mentioned earlier, we deemed trees as infected, using the Free Growing Damage Standards of the BC Ministry of Forests 1995. To test the sensitivity of the model to this assumption we ran TASS using varying levels of rust lethality including; gall rust infections 100, 50 and 25 % lethal, and comandra infections 100 and 50 % lethal.

In answer to the third question, we assumed that the voids created by rust infected trees dying would not be filled with a merchantable sized tree by the end of the rotation period, typically 70 to 80 years. Lodgepole pine is a shade intolerant species. It is unlikely that the voids created by the rusts would fill with a lodgepole pine tree and that these understory lodgepole pine could reach a merchantable size by the time the rust free dominant lodgepole pine stand was harvested. It is similarly unlikely that a subalpine fir or interior spruce tree, the only other timber species in these stands, could reach a merchantable size in these voids. Both of these species are more shade tolerant but they are also slower growing and would not be of a harvestable size by the time the lodgepole pine was.

I compared the mean merchantable volume at culmination age with all rust infected trees considered healthy (control) to the mean volumes under those six scenarios outlined in question one and two above, namely:

rust trees killed from age 21-50, gall and comandra 100 % lethal,  
 rust trees killed from age 21-40, gall and comandra 100 % lethal,  
 rust trees killed from age 21-30, gall and comandra 100 % lethal,  
 rust trees killed from age 21-40, gall 50 %, comandra 100 % lethal,  
 rust trees killed from age 21-40, gall 25 %, comandra 100 % lethal,  
 rust trees killed from age 21-40, gall 100 %, comandra 50 % lethal.

I compared the merchantable volume for the rust affected runs at the culmination age of the rust free control run. Culmination age was the age at which merchantable mean annual increment (MAI) was maximized. I determined the percent volume reduction (or addition) by subtracting the merchantable volume for the rust influenced runs from that of the rust free run and dividing that value by the rust free volume.

I also looked at the impacts of western gall rust and comandra rust individually. We ran the model killing only the gall rust infected trees over the ages of 21 - 40. Then, over the same time period, we modelled tree mortality for only the comandra infected trees.

## Results:

### Landscape Level Rust Incidence Survey

A total of 3322.2 ha were surveyed of which, 45.75 % was in the low incidence class, 27.68 % was in the moderate and 26.57 % was in the high incidence class. The relatively large proportion of stands in the high incidence stands was in itself an important finding in this study.

### Stem Mapped Stand Rust Characteristics

In the moderate and low incidence stands the majority of the rust infections were caused by western gall rust. In the high incidence stands, the majority of infections were caused by comandra blister rust (Table 1).

**Table 1.** Proportion of total rust infections represented by each of the rust species in the three rust incidence classes as determined from the stem mapped stands.

Rust Species	Low	Moderate	High
Western gall rust	63.1 %	86.8 %	37.0 %
Comandra blister rust	36.9 %	12.3 %	62.7 %
Stalactiform blister rust	0.0 %	0.9 %	0.3 %
Total infections	1719	2262	7888

### Comparison of Mean Volumes at the Rust Free Culmination age among Mortality Scenarios and Rust Incidence Classes

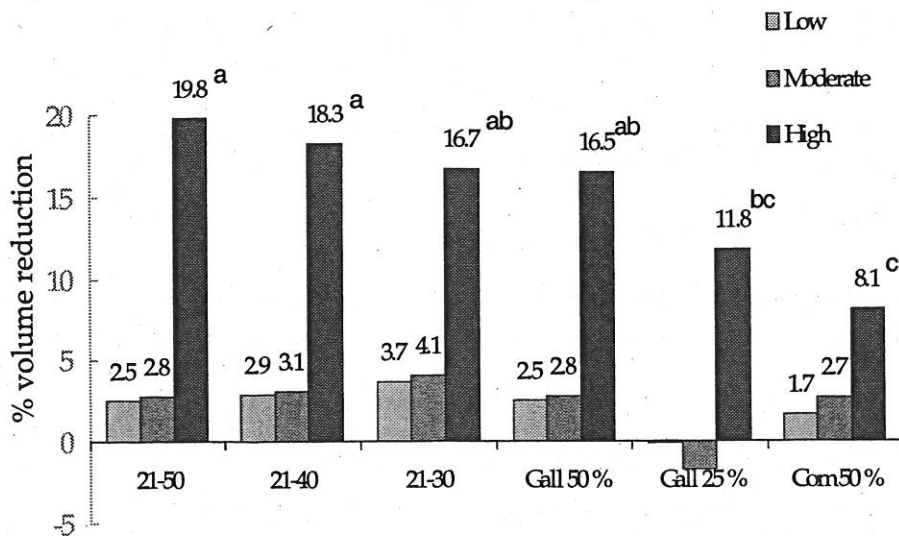
We found that mean volumes at culmination age differed significantly ( $\alpha = 0.05$ ) among rust incidence classes and mortality scenarios. Duncan's multiple range test indicated that there was a significant difference in mean volumes between the high incidence class and the other two (SAS Institute Inc. 1990). There was no significant difference in mean volume between the low and moderate rust incidence classes. The ANOVA results also indicated that there was a significant interaction between rust incidence class and rust mortality scenario (Table 2).

**Table 2.** The ANOVA results of the comparison of mean volumes at rust free culmination age for all combinations of rust incidence class and rust mortality scenario.

Source	df	F-Value	p of F value
Rust Incidence Class	2	8.39	0.0015
Rust Mortality Scenario	5	21.16	0.0001
Rust Incidence X Mortality Scenario	10	9.35	0.0001

The significant interaction between rust incidence class and rust mortality scenario meant that the mortality scenario did not affect volumes consistently among incidence classes. We therefore analysed the affects of rust mortality scenario for each rust incidence class individually. Every mortality scenario except that in which gall rust was 25 % lethal, resulted in significantly reduced mean volumes in the low and moderate incidence classes. The magnitude of these losses, though statistically significant, only account for a reduction of at worst 3 % in the mean volume at rust free culmination age for the low and moderate incidence classes. The losses in the high incidence class were considerable. In the worst case scenario, in which both rusts were 100 % lethal and took 50 years to kill, the losses ranged from 14.5 to 25.1 % in merchantable volume for the lower and upper 95 % confidence limits with a mean loss of 19.8 % (Figure 2).

Percent reduction in volume at rotation for High, Moderate, and Low incidence stands under 6 modeled mortality scenarios



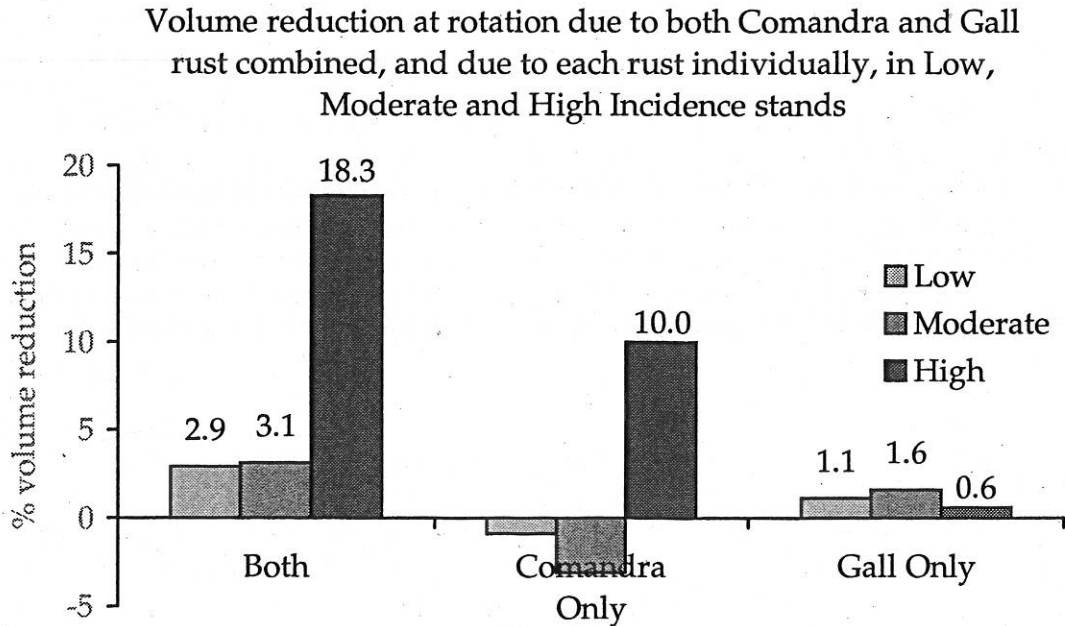
**Figure 2.** Percent reduction in mean volume at rust free culmination age from the rust free control volume, for the High (386.4 m<sup>3</sup>/ha), Moderate (382.5 m<sup>3</sup>/ha) and Low (394.9 m<sup>3</sup>/ha) rust incidence classes, under six mortality scenarios.

(note: those values with the same letter behind them are not significantly different from each other)

For those mortality scenarios that did have a significant impact on volume in the low and moderate rust incidence classes, the specific choice of mortality scenario was irrelevant (Figure 2). In the high incidence class there were significant differences between mean volumes depending on the mortality scenario. There was no significant difference between killing all rust

infected trees over 50 years rather than 40 or 30 years. The high incidence stands were more sensitive to changes in the lethality of comandra blister rust than they were to changes in western gall rust.

I also looked at the impact of each rust species individually (Figure 3). The individual impacts of comandra and western gall rust did not add up to the impact of the combined model run.



**Figure 3.** The combined impact in terms of percent volume reduction of comandra blister rust and western gall rust and both rusts modelled individually under the scenario where rust infected trees die from age 21 - 40 years.

#### Discussion:

The relatively high proportion of stands in the high rust incidence class coupled with the impacts suffered in that incidence class, result in significantly less productive young forests. There are approximately 77 000 ha of juvenile lodgepole pine stands in the Lakes TSA, of which, 26.6 % or 20 790 ha are in the high incidence class. If the mortality scenario in which both rusts are 100 % lethal and rust infected trees die from age 21 - 40 is used, the losses at rotation age range from 1.05 million m<sup>3</sup> to 1.90 million m<sup>3</sup> (95 % confidence limits) with a mean of 1.45 million m<sup>3</sup>. Under the same mortality scenario, the mean losses due to rust in the low and moderate incidence stands is approximately 650 000 m<sup>3</sup>. Thus the total losses due to rust over a rotation amount to 2.1 million m<sup>3</sup>.

It is difficult to make comparisons between the rust impacts that we found and others in the literature. Bella and Navratil (1988) estimated that losses due to western gall rust in west-central Alberta amounted to a 15 % reduction in volume over a 20 year period when stands are most susceptible. They did not relate this loss early in the stands life to a loss over the length of a rotation. They also did not have comandra blister rust in their study stands. van der Kamp (1981) estimated the volume loss due to rusts throughout British Columbia at 5.5 %. In our study the mean percent volume loss in the high incidence stand was 18.3 % when both rusts were 100 % lethal and the trees died over 40 years. This percentage translates into a loss of 4.87 % reduction in volume for the entire TSA. Hard pine rusts in the low and moderate incidence stands account for a 2.18 % reduction in volume using the same calculations. The total losses

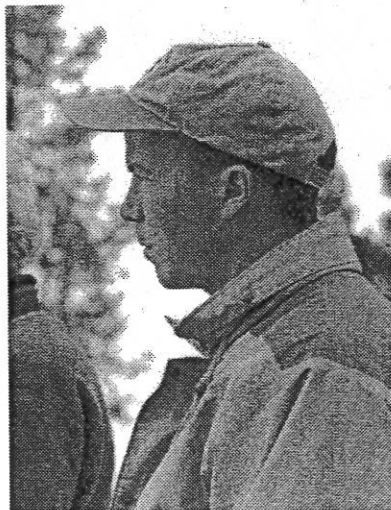
due to rusts in this scenario therefore account for a reduction of 7.05 % in volume at rotation over the entire TSA. If we consider that the central interior of BC has a large component of lodgepole pine and, in general, a higher rust incidence than southern BC, our results do not refute those of van der Kamp (1981).

The impact on timber productivity due to rusts is a function of four factors: rust incidence, rust species, stand density and tree distribution. For each of the ten high incidence stem mapped stands there was a different combination of these factors that influenced the loss in productivity. In some cases the rusts incidence alone accounted for most of the volume loss. In others it was apparent that the species of rust and the distribution of trees within the stands were as important.

It is not clear why the model run results for comandra and western gall rust individually did not add up to the volume loss determined when the two rusts were combined. The two rusts do have quite different distribution patterns within stands. Western gall rust tends to be quite evenly spaced throughout stands. Comandra blister rust tends to have a clumped distribution. The TASS model appears to be very sensitive to the creation of voids, such as those created by the clumped pattern of comandra blister rust. A possible explanation for the high combined impact is that the even distribution of gall rust over the clumped distribution of comandra simply increases the size of those voids.

#### **Acknowledgements**

I thank Teresa White of Cedrus Consulting for the landscape level rust incidence survey; Dave Walters and others of Silvicon Services for their attention to detail and diligence in the task of GPS data collection and stem mapping. I also thank Ken Polson of BC Ministry of Forest, Research Branch for his assistance in stand modelling using TASS. Financial support was provided by Forest Renewal BC through Forest Health Block Funding.



Alex Woods

## References

Anonymous 1995. Lakes Timber Supply Area: Timber Supply Review Discussion Paper, June 1995. BC Min. For.

BC Ministry of Forests. 1996. Forest Practices Code of BC, Pine Stem Rust Management Guidebook. Victoria BC. 30 pp.

BC Ministry of Forests. 1995. Forest Practices Code of BC, Establishment to Free Growing Guidebook: Prince Rupert Forest Region. Victoria BC. 146 pp.

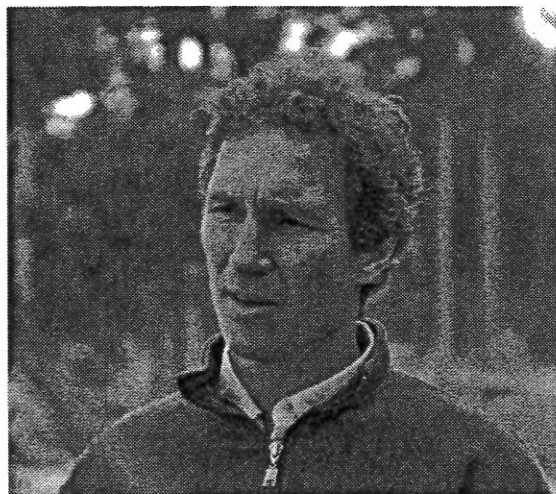
BC Ministry of Forests. 1992. Annual Report of the Ministry of Forests, 1991-1992. BC Ministry of Forests, Victoria BC

Bella, I.E., and Navratil, S. 1988. Western gall rust dynamics and impact in young seedlings of lodgepole pine with *Endocronartium harknessii*. Can. J. For. Res. 18: 1437-1442.

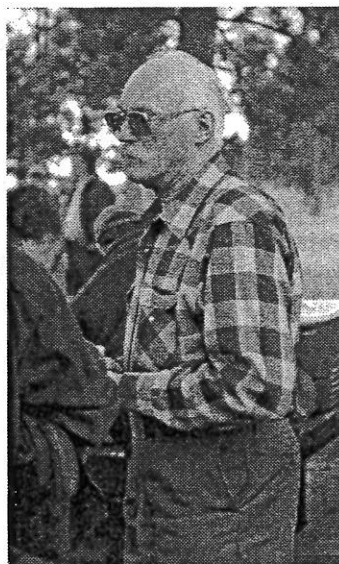
Mitchell, K.J. 1975. Dynamics and simulated yield of Douglas-fir. For. Sci. Monogr. 17. 39p.

SAS Institute Inc. 1990. SAS procedures guide. Version 6. 3<sup>rd</sup>. ed. SAS Institute Inc., Cary, N.C.

van der Kamp, B.J. 1981. The incidence and impact of western gall rust, stalactiform and atropellis canker in managed stands of interior lodgepole pine. BC Min. For. 56p.



Alan Kanaskie



Tom Laurent

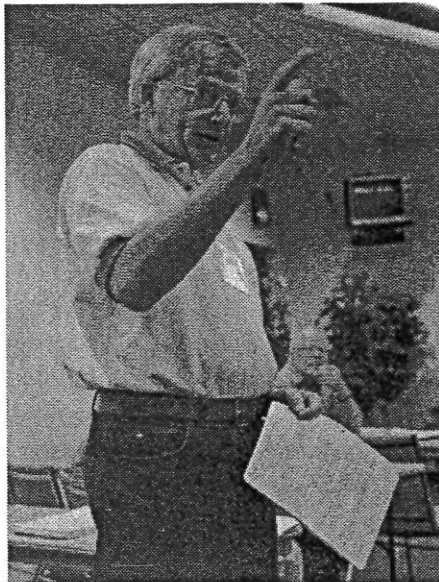
**Occurrence of stem rusts of lodgepole pine in a site preparation trial at  
Bednesti, British Columbia.**

John Muir  
B.C. Ministry of Forests  
Victoria, B.C.

Site preparation treatments had a significant effect on infection of ten-year-old lodgepole pine. In many of ten treatments, infection reduced stocking below 1200 stems per hectare, the desired stocking level, based on free-growing damage criteria used to assess trees. From 10 to 30 per cent of trees were infected per treatment, mostly by western gall rust on tree stems and branches. Higher percentages of infection were generally associated with treatments that stimulated tree height growth. Only comandra blister rust on stems significantly reduced recent height growth increments and total tree height.

Based on detailed height and tree age measurements in four treatments that represented the highest and lowest percentage of rust infection, most infections occurred on trees at a height of 1 metre or less, and infections occurred higher on trees in treatments with higher overall percentages of infections. Contrary to results of a previous study where most infection occurred in a "wave" year (1990), rust infection in the trial area, including on untreated control blocks, occurred mostly in both 1990 and 1993 with almost equal frequency.

We suggest that where site preparation treatments are desirable for reforestation with lodgepole pine in areas with high hazard or risk of infection by stem rusts, foresters could plant seedlings from genetically resistant provenances (identified recently by Cheng Ying and associates in BC) or protect trees by branch pruning. Observations will be continued to determine long-term effects of infection, particularly western gall rust on branches, on tree growth, survival and wood quality.



John Muir

## **Development of the Understory Enhancement for the Dwarf Mistletoe Spread and Intensification Model**

Helen Maffei<sup>1</sup>, Jim Stone<sup>2</sup>, Lance David<sup>3</sup>, Tom Gregg<sup>4</sup>, Judy Adams<sup>5</sup>, Brian Geils<sup>6</sup>

<sup>1</sup> Area IV Pathologist at the Central Oregon Field Office, Bend, Oregon.

<sup>2</sup> Silviculturist detailed to the Central Oregon Field Office, Bend, Oregon.

<sup>3</sup> Senior Systems Analyst (contractor), Forest Health Technology Enterprise Team, Fort Collins, Colorado.

<sup>4</sup> Insect and Disease Biometrician, Regional Office, Portland, Oregon.

<sup>5</sup> Computer Specialist, Forest Health Technology Enterprise Team, Fort Collins, Colorado.

<sup>6</sup> Research Plant Pathologist, Rocky Mountain Research Station, Flagstaff Laboratory, Flagstaff, Arizona.

**Abstract--** Forest Vegetation Simulator includes the effects of dwarf mistletoe in its projections through the Dwarf Mistletoe Impact model. However, its appropriate use is limited to single story stands because spread and intensification predictions do not address the increased spread and intensification rates that occur from infected overstory- to understory trees. In order to correct this deficiency within a relatively short time frame, a prototype "Understory Spread and Intensification Enhancement" was added to the Dwarf Mistletoe Impact Model. This enhancement provides the framework for the model to: 1) Identify understory tree records that are likely to be affected by mistletoe spreading from an overstory infection source; and 2) Increase the predicted spread and intensification probabilities for these trees. The prototype enhancement was tested using ponderosa pine. The spread and intensification probabilities for the test were developed from measured rates in understory ponderosa pine in a 10 acre long term permanent plot in the Southwest. We believe this relatively simple enhancement will greatly increase the capability of the Dwarf Mistletoe Impact Model to more accurately project the effects of mistletoe on a wide variety of stand structures.

### **Introduction**

The dwarf mistletoes are important disturbance agents which can significantly change forest structure, density and spatial patterns. This effect arises primarily from the growth loss and decreased survival that individual trees experience at higher levels of infection severity. Because these effects are often undesirable to land and resource managers, dwarf mistletoes have often been characterized as some of the most damaging pathogens in Western North America. The effects of dwarf mistletoe on the future forest can often be changed considerably through silvicultural treatments. In many instances, effects that are perceived to be undesirable can be dramatically reduced or even eliminated. Conversely, other silvicultural treatments can actually intensify the proliferation and ultimately the impacts of dwarf mistletoe.

Forest Vegetation Simulator includes the effects of dwarf mistletoe in its projections through the Dwarf Mistletoe Impact Model. Use of this tool can help the land manager assess the potential outcome of various management alternatives in infected stands and compare it to a desired future condition. Often, the benefit of controlling dwarf mistletoe effects must be balanced and evaluated against the "tradeoffs" to other resources that might be necessary, such as mixed species stand composition, preservation or creation of wildlife habitat, wildfire risk and insect outbreak risk along with other less measurable characteristics like scenic and recreational values. Often the stands being considered are multistoried and this enhancement to the Dwarf Mistletoe Impact Model increases the accuracy of simulations when dwarf mistletoe is a factor the land manager must include. One should also consider that dwarf mistletoe infections can increase susceptibility of trees to other insects and diseases.

*In this paper we will describe* how we have enhanced the Dwarf Mistletoe Impact Model to enable it to more accurately project mistletoe effects in stands with more than one canopy layer. Using ponderosa pine, we will then demonstrate projections from the amended version and compare them to projections from the original model.

## Background

**Review of the Dwarf Mistletoe Impact Model.** Before describing our enhancement of the existing Dwarf Mistletoe Impact Model, it would be useful to provide a brief review of how this model projects the effects of dwarf mistletoe. The Dwarf Mistletoe model predicts both how the mistletoe spreads throughout the stand and the effect it will have on tree growth and survival. These predictions are made on the tree records that are passed in from the FVS base model via three modules:

1. The Non spatial Spread and Intensification Module;
2. The Growth Module and
3. The Mortality Module.

First, the change in individual tree record's dwarf mistletoe severity rating (DMR, Frank Hawksworth's method of dwarf mistletoe rating) is predicted in the Non spatial Spread and Intensification Module. These changes in severity rating can be regarded as being one of three types depending on the initial DMR of the tree record. The first type of severity change, *spread*, occurs when a previously non infected trees become infected. Dwarf mistletoe spreads to a tree record when an initial DMR =0 changes to a DMR>0. The second type of severity change, *intensification*, occurs when infected trees become more severely infected. The third type of severity change, *decrease*, occurs when a tree record decreases in DMR. Increase or decrease in DMR for a given tree record is determined by a set of probabilities that the tree either increases, decreases or stays the same. In the original spread and intensification module increase or decrease in DMR is limited to one severity rating per 10-year projection period. For example, a tree record with a DMR=2 would only have 3 possible ways it could change in a projection period; it could increase to 3; it could remain at 2 or it could decrease to 1. Of course, tree records with DMR=6 can only remain the same or decrease to DMR=5; and tree records with DMR=0 can only remain the same or increase to DMR=1. These probabilities were developed based data collected from 1,200 lodgepole pine on the Gallatin National Forest, Montana. Variables that affect calculation of the three probabilities include: trees per acre and predicted height growth of the tree record during the projection cycle. Stand structure, or the relative heights of trees to each other is not considered.

FVS calculates growth, period (cycle) growth increment, and mortality for individual trees without insect and disease impacts. The Dwarf Mistletoe Model adjusts those values relative to the individual tree's DMR. Once spread and intensification have been calculated and a predicted DMR has been assigned to each tree record, the tree records are processed by the mortality module and the growth module. These modules compute the probability of mortality and percent growth reduction (both height and diameter growth), respectively based on individual tree record characteristics, including its DMR. These numbers are then passed back to the base model and incorporated into the overall predictions of tree growth and survival.

**Mistletoe Infection of Understory Trees and the Dwarf Mistletoe Model.** A number of research studies as well as field experience have demonstrated that dwarf mistletoe disperses most effectively from overstory trees to smaller trees of the same species. The ultimate effect of dwarf mistletoe is greatly magnified in these situations because the understory trees rapidly become severely infected.

The non-spatial spread and intensification module assumes a single story canopy structure. It does not have functions which describe the effect of an overstory on spread and intensification. As a result, spread and intensification rates and thus, associated growth reductions and increased mortality may be underestimated in stands with more than one canopy layer. This in turn can result in projections which can mislead the land managers in terms of how much importance to give mistletoe and the effectiveness of treatment choices that may in reality fall far short of expectations.

To illustrate this point, consider an example ponderosa pine plantation with a mistletoe infected overstory (Figure 1). The most important objective is for the plantation to develop into a productive and long-lived ponderosa pine forest. But it is also desirable to leave a residual overstory as green tree replacements (to provide snags over time, our Forest Land and Resource Management Plan requires 30 per acre) and enhanced aesthetics. What would the present non spatial dwarf mistletoe model predict the effect of indefinitely leaving the infected overstory be on the development of this stand versus removing it? According to the model, very little! Dwarf mistletoe infection levels remain light. Even after 100 years the stand DMR is only 1.5 and only 50% of the trees are infected (Figure 1). In addition, there is only a minor effect on stand productivity. Using percent of expected total cubic ft. (in the absence of mistletoe) to represent productivity we see that after 100 years we are still at 80% of potential productivity. Leaving the trees might appear to be a wise course of action given these projections and our other resource concerns. Unfortunately, this projected result is not what experience (and research) indicates is a likely outcome.

We have illustrated how a model limited to projecting mistletoe effects for evenaged stands is not sufficient to address the resource questions we are faced with today. In order to build more flexibility into the dwarf mistletoe model within a reasonably short time frame, we have modified the nonspatial spread and intensification module by developing and adding a fairly simple prototype we will call the "Understory Spread and Intensification Enhancement".

### **The Prototype Understory Spread and Intensification Enhancement..How Does it Work?**

The prototype Understory Spread and Intensification Enhancement (USIE) is designed to project the spread and intensification of dwarf mistletoe in understory trees in two distinct steps.

**The first step is to identify and select understory tree records that are likely to be affected by an overstory infection source.** In other words, the USIE first identifies and selects the understory tree records that are likely to have their infection severity affected by inoculum from infected overstory tree(s). Selection of understory tree records is a *four-phase process of elimination based on:*

1. *Grouping by sample point*
2. *Grouping further by susceptible species,*
3. *Identification of understory and infected overstory trees, and,*
4. *Identification of proportion of understory trees affected by the infected overstory*

In the first phase the *tree records are grouped by sample point*. The dissemination of dwarf mistletoe seeds, thus the spread and intensification of dwarf mistletoe, is highly affected by species composition and geometric arrangement of the canopy. We wanted to have the best representation possible (within the limitations of how inventory data is taken) of the spread and intensification environment and correctly identify portions of the stand where the spread of dwarf mistletoe from an overstory to an understory is likely to take place.

In the second phase, *all trees, on a sample point, that are susceptible to a specific type of mistletoe are grouped* together. Dwarf mistletoes are host specific. Thus, for each sample point, there will be as many tree record groups as there are types of dwarf mistletoes that attack the tree species recorded on the sample point. The objective here is to group trees according to host so that the USIE enhancement does not spread and intensify dwarf mistletoe on a non host tree. For example, a small ponderosa pine would be grouped with a large mistletoe infected ponderosa pine. But it would not be grouped with large mistletoe infected Douglas-fir. This operation is also performed in the original non-spatial spread and intensification model.

In the third phase, *understory and overstory trees are defined*. Within each mistletoe type tree record group, understory trees are identified based on their height relative to infected trees within the group. *Tree records are labeled as "understory" when they are 30% shorter than an infected tree or trees on the same plot*. This criteria gives the model flexibility to span any range of heights the trees on the plots might have as well as the flexibility to define any number or combination of canopy layers.

The fourth and final phase of the selection process, was to *estimate how many of the identified understory trees were likely to be influenced by the dwarf mistletoe infected overstory*. This operation is actually performed in the FVS base model. The identification of understory trees is a multiple step process. First, values for key variables are captured by looking at each current tree record in the simulation. The information required to determine the presence or absence of an overstory infection source for each plot (sample point) in the FVS simulation stand includes: the height of the tallest dwarf mistletoe infected tree of each dwarf mistletoe host tree species recognized by FVS and the Dwarf Mistletoe Impact model. Barring the assistance of forest creatures such as birds and squirrels, dwarf mistletoe infections do not normally occur beyond a short distance (35 ft.) from the infection source. That is why sample points within the stand are treated independently and an infected overstory tree on one sample point will not affect the spread and intensification on any other sample point in the simulation stand. We recognize the assumptions implied and they are specifically stated later in this paper, but since neither the FVS or Mistletoe models use specific spatial information for individual trees, utilization of point information is one way to represent this one characteristic of spread and intensification (horizontal distance) which we feel is quite important.

The tree list is then processed again and the probabilities for changing the DMR (intensification increase or decrease) for each individual tree is calculated using the original functions. If the tree (tree record) has been selected for intensification, the height of the tree is compared to the height of the tallest infected tree of the same species on its sample point to determine if it is currently subject to overstory affects. When the current tree is less than 70% the height of the tallest tree, it is considered overstoried and the degree of intensification is then determined. The degree of intensification is selected by drawing a pseudo random number that is applied to a distribution of intensification (rating increase of 1, 2 or 3) statistically developed for the current DMR of the tree. In other words, each DMR has a specific degree of intensification distribution from which a value is selected. Additionally, uninfected trees subject to overstory affects will be infected with an initial DMR of 1, 2 or 3 from an initial infection distribution.

The structure and characteristics of a stand is dynamic and unique throughout a simulation and for any cycle the above described overstory affects may be active or inactive on one, all or none of the stand's sample points.

For example, Figure 2 illustrates that there is a significant difference between leaving 1-5 infected overstory trees per acre and leaving 15 or more infected overstory trees per acre on the intensification of a plantation over time. Leaving 15 or more infected overstory trees per acre will result in an

infection severity (stand DMR) projections that are more than twice that of leaving 5 or less infected overstory trees per acre.

Dwarf mistletoe host-specificity is maintained in this model. Inoculum from one tree species cannot infect trees of another species.

**Assumptions:** There are some assumptions associated with the selection process we would like to bring to your attention. First, we assume that the understory trees and infected overstory trees are distributed evenly within the plot sample space. This may or may not be the case. Second, we are also assuming that other species of overstory trees do not present physical barriers to the distribution of inoculum from overstory trees to understory trees. Again, this may or may not be the case, depending on the density of the overstory trees. We also assume that trees on one sample point do not impact those on another. This may or may not be true depending on the sample design.

**The Second Step is to project dwarf mistletoe spread and intensification for susceptible understory trees.** Once the understory trees that are likely to be affected by mistletoe inoculum from overstory trees have been identified, increase in their infection rate and severity level is then simulated.

Like the Non-Spatial Spread and Intensification Module, the prototype Understory Spread and Intensification Enhancement (USIE) projects rates of spread and intensification in terms of the probability of a tree record changing its DMR over a decade. However, the USIE differs from the non spatial model in two significant respects.

First, it is *not limited to changing a maximum of one DMR severity rating per decade*. Instead within the mathematical limits of DMR (0 to 6), any increase, or decrease, in severity is possible. For example, a tree with a DMR of 1 could potentially increase 5 severity ratings to a DMR of 6 or decrease 1 severity rating to a DMR of 0. Even though it is possible for DMR to change by 4 or 5 ratings in a 10-year period, the probability is very low and therefore the maximum change was limited to 3 DMR ratings. We felt this feature was important because we assumed that trees under an infected overstory commonly experience increases in DMR of more than one severity rating per decade.

The second difference is that the USIE also *has the capability to generate different probabilities of severity increase based on the initial DMR of the tree record*. This flexibility was added because we also assumed that different initial severity levels might have an important influence on probabilities of increase.

Data used to develop the probabilities for this iteration of the understory spread and intensification enhancement came from repeated measurements of understory trees from a 10 acre long term ponderosa pine plot, "Plot 12" in the Southwest. Plot 12, located on the south rim of the Grand Canyon, is the untreated control plot originally established to compare long term survival of pruned ponderosa pine with those that had not been pruned. The minimum data needed to develop predictions of 10-year changes in dwarf mistletoe severity, were actual measured changes in DMR for individual trees. This necessary data is only found in research or inventory situations where specific trees had been initially measured with mistletoe severity described in terms of "DMR" and then remeasured (again recording DMR) a decade later (or approximately). In this plot, individual trees had been tagged and remeasured (including individual tree DMR) for over four decades. Individual trees were assumed to be understory trees if they were 50 percent, or less, the height of the tallest tree (Figure 3). Ten year change by initial DMR was summarized for these trees and the probabilities of increase found in the USIE were taken directly from these summaries (Figure 4).

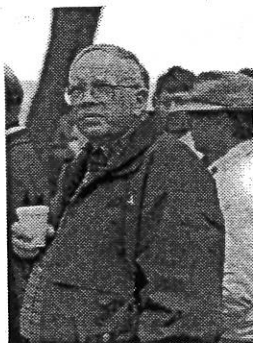
We used Plot 12 because it was the first suitable data set we could obtain. By no means do we claim it is sufficient to develop a finished understory spread and intensification model. We hope to incorporate the information from other data sets as they become available. The way this enhancement is structured it would be simple, using the above analysis process, to compute local spread and intensification probabilities, or those of species other than ponderosa pine when additional data sets become available. We hope to work with others to modify the existing probabilities so they apply to all species of dwarf mistletoe of interest to land managers. Our initial observation is that the probabilities definitely represent some species better than others. For example, the results predicted using this data set look fairly satisfactory for ponderosa pine. However they are not adequate for lodgepole pine since the projections of dwarf mistletoe severity do not correspond very well to what has been published.

In the USIE, after new DMRs have been assigned to tree records, the FVS predicted growth and mortality values for each tree record are adjusted to reflect the dwarf mistletoe impact for the growth period (FVS cycle). It is important to understand that the period's growth and mortality predicted by FVS assumes no insect or pathogen activity in the stand. But there may be other events taking place in the stand that the mistletoe model does not recognize; therefore, comparisons are made between FVS-predicted values and Dwarf Mistletoe model-predicted values for each tree record and, if appropriate, proportionate adjustments are made to the FVS predicted growth and mortality based on its new DMR value.

Let's return to the example ponderosa pine plantation we discussed in the first section and compare the predicted effects of leaving an infected overstory, using the original Dwarf Mistletoe Impact Model, with projections using the Understory Spread and Intensification enhancement. Projections now show a very significant effect on the plantation in both in terms of its growth and productivity and the severity of mistletoe infection (Figure 5). After 100 years stand DMR projected to be 4.8 and 100% of the trees are infected (note: we are not projecting ingrowth). After 100 years the stand is at only 45% of its potential total volume. These effects are more in line with what our studies and experience tell us will happen.

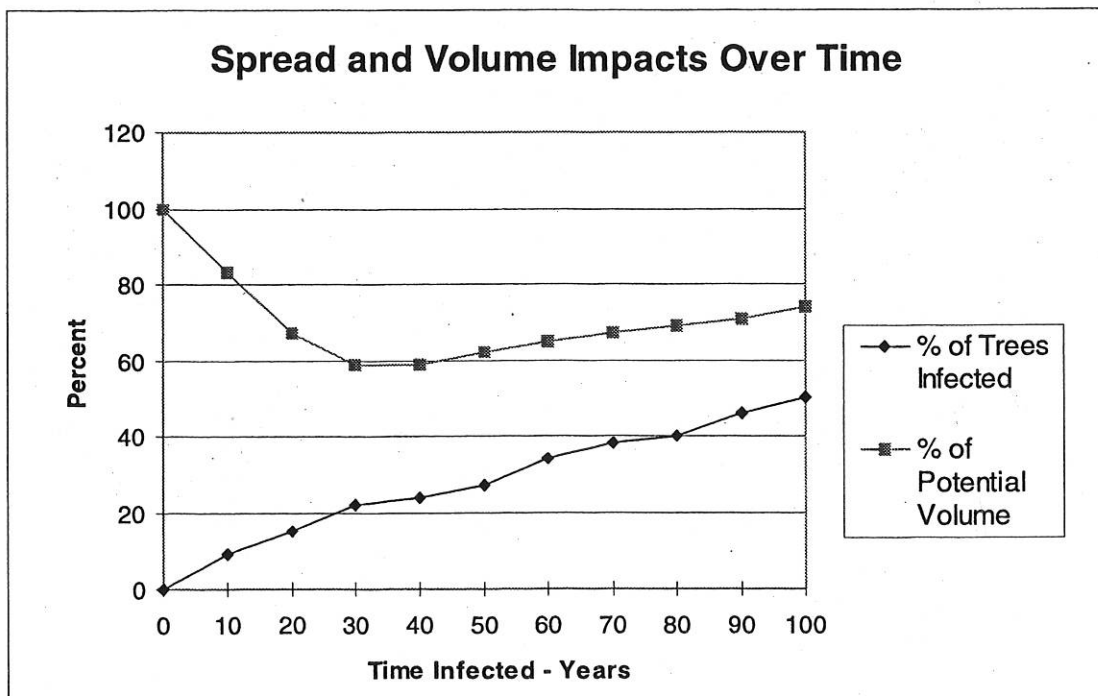
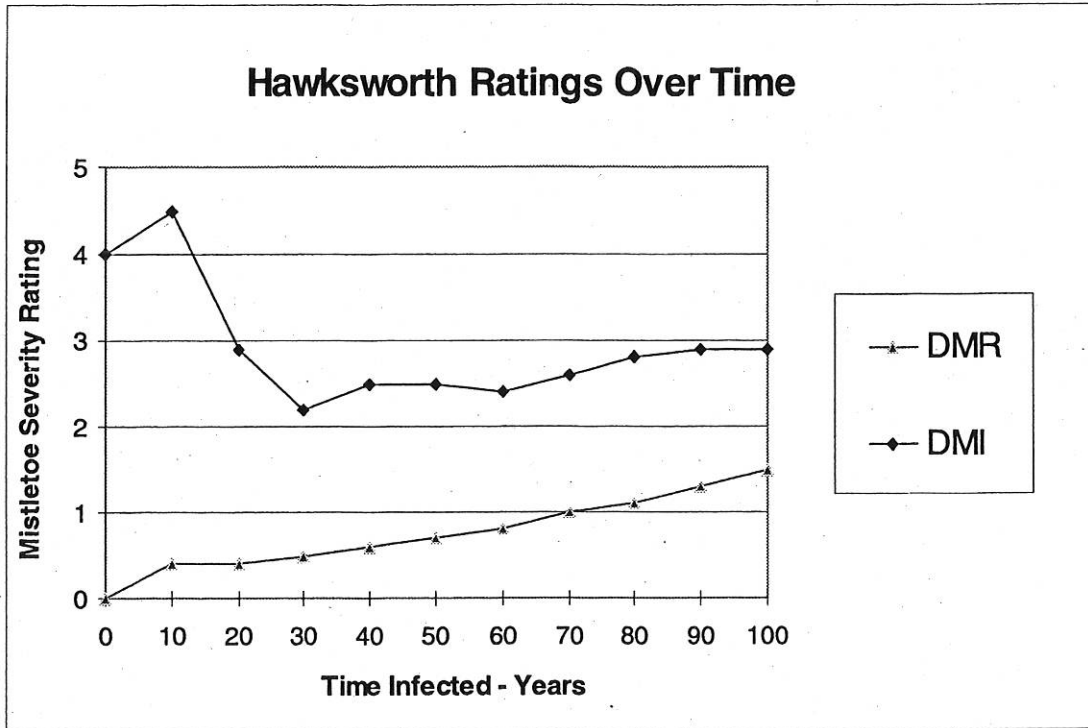
### Summary

Initial testing of the prototype Understory Spread and Intensification Enhancement with ponderosa pine indicates that this model enhancement shows considerable promise as a relatively simple solution to the limitations of the Non-spatial Spread and Intensification Module. It establishes a basic framework which will enable the Dwarf Mistletoe Impact Model to recognize situations where understory trees are likely to be affected by dwarf mistletoe spreading from overstory infection sources; and to compensate by increasing the predicted spread and intensification rates. We believe this enhancement will greatly increase the capability of the Dwarf Mistletoe Model to more accurately reflect the effects of mistletoe on a wide variety of stand structures.

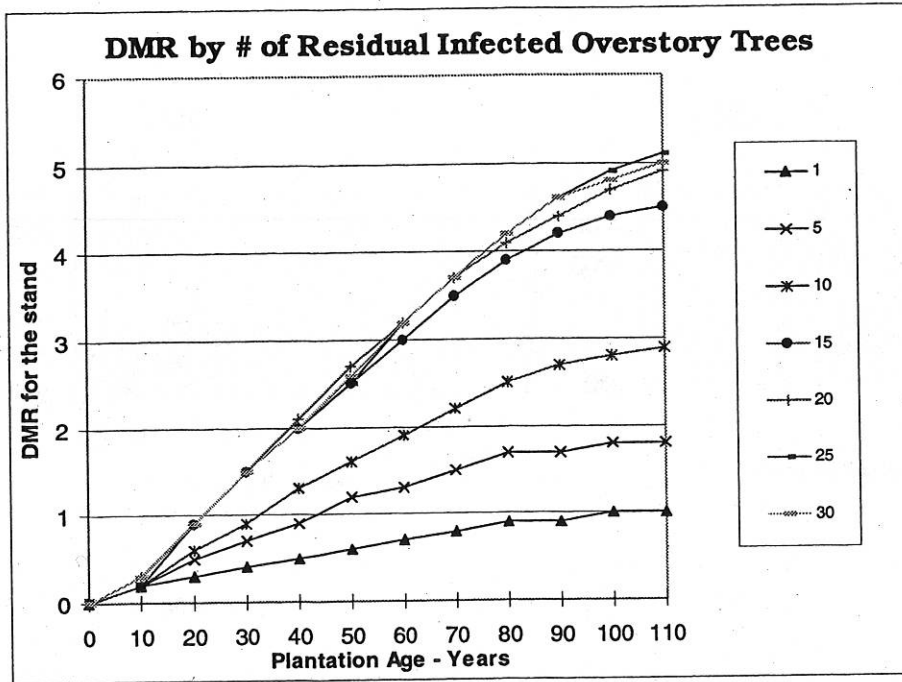


Tom Gregg

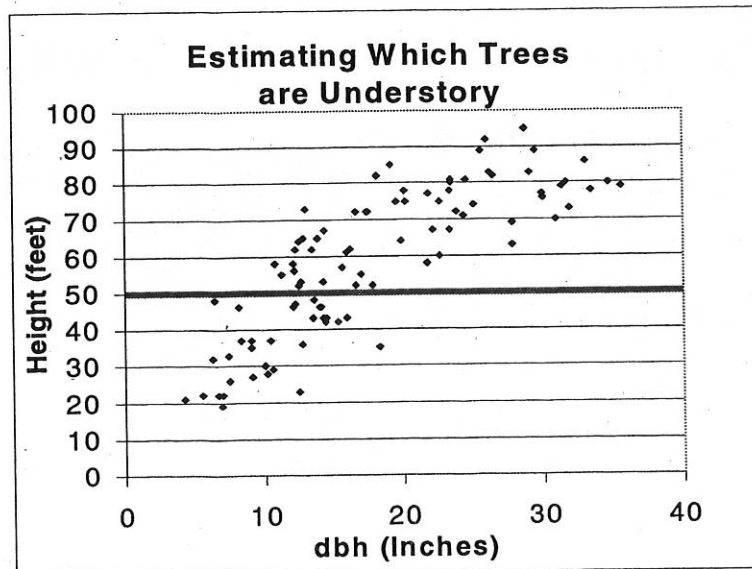
**Figure 1:** Hawksworth ratings, spread and volume impacts shown over 100 years from the present Dwarf Mistletoe Impact Model. This is a ponderosa pine stand with 25 infected overstory trees, each with a DMR of 4, left standing over 200 mistletoe-free seedlings, an amount which is commonly planted.



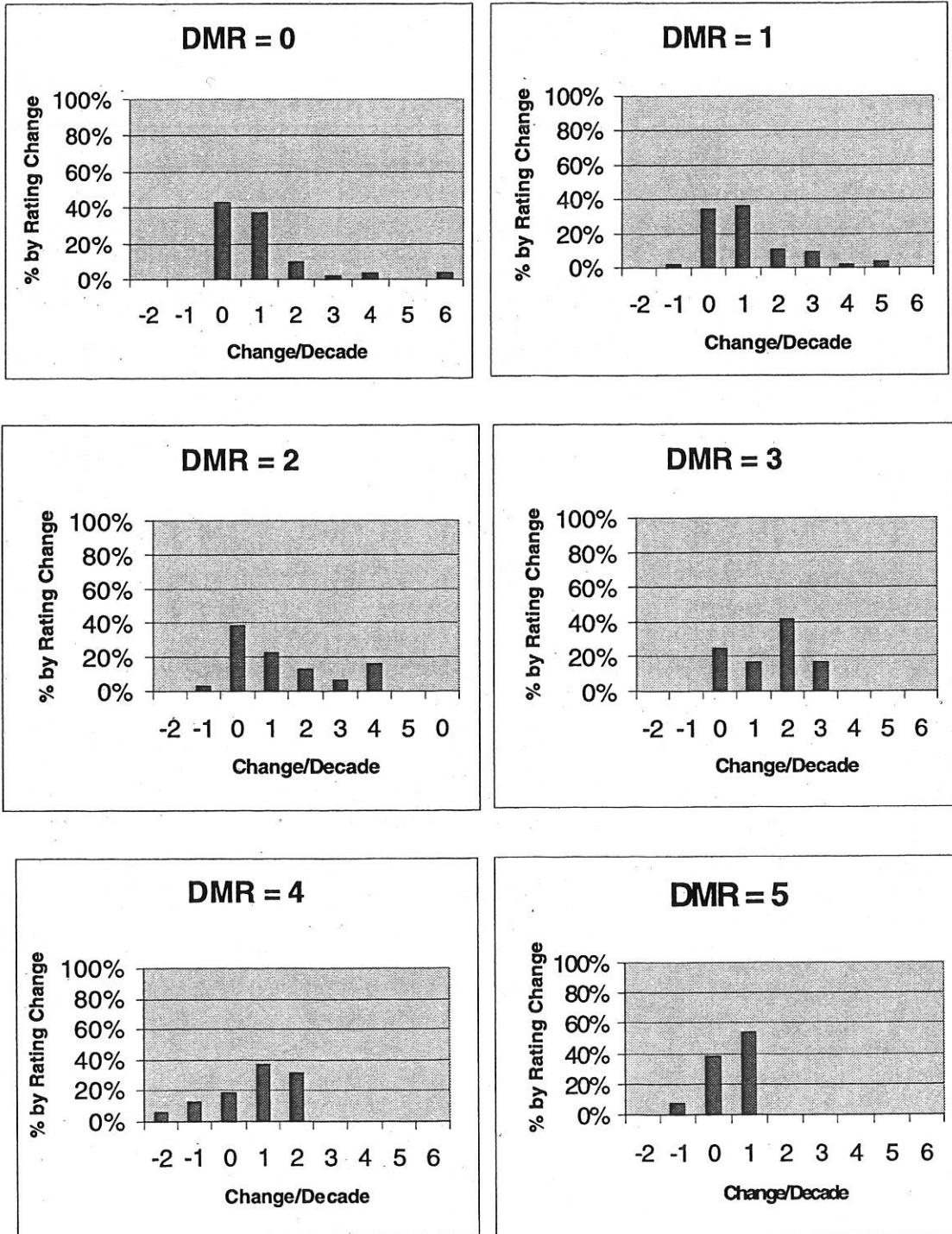
**Figure 2:** Projections of various numbers of residual infected overstory trees, each with DMR of 4. Projections were done with the Prototype Understory Spread and Intensification Sub-Module.



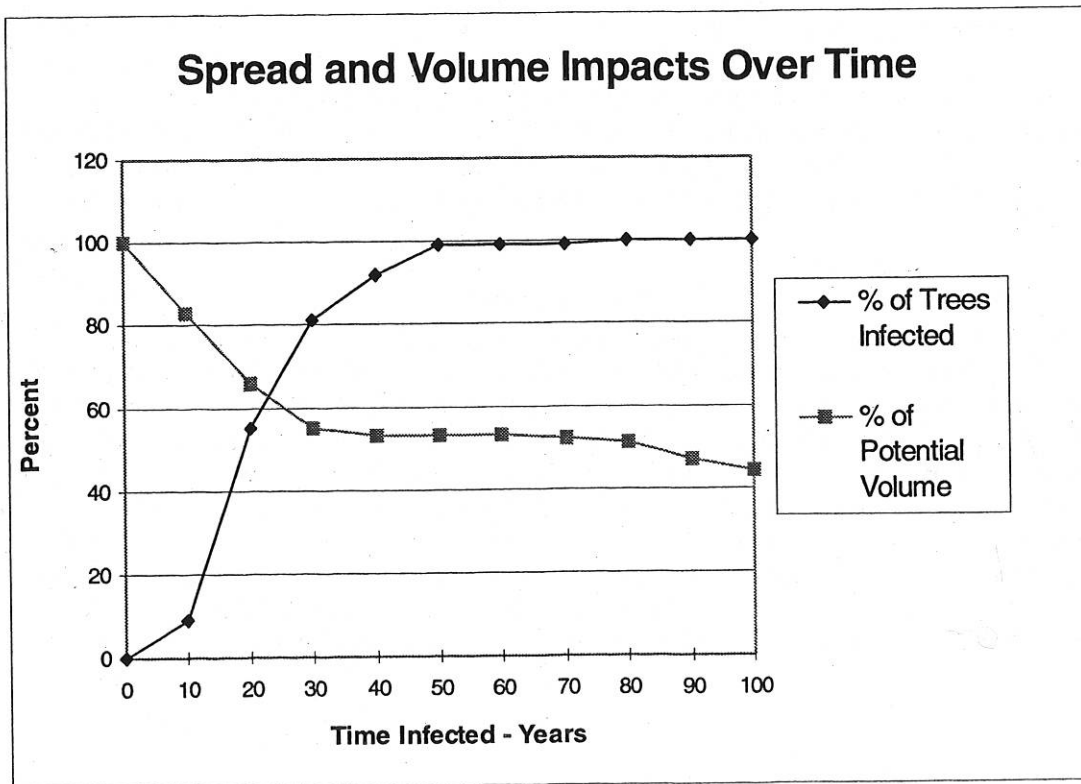
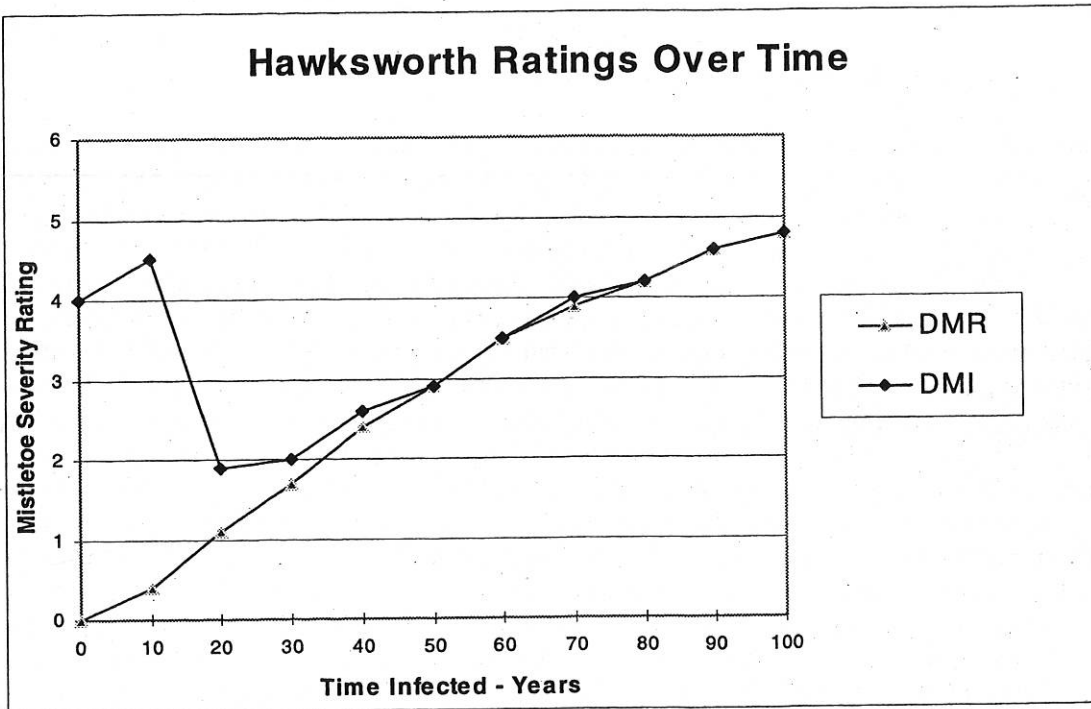
**Figure 3:** The trees selected as the understory portion of the model. There were 31 of the trees that were in the lower 1/3 of the canopy and selected for evaluation. Thus, n=31 means the probabilities were developed with these 31 understory trees.



**Figure 4:** The proportional increases in infection intensity per decade are shown here. The DMR value is the severity rating at the beginning of the decade. The graphed data are the amounts of change in severity over a decade.



**Figure 5:** Hawksworth ratings, spread and volume impacts shown over 100 years from the Prototype Understory Spread and Intensification Sub-Module. Compare these results with those shown in Figure 1.



**Rare hybrids of *Heterobasidion annosum* provide insights on mechanisms of fungal speciation:  
Potential effects of environmental alterations on the speciation of a forest pathogen**

M. Garbelotto<sup>1</sup>, W. Otrosina<sup>2</sup>, and I. Chapela<sup>1</sup>

<sup>1</sup>University of California, Berkeley, CA.

<sup>2</sup>Tree Root Biology Institute, US Forest Service, Athens, GA.

**Abstract.** Although inter-specific hybridization may play an important role in the evolution of endophytic and pathogenic fungi, reports of fungal hybrids are still scant. Lack of hybridization is thought to be determined by incompatibility of different mating systems (prezygotic isolation), or by low survival of hybrids comprising two incompatible genomes (unconditional postzygotic isolation). We have recently found an extensive hybrid genotype of the two host-specialized intersterility groups (ISGs) of the forest pathogen *Heterobasidion annosum*. The S and P ISGs are partially interfertile in laboratory pairings, nevertheless hybrids have never been found before. We tested the hypothesis that hybrid inviability may be due to host adaptation of ISGs, resulting in hybrids that are less fit than either parent on their "adapted" host plant (environment dependent postzygotic isolation). We performed two greenhouse trials: one using field S, P, and SP hybrid isolates on white fir (S-host), ponderosa pine (P-host) and Sitka spruce (S and P "universal" host) seedlings. The second trial was performed by inoculating ponderosa pine seedlings with one S and one P homokaryon and with a SP dikaryon obtained by mating the two in the lab. In the first trial, the P isolate killed more pines (69%) than the S isolates (29%), and the S isolates killed more white firs (15%) than the P isolate (6%). Mortality levels caused by the hybrid isolate matched those of S isolates in the pine trial (25%), and those of the P ISG in the white fir trial (7%). Nonetheless, the hybrid isolate caused as much mortality (94%) as the S and P isolates (85 and 97%) on the universal host Sitka spruce. Comparable results were obtained in the second trial. The following conclusions were drawn: a) the hybrid is a virulent pathogen in a benign environment (the universal host); and, b) the hybrid behaves as a "non-pathogen" on both specific hosts and thus is less competitive than either parent. These results are in accordance with the environment dependent postzygotic isolation hypothesis. Although less fit than the parental types in "natural" situations, hybrids have an increased chance of survival and establishment in forests where logging has created a large number of "non-selective" stumps that provide a more benign environment.

#### INTRODUCTION

With a few exceptions (1, 2), interspecific hybridization appears to be a rare event in fungi, often leading to transient and unfit hybrid individuals (3). Nevertheless, new evidence is suggesting that hybridization may play an important evolutionary role in fungi, resulting in either significant gene transfer between taxa, or to the creation or extinction of species (3, 4). Environmental disturbances may also favor hybridization through a process defined as episodic selection (5). Although there may be several mechanisms selecting against fungal hybrids, none of them are fully understood. We provide here evidence that environment-dependent postzygotic isolation (i.e. parental types are clearly separated in different niches and hybrids are less fit than either parent in such niches) is an important mechanism limiting fungal hybridization in nature. We also suggest that massive modifications in the natural habitat may lead to hybridization of taxa that would be genetically isolated in undisturbed environments.

## EXPERIMENTAL TESTING

### TESTS 1a & 1b.

1a- Greenhouse inoculation (9) of S-host, P-host, and Universal host seedlings with field S, P, and SP hybrid heterokaryons. Seedlings' mortality is variable scored (Fig. 2).

1b- For a genetically more controlled test, we inoculated pine seedlings with a P homokaryon, a S homokaryon and the SP hybrid obtained by mating the two in the laboratory (Fig. 3).

### PREDICTED RESULTS

Do not reject 1Ho if:

P-hosts: P- caused mortality > S-mortality; SP-mortality = S-mortality

S-hosts: S-mortality > P-mortality; SP-mortality = P-mortality

Univ. host: P-mortality = S-mortality = SP-mortality

Reject 1Ho.

SP-caused mortality < P/S-mortality on all three types of hosts  
(accept unconditional postzygotic isolation hypothesis: hybrids are unfit because of genomic incompatibility of nuclei)

Reject 1Ho.

P-hosts: P- caused mortality > S-mortality; SP-mortality = P-mortality

S-hosts: S-mortality > P-mortality; SP-mortality = S-mortality

Univ. host: P-mortality = S-mortality = SP-mortality (hybrid may be superpathogen; then why not hybridize more frequently?).

### TESTS 2a & 2b (TO TEST BOTH 2Ho AND 3Ho)

2a-Identify a stable, invariable ISG-diagnostic marker for the nuclear genome, and a similar marker for the mitochondrial genomes. Sample populations and see if nuclear typing and mitochondrial typing are not congruent at times (e.g. nuclear S type and P mitochondrial type).

2b-Identify alleles that are private (specific) to only one of the ISGs and see if they are present in the other ISG (sign of F1 or F2 gene introgression).

### PREDICTED RESULTS

Do not reject 2Ho if:

There are isolates showing mixed mitochondrial-nuclear typing, and there are alleles specific to one ISG showing up in isolates with a genetic characterization typical of the other ISG.

Reject 2Ho.

There is perfect congruence of nuclear and mitochondrial typing, and no gene introgression can be detected.

Do not reject 3Ho if:

Gene introgression is present in the hybridization zone, but absent in other areas.

Reject 3Ho.

Gene introgression is not associated with a specific area or niche, but randomly distributed. Alleles may not be introgressed but shared ancestral traits

## RESULTS

Test 1a: see figure 2.

Test 1b: see figure 3

Test 2a: see figure 4

Test 2b: P-specific isozyme alleles (e.g. Aconitase, Malate Dehydrogenase, Isocitrate Dehydrogenase, Sorbitol dehydrogenase) were found in the S ISG in percentages ranging from 2 to 5% of the samples studied (n=30) in the putative hybridization zone.

## CONCLUSIONS

## WHY ARE HYBRIDS RARE?

In California, *H. annosum* SP hybrids are at an ecological disadvantage, being less fit than either parent on their "adapted" host plant. When the mechanisms regulating host-pathogen specificity are not present or expressed, hybrids can thrive. Stumps represent a relatively recent (approx. 125 years old) habitat in California forests, and provide a new abundant favorable ecological condition for hybridization. On stumps, in fact, both ISGs can live in the same substrate, thus enhancing the potential for somatic contact and inter-ISG mating. Stumps can also provide an available niche/food source used by hybrids to get established in a site and from which to infect standing trees, maybe predisposed by drought, insects or pathogens. While our results indicate that hybrids are less pathogenic than S or P isolates on some of the most common hosts in California, it should be noted that potential high pathogenicity may result in hosts not yet encountered by hybrid genotypes. Furthermore, nothing is known about the relative saprobic ability of SP isolates. Because of the ability of *H. annosum* to alternate between pathogenic and saprobic lifestyles, both abilities need to be evaluated. The ability of *H. annosum* to spread "vegetatively" and the copious production of asexual conidia may also favor the establishment and spread of a successful hybrid genotype at a large geographic scale. Gene introgression as a result of hybridization may also gradually alter the pathogenicity of the current ISGs

## WHY ARE THERE HYBRIDS?

We believe hybridization is more likely to be occurring in areas extremely affected by human activities and in which the following conditions are met: abundant presence of both inoculum types, ecological conditions conducive to disease expression by both ISGs, abundance of "benign" environments such as stumps or trees predisposed to disease; high tree density to facilitate clonal establishment of novel hybrid genotypes. Data on inter-ISG gene flow support our ideas. Figure 5 summarizes features favoring hybridization (used to define the boundaries of the hybridization zone).

## DISRUPTIVE SELECTION AS A MECHANISM OF SPECIATION: POTENTIAL FOR SECONDARY CONVERGENT EVOLUTION FOR THE TWO ISGs.

Success of greenhouse and field inoculation tests on the alternative host plants (e.g. mortality caused by S isolates on pines) indicates that genes necessary to utilize the alternative hosts exist in both ISGs. Each ISG though is more competitive on its adapted host. Greater pathogenicity assures 1- general greater efficiency of the inoculum in establishing itself, and, 2- ability to outcompete the other ISG. This disruptive selection for host use may be acting as a reinforcement in the divergent evolution of these two sympatric species. Because of the distant taxonomic positioning of these two ISGs in the *H. annosum* complex though (7), it is impossible to determine whether this is reinforcement of a sympatric or of an allopatric speciation process.

## RESULTS

Test 1a: see figure 2.

Test 1b: see figure 3

Test 2a: see figure 4

Test 2b: P-specific isozyme alleles (e.g. Aconitase, Malate Dehydrogenase, Isocitrate Dehydrogenase, Sorbitol dehydrogenase) were found in the S ISG in percentages ranging from 2 to 5% of the samples studied (n=30) in the putative hybridization zone.

## CONCLUSIONS

### WHY ARE HYBRIDS RARE?

In California, *H. annosum* SP hybrids are at an ecological disadvantage, being less fit than either parent on their "adapted" host plant. When the mechanisms regulating host-pathogen specificity are not present or expressed, hybrids can thrive. Stumps represent a relatively recent (approx. 125 years old) habitat in California forests, and provide a new abundant favorable ecological condition for hybridization. On stumps, in fact, both ISGs can live in the same substrate, thus enhancing the potential for somatic contact and inter-ISG mating. Stumps can also provide an available niche/food source used by hybrids to get established in a site and from which to infect standing trees, maybe predisposed by drought, insects or pathogens. While our results indicate that hybrids are less pathogenic than S or P isolates on some of the most common hosts in California, it should be noted that potential high pathogenicity may result in hosts not yet encountered by hybrid genotypes. Furthermore, nothing is known about the relative saprobic ability of SP isolates. Because of the ability of *H. annosum* to alternate between pathogenic and saprobic lifestyles, both abilities need to be evaluated. The ability of *H. annosum* to spread "vegetatively" and the copious production of asexual conidia may also favor the establishment and spread of a successful hybrid genotype at a large geographic scale. Gene introgression as a result of hybridization may also gradually alter the pathogenicity of the current ISGs

### WHY ARE THERE HYBRIDS?

We believe hybridization is more likely to be occurring in areas extremely affected by human activities and in which the following conditions are met: abundant presence of both inoculum types, ecological conditions conducive to disease expression by both ISGs, abundance of "benign" environments such as stumps or trees predisposed to disease; high tree density to facilitate clonal establishment of novel hybrid genotypes. Data on inter-ISG gene flow support our ideas. Figure 5 summarizes features favoring hybridization (used to define the boundaries of the hybridization zone).

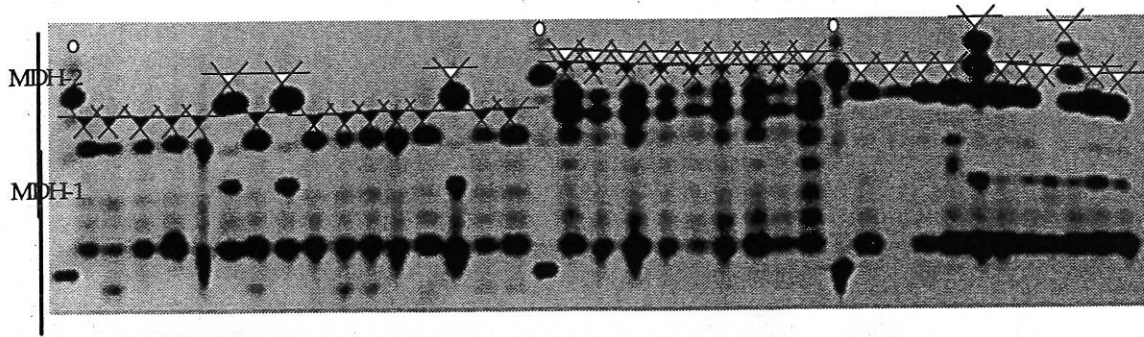
### DISRUPTIVE SELECTION AS A MECHANISM OF SPECIATION: POTENTIAL FOR SECONDARY CONVERGENT EVOLUTION FOR THE TWO ISGs.

Success of greenhouse and field inoculation tests on the alternative host plants (e.g. mortality caused by S isolates on pines) indicates that genes necessary to utilize the alternative hosts exist in both ISGs. Each ISG though is more competitive on its adapted host. Greater pathogenicity assures 1- general greater efficiency of the inoculum in establishing itself, and, 2- ability to outcompete the other ISG. This disruptive selection for host use may be acting as a reinforcement in the divergent evolution of these two sympatric species. Because of the distant taxonomic positioning of these two ISGs in the *H. annosum* complex though (7), it is impossible to determine whether this is reinforcement of a sympatric or of an allopatric speciation process.

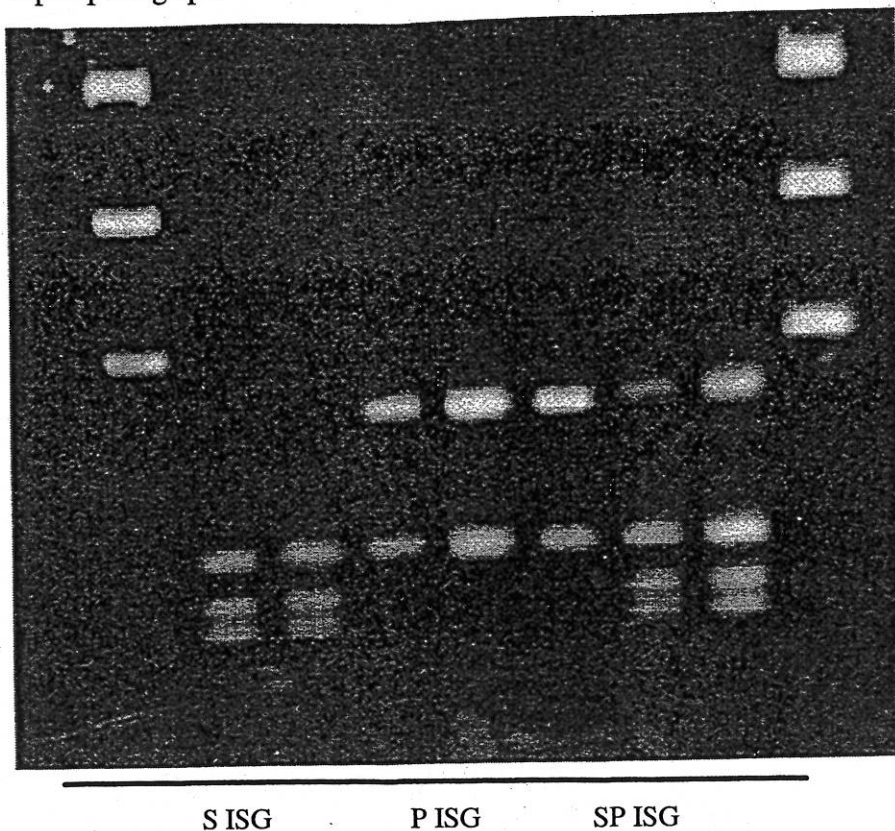
Although it appears as if hybrids do not pose a threat, being less aggressive than either parents, the outcome of an increased hybridization process is uncertain. Figure 6 summarizes some of the potential effects of hybridization.

#### REFERENCES

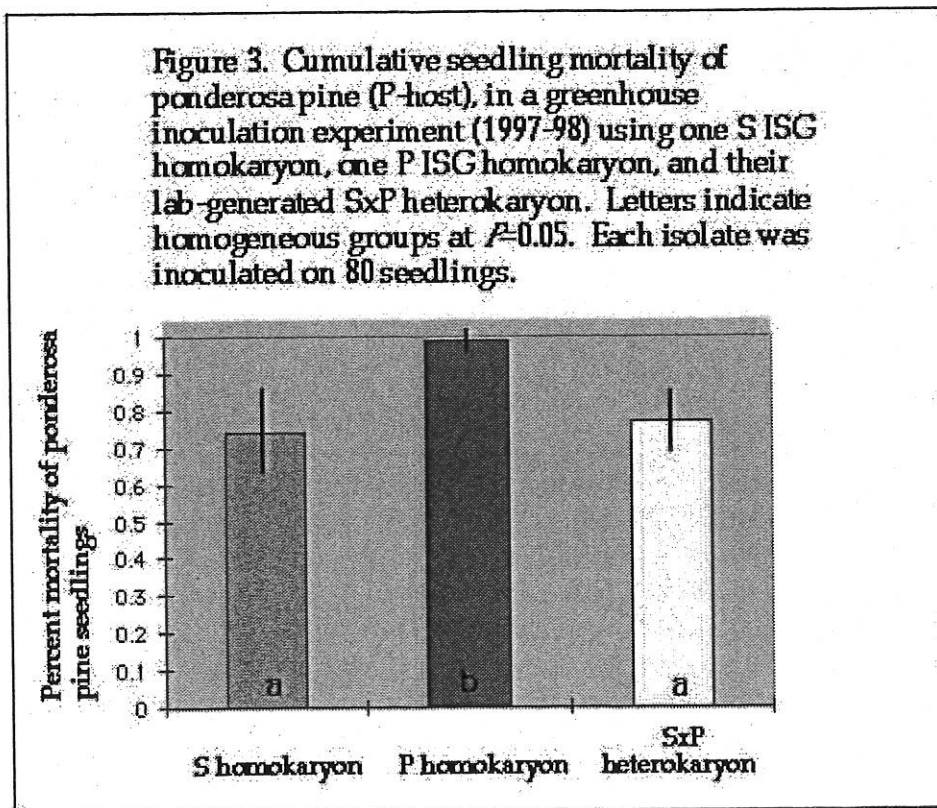
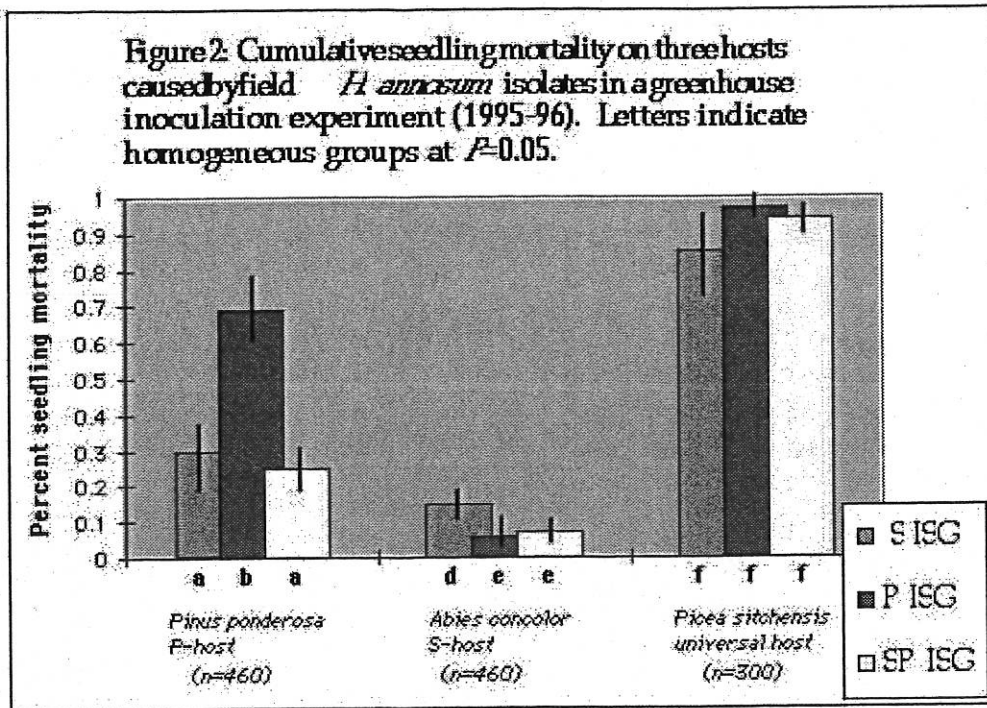
- 1 Emerson, R. , and Wilson, C. M. 1954. Interspecific hybrids and the cytogenetics and cytotaxonomy of *Euellomyces*. *Mycologia* 46: 393-434.
- 2 Fischer, G. W., and Holton, C. S. 1957. *Biology and control of the smut fungi*. Ronald press, New York.
- 3 Brasier, C. M., Kirk, S. A., Pipe, N. D., and Buck, K. W. 1998. Rare interspecific hybrids in natural populations of the Dutch elm disease pathogens *Ophiostoma ulmi* and *O. novo-ulmi*. *Myc. Res.* 101: 45-57
- 4 Tsai, H. F., Liu, J. S., Staben, C., Christiensen, M. J., Latch, G. C. M., Siegel, M. R. and Schardl C. L. 1994. Evolutionary diversification of fungal endophytes of tall fescue grass by hybridization with *Epichloe* species. *PNAS, USA* 91: 2542-2546.
- 5 Brasier C. M. 1995. Episodic selection as a force in fungal microevolution, with special reference to clonal speciation and hybrid introgression. *Can. J. Bot.* 73 (Suppl 1): 1213-1221.
- 6 Otrrosina, W. J., and Cobb, F. W., Jr. 1989. Biology, ecology and epidemiology of *Heterobasidion annosum*. Pages 26-33 in Proc. Symposium on Research and Management of Annosus Root Disease (*Heterobasidion annosum* ) in Western North America.
- 7 Otrrosina, W. J., Chase, T. E., Cobb, F. W., Jr., and Korhonen, K. 1993. Population structure of *Heterobasidion annosum* from North America and Europe. *Can. J. Bot.* 71:1064-1071.
- 8 Harrington, T. C., Worrall, J. J., and Rizzo, D. M. 1989. Compatibility among host-specialized isolates of *Heterobasidion annosum* from western North America. *Phytopathology* 79:290-296.
- 9 Worrall, J. J., Parmeter, J. R., Jr., and Cobb, F. W., Jr. 1983. Host specialization of *Heterobasidion annosum*. *Phytopathology* 73:304-307.
- 10 Cobb, F. W., Jr. , Chase, T. E. , Otrrosina, W. J. , Ratcliff, A. , and Popenuck, T. 1989. Comparative virulence of *Heterobasidion annosum* isolates. *Phytopathology* 79:1164.
- 11 Garbelotto, M., Lee, K. K., Slaughter, G., Popenuck, T., Cobb, F. W., and Bruns, T. D. 1997. Heterokaryosis is not required for virulence of *Heterobasidion annosum*. *Mycologia* 89:92-102.
- 12 Chase, T. E., and Ullrich, R. C. 1990. Five genes determining intersterility in *Heterobasidion annosum*. *Mycologia* 82:73-81.
- 13 Garbelotto, M., Ratcliff, A., Bruns, T. D., Cobb, F. W., and Otrrosina, W. J. 1996. Use of taxon specific competitive priming PCR to study host specificity, hybridization, and intergroup gene flow in intersterility groups of *Heterobasidion annosum*. *Phytopathology* 86:543-551.
- 14 Rosemann, D., Heller, W., and Sandermann, H. Jr. 1991. Biochemical responses to Ozone. II. Induction of stilbene biosynthesis in Scots pine (*Pinus sylvestris* L.) seedlings. *Plant Physiology* 97, 1280-1286.



**Fig. 1a.** Starch gel showing banding patterns of malate dehydrogenase (MDH) for isolates of *Heterobasidion annosum*. MDH-1 is monomorphic for all isolates. MDH-2 is polymorphic and can be used to differentiate S ISG, P ISG, and hybrid SP isolates. Dark triangles highlight S ISG isolates (allele B). White triangles highlight P ISG isolates (alleles A, C, and AC). Stacked triangles highlight hybrid SP isolates (alleles A, B, and AB). White circles are control samples of red pine. Direction of migration is towards top of photograph.



**Fig 1b** RFLPs obtained by Cfo I endonuclease treatment of the ITS region of *Heterobasidion annosum*. ITS amplifications were obtained with the primer combination ITS1F and ITS4. First and last lanes are molecular standards (pUC19 cut by Taq I). Lanes 2 and 3 are S ISG isolates. Lanes 4 to 6 are P ISG isolates. Lanes 7 and 8 are hybrid SP isolates



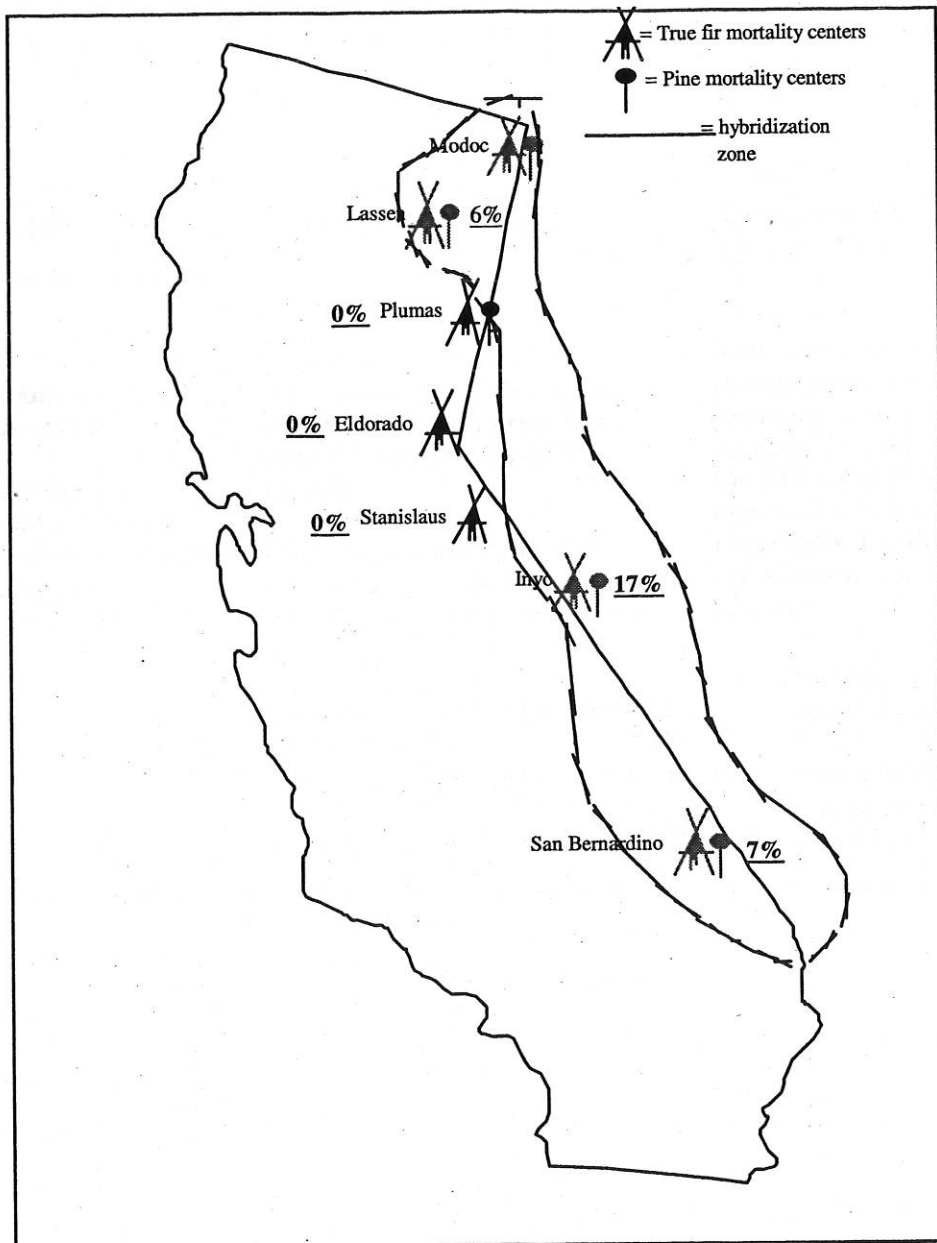


Figure 4: mitochondrial P marker introgressing in S populations where hybridization may be occurring. The ISG of approximately 500 isolates was determined by ISG-diagnostic sequences in the nuclear ITS region of the ribosomal DNA. The mitochondrial type was determined by presence or absence of S-specific and P-specific introns in the large subunit of the mitochondrial ribosomal DNA. RFLP and sequencing data (not presented) show that the P intron found in the S population is not an ancestral shared trait, but that it is an intron that has recently moved from the P into the S ISG.

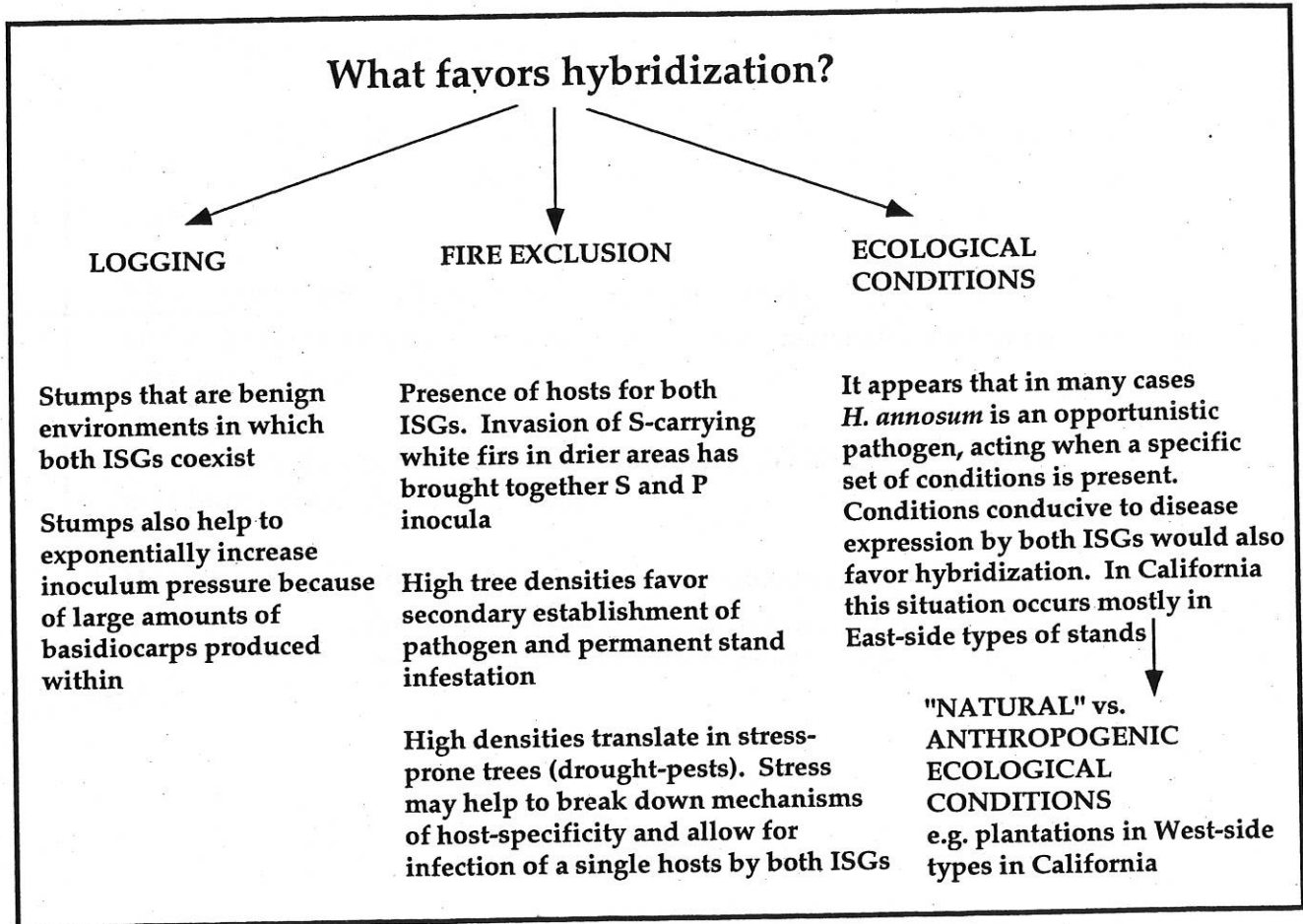


Figure 5

### **CONSEQUENCES of HYBRIDIZATION**

**Hybrids are NOT genetically disadvantaged, they are at an ecological disadvantage. When forests are ecologically altered, hybrids may be successful.**

**Although hybrids are less adapted than the parental S and P ISGs on the specific hosts, we do not know the type of interaction when new host may be encountered.**

**Host-specificity regulates pathogenic but not saprobic activity, hybrids may have enhanced saprobic ability.**

**Hybridization may lead to introgression of pathogenicity genes from one ISG into the other, thus enlarging the pathogenic ability on non-hosts.**

**Figure 6.**



**Will Littke, Terry Shaw and Bob Edmonds**

**The Great Debate:  
Swiss Needle Cast in Coastal Oregon: Pathology or Mythology**

Gregory M. Filip  
Oregon State University, Corvallis, OR

Plantations of Douglas-fir along the Oregon and Washington coast have been experiencing severe damage from Swiss needle cast, a native foliage disease caused by the needle pathogen, *Phaeocryptopus gaeumannii*. Damaged trees are chlorotic, lose their older needles after one or two years, and often show a progressive loss in height and diameter growth.

The disease, and the fungus that causes it, were first described in 1925 on Douglas-fir introduced from the US and planted in Switzerland. In 1939, the first survey for Swiss needle cast presence in the western US and Canada was conducted. The fungus was found in most locations but at non-damaging levels. In the 1970's, Swiss needle cast became an important disease of Christmas trees, coincident with the increase in Douglas-fir Christmas tree acreage and culturing in western Oregon and Washington. In the early 1980's came the first report of Swiss needle cast causing damage in forest plantations. From aerial surveys conducted by the Oregon Department of Forestry, Swiss needle cast was detected on 392,800 acres in 1997.

In 1997, a study was conducted under the auspices of the Swiss Needle Cast Cooperative at OSU to quantify growth losses from Swiss needle cast in 10 to 30-year-old Douglas-fir plantations in coastal Northwestern Oregon. In a 187,545 acre sample area, volume growth loss was estimated at approximately 23% which translates to a loss of 1,668 MMBF over a normal 40-year rotation (Maguire et al. 1998). These are some of the best timber growing sites in the Pacific Northwest, and a volume growth loss of 23% is substantial on such normally productive sites.

In the tradition of OSU-sponsored research cooperatives, the College of Forestry established in January 1997 a new cooperative called the Swiss Needle Cast Cooperative (SNCC). Damage caused by Swiss needle cast made it imperative that new research be conducted to learn practical methods of disease detection and management to maintain the health and productivity of coastal Douglas-fir plantations. A well-run cooperative is an efficient means of increasing and accelerating the level of forest disease research in the region for this purpose. Cooperatives are a method of pooling limited resources at a modest cost per cooperative member. Because members participate directly in problem identification and research solutions, communication of results is speeded and results are applied more rapidly and effectively than occurs with conventional research methods. Shared decision making and active management of cooperative members are key elements of a successful cooperative.

Members in SNCC include private, county, state, tribal and federal landowners. The following were members of SNCC in 1998: Boise Cascade Corporation, Bureau of Land Management, Confederated Tribes of the Grand Ronde, Confederated Tribes of the Siletz, Coos County Forestry Department, Davidson Industries, The Timber Company (formerly Georgia-Pacific), Hampton Resources, Inc., Longview Fibre Co., Menasha Corporation, Miami Corporation, Oregon Department of Forestry, Port Blakely, Rayonier, Roseburg Lumber Co., Rosboro Lumber Co., Simpson Timber Company, Starker Forests, Inc., Swanson-Superior Forest Products, USDA Forest Service, and Willamette Industries, Inc.

Members pay dues based on their forest land holdings on the coast as follows: >50,000 acres = \$15,000/yr; 25,000 to 50,000 acres = \$10,000/yr; and <25,000 acres = \$5,000/yr. Funds are used primarily to support research and projects concerning Swiss needle cast that fall into four categories: basic biology, tree growth impacts, survey and detection, and strategies for control.

Basic biology studies concerning the pathogen currently include: histological studies on needle colonization; molecular studies on fungal strains; DNA methods for detecting spores in rain, air, and needles; mechanisms of spore dispersal and types of spores; and timing, sites, and mechanisms of infection.

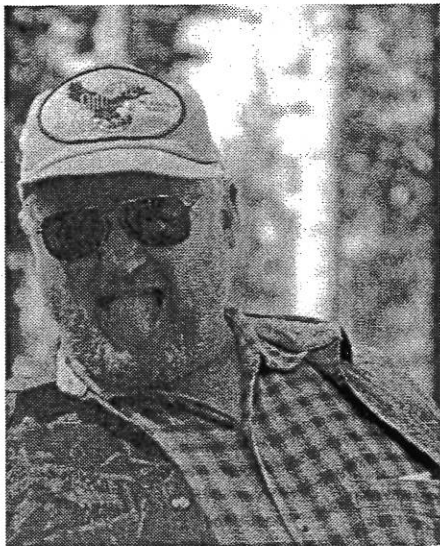
Basic biology studies concerning the host include: needle biomass on infected vs non-infected Douglas-firs; net photosynthesis and stomatal conductance rates on infected vs non-infected foliage; screening for early resistance to Swiss needle cast; role of the pathogen in needle drop; and springwood vs summerwood imbalance.

Tree growth impact studies include: current height and diameter growth impacts at different levels of needle cast; Swiss needle cast symptoms that are reliable indicators of growth impact; and long-term growth impacts of infection.

Survey and detection projects include: geographic range and levels of Swiss needle cast in Oregon and Washington; use of satellite imagery in detection and links with stand and site characteristics; and links among attributes monitored in satellite imagery, aerial surveys, low-intensity ground truthing, and intensively measured growth plots.

Strategies for control being studied include: chemical and biological fungicides; balanced fertilizers and control of competing vegetation; use of resistant Douglas-fir; and effects of precommercial thinning.

Members of the Swiss Needle Cast Cooperative believe that Swiss needle cast is no myth and that our effort to study and manage the disease is a major contribution to the field of forest pathology and the forestry profession.



Terry Shaw



Greg Filip

## Swiss Needle Cast on Douglas-fir in Coastal Oregon: Is it time to Reexamine the Paradigm?

Charles G. "Terry" Shaw III  
USDA Forest Service  
PNW Research Station  
Juneau, Alaska

### Introduction

My purposively provocative position in this "great debate" is to raise two primary issues that I believe are central to the way our profession functions. The first is a perspective on Swiss Needle Cast along the Oregon coast that differs from current conventional wisdom. The second, and perhaps more important issue, is the mobilization response by our profession and others to this disease outbreak. The point of the latter discussion is not to cast stones (or needles) at the approach currently being employed by a cadre of dedicated scientists and practitioners to address *Phaeocryptopus gaeumannii* on the Oregon coast, but rather to examine this approach as a model of how our profession might choose to deal with emerging forest disease situations in the future.

### Are We Living in a False Paradigm?

Dr. Filip cites a study purporting to show a 23% growth loss caused by Swiss Needle Cast in stands of Douglas-fir on "some of the best growing sites in the Pacific Northwest". Accepting for the moment that these conclusions are correct, I contend that this measured response is not a growth loss at all. Rather, it is a reduction in a perhaps undeserved bonus that foresters have falsely come to expect as reality! The most long-standing and serious "impacts" of Swiss Needle Cast are in the fog-belt stands around Tillamook, Oregon. Much of this area was ravished by a spectacular fire in the 1930's; an event that led to a massive reforestation effort. Douglas-fir planting stock from any and all sources were popped in the ground as quickly as possible by foresters, church groups, and Boy Scouts. Indeed, most of the resulting stands of often off-site Douglas-fir grew very well and, in so doing, generated false expectations regarding "normal" growth.

And then, when conditions became favorable, the native needle pathogen *P. gaeumannii*, which had been present all along, helped rebalance the scales and perhaps establish more appropriate growth

expectations for Douglas-fir planted where western hemlock, Sitka spruce, and red alder likely belong. The current management issue is not lost growth but what should be done now with affected stands and how can foresters best plan for the composition of future stands? Where is the effort to "game" with stand development models and ask "what if" questions regarding alternative scenarios for continued development of currently affected stands by varying an array of assumptions through time and space? For example, project future development in stands of age 10, 20, and 30 under assumptions of continued Swiss Needle Cast infestations at 50% and 10% of the current intensity. Expand the affected area by 20% or more; then, shrink it to nothing. Such exercises should expand our understanding of possible silvicultural options and, by examining a critical and immediate management need, add another dimension to the current effort to address the disease situation.

### The Cooperative Model

I agree with Dr. Filip that a well run cooperative is an efficient means of accelerating forest disease research; however, does this approach offer the most scientifically objective and credible method to deal with emerging pathological issues? I think not. In the cooperative model, scientists actively involved in investigating the situation could sit on a board that, among other things, passes out money

to conduct investigations--some of which they hope to get\*. At the very least this approach sacrifices the appearance of objectivity. Perhaps the need to invoke this approach is symptomatic of what is wrong with the current funding structure at land grant universities! Why are scientists out "drumming-up" funds rather than the concerned land owners using the legislative process or other avenues to fund the necessary work? And where is the USDA Forest Service in the process? Why are they, through either their Research or State and Private arm, not at least conducting an independent analysis of the situation so that land managers and the public can have a clear prognosis without even a hint that the outcome may have been influenced by other considerations?

---

\*Again, this discussion examines the cooperative approach as a model; it is not intended to be a direct commentary on the Swiss Needle Cast Cooperative where I understand only one member of the executive committee received funding to support investigations in 1999.

I contend that when investigation of a new disease situation is initiated, we want to invoke a process that will maintain a clear, independent channel for the scientific endeavors rather than melding them with other components of the process. Best I can tell, the cooperative approach, whatever other advantages it may have, fails to meet this need. As such, the scientists could eventually find themselves in an awkward situation if the rest of the cooperative starts to advocate some particular outcome or approach that is not supported by the available scientific information. The scientists must be free to advocate sound scientific approaches without the temptation to be politically correct in order to obtain support for an ongoing research program.

Thus, my caution: we should strive to develop a model that in no way sacrifices even the appearance of an objective scientific investigation. Without that, investigating scientists could end-up defending a particular position and thus be assuming an advocate's role, rather than defending the use of sound scientific information in decision-making. The scientists don't make the decisions, the managers do; so, scientists should not take-on even an appearance of invading their decision space. I contend that a cooperative structure fails this test and thus is not a good model to adopt for the science component of future disease outbreak investigations. The addition of an outside, independent peer review of studies to be funded by a cooperative structure could perhaps help restore the appearance of objectivity, but a whole different approach to how we as a profession may want to deal with any future disease outbreaks needs to be considered. And that could be the topic for WIFDWC's next "great debate"!

## Armillaria Root Disease In California

Kendra Baumgartner and David M. Rizzo  
Department of Plant Pathology  
University of California  
Davis, CA

### SUMMARY

Over 600 isolates of *Armillaria* were collected from throughout the state of California. Species identified include *A. mellea*, *A. gallica*, *A. nabsnona*, and NABS X. *Armillaria mellea* is common throughout the state, including the Central Valley, the Coastal mountains, and the Sierra Nevada. This species was identified from orchard trees, grapevines, and forest trees (hardwoods and conifers). *Armillaria gallica* is common in the Coastal Mountains, the Sierra Nevada, and in parts of the southern cascades. This species was isolated from forest trees as epiphytic rhizomorphs on living hosts or decay on dead hosts. Both *A. nabsnona* and NABS X were rarely collected. NABS X was isolated from symptomatic conifers in a single location. Other than NABS X, only *A. mellea* has been associated with mortality of forest trees. To date, *A. ostoyae* has not been identified in California.

### INTRODUCTION

There are a number of diverse forest types in California, ranging from the sparse oak savanna of the Central Valley to the pure red fir stands just below tree line in the Sierra Nevada. It is also home to some unique forest types, like the old-growth redwood stands of Humboldt County and the Giant Sequoias of Kings Canyon National Park.

The distribution of *Armillaria* species in the United States has been determined on a state-by-state basis. State-wide surveys have given us a general idea of the habitat and ecology of the North American *Armillaria* species. Despite the fact that adequate sampling for *Armillaria* has been done in the Northeast (Blodgett & Worrall, 1992; Harrington & Rizzo, 1993), the Lake states (Banik *et al.*, 1995; Proffer *et al.*, 1987), the Pacific Northwest (Banik *et al.*, 1996; Shaw & Loopstra, 1988) and the Inland Empire (McDonald *et al.*, 1987), California has never been thoroughly surveyed.

The objectives of this study were to determine the identity and distribution of *Armillaria* species in California. A previous study showed that three species were present: *A. mellea*, *A. gallica*, and *A. nabsnona* (Jacobs *et al.*, 1994). However, only 30 isolates were collected, most of which were representative of agricultural areas in the Central Valley. The goal of our research was to collect more isolates that were representative of most of the forest types in California.

### MATERIALS AND METHODS

We put together a collection of approximately 600 *Armillaria* isolates from throughout the state. Isolates obtained from orchards and vineyards were collected from symptomatic hosts or roots of plants adjacent to dead/dying hosts. Isolates obtained from forest tree species were collected from the roots of dead, standing trees, stumps, symptomatic trees and healthy, asymptomatic trees. Rhizomorphs, decay, and mycelial fans collected from the same host were kept separate throughout the identification process. Some isolates were obtained from fruiting bodies and spores. We obtained a collection of approximately 200 unidentified isolates from Dr. Bob Raabe (UC Berkeley). Also, some of the isolates from symptomatic orchard trees, grapevines, and street trees were collected by county farm advisors.

All isolates were initially identified using the PCR-based technique of Harrington and Wingfield (1995). For most isolates, DNA was amplified directly from fresh mycelium by gently scraping a pipette tip over the surface of the culture and dipping it into the PCR vial immediately before starting the reaction. Restriction digests were done by adding *AluI* directly to the PCR vial and

incubating it in a 37-degree water bath for two hours. The identity of some isolates was confirmed through matings with haploid testers (Anderson & Ullrich, 1979). Mating tests were also used to identify isolates with restriction patterns that were not described by Harrington and Wingfield.

## RESULTS

*Armillaria* species identified in California include *A. mellea*, *A. gallica*, *A. nabsnona*, and NABS X. A single restriction pattern was shown by all isolates of *A. mellea*, *A. nabsnona*, and NABS X. For *A. gallica*, three different restriction patterns were found.

The most commonly identified species was *A. mellea*. Isolates of this species were collected from the Central Valley, the Coastal Mountains, and the Sierra Nevada. It was the only *Armillaria* species isolated from symptomatic hosts, including both planted hosts and forest trees. Despite the presence of large mycelial fans at their root collars, most forest trees from which *A. mellea* was isolated were asymptomatic. Locations where *A. mellea* was collected from symptomatic forest trees include the Yosemite Valley, the Napa Valley and Mendocino National Forest. Symptomatic hosts at all three locations were either *Pseudotsuga menziesii* or *Abies concolor*.

The second most commonly identified species was *A. gallica*. Isolates of this species were collected from the Coastal Mountains, the Sierra Nevada, the Warner Mountains, and Mount Shasta. Isolates of *A. gallica* collected from living hosts were obtained from rhizomorphs. Most isolates of this species were collected from wood decay and rhizomorphs found on dead hosts. A few were collected from hosts killed by other fungi, including *Armillaria mellea* and *Heterobasidion annosum*.

Only a single isolate in our collection was identified as *A. nabsnona*. It was collected from woody debris in a redwood forest in the Coastal Mountains of Mendocino County. Another species identified from a limited number of locations was NABS X. This species was collected on Mount Shasta and in the Warner Mountains. On Mount Shasta it was collected from a red fir stump and a dead, standing red fir. In the Warner Mountains, it was collected from symptomatic ponderosa pine saplings in a clear cut full of white fir stumps.

While comparing *AluI* restriction digests of haploid testers of known North American *Armillaria* species to that of our collection from California, we found that some isolates of *A. sinapina* shared the same restriction pattern as some isolates of *A. gallica* (fragments sizes: 390, 240, 183 bp). We confirmed the identity of a portion of our California isolates that show this pattern as *A. gallica* through mating tests.

## DISCUSSION

*Armillaria mellea* is the most widely-distributed species in California. Its range covers the entire Central Valley, which sits near sea level, and extends up into the surrounding mountain ranges where it has been collected as high as 2,000 m. *Armillaria mellea* is also the most virulent species in the state. It is the only *Armillaria* species isolated from symptomatic hosts. *Armillaria mellea* is common in oak woodlands, where it rarely causes extensive mortality. *Armillaria* root disease in orchards and vineyards, which now inhabit land once covered with oak woodlands, is more severe. Inadequately cleared land, previously inhabited by living oaks, likely contains infected roots. Inoculum builds up on pieces of roots that are no longer connected to a living host. Orchard trees and grapevines are non-native hosts to this indigenous fungus. Also, irrigation systems provide water year-round. The combination of excessive water during the summer months and lack of tolerance to infection allow *A. mellea* to spread quickly through rows of closely-planted hosts.

*Armillaria gallica* is the second most common species in the state. Its range includes the Coastal Mountains, the Sierra Nevada, Mount Shasta, and the Warner Mountains. This species is often found in the form of rhizomorphs, epiphytically colonizing the roots of living trees. Once these hosts are killed by insects or other fungi, *A. gallica* saprophytically colonizes the root system. *Armillaria gallica*'s range overlaps so thoroughly with that of *A. mellea* in the Coastal Mountains, that the two species can often be found inhabiting the same tree.

*Armillaria nabsnona* and NABS X likely have more extensive ranges in the Northern part of California, an area of the state we have yet to sample thoroughly. The ecology of these two species in California's Northern forests can not be adequately assessed until we find more isolates. We have isolated NABS X from one location in which it was killing conifer saplings. The identity of these isolates is currently being confirmed by mating tests. They could possibly be isolates of another *Armillaria* species that happen to share the same restriction pattern as NABS X.

We have yet to sample coniferous forest types of the Northwestern counties and the high Sierra's. It is possible that other *Armillaria* species exist in these areas. For example, we have yet to identify *A. ostoyae* from California, even though it has been identified in adjacent states. We have sampled some coniferous forests in the Sierra Nevada and the Warner Mountains, but the only *Armillaria* species found causing mortality of conifers were *A. mellea* and NABS X. Another species we have not found is *A. sinapina*, which has been found in coastal areas of Oregon. We plan to expand our sampling of forest types throughout California.

#### ACKNOWLEDGMENTS

Special thanks to Matt Smith, Garey Slaughter, and Cameron Whiting for field assistance. We also thank Greg DeNitto, Jim Downer, and Bob Raabe for isolates.

#### REFERENCES

- Anderson, J. B., and R. C. Ullrich. 1979. Biological species of *Armillaria mellea* in North America. *Mycologia* 71: 402-414.
- Banik, M. T., J. A. Paul, and H. H. Burdsall Jr. 1995. Identification of *Armillaria* species from Wisconsin and adjacent areas. *Mycologia* 87: 707-712.
- Banik, M. T., T. J. Volk, and H. H. Burdsall Jr. 1996. *Armillaria* species of the Olympic Peninsula of Washington state, including confirmation of North American biological species XI. *Mycologia* 88: 492-496.
- Blodgett, J. T., and J. J. Worrall. 1992. Distributions and Hosts of *Armillaria* species in New York. *Plant Disease* 76: 166-174.
- Harrington, T. C., and D. M. Rizzo. 1993. Identification of *Armillaria* species from New Hampshire. *Mycologia* 85: 365-368.
- Harrington, T. C., and B. D. Wingfield. 1995. A PCR-based identification method for species of *Armillaria*. *Mycologia* 87: 280-288.
- Jacobs, K. A., J. D. MacDonald, F. W. Cobb Jr., and K. Wells. 1994. Identification of *Armillaria* species in California. *Mycologia* 86: 113-116.
- McDonald, G. I., N. E. Martin, and A. E. Harvey. 1987. Occurrence of *Armillaria* spp. in Forests of the Northern Rocky Mountains. Res. Pap. INT-381. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 7 p.
- Proffer, T. J., A. L. Jones, and G. R. Ehret. 1987. Biological species of *Armillaria* isolated from sour cherry orchards in Michigan. *Phytopathology* 77: 941-943.
- Shaw, C. G. III, and E. M. Loopstra. 1988. Identification and Pathogenicity of Some Alaskan Isolates of *Armillaria*. *Phytopathology* 78: 971-974.

Table 1. *Armillaria* species and number of isolates collected from various hosts in California.

Host	<i>A. mellea</i>	<i>A. gallica</i>	<i>A. nabsnona</i>	NABS X
<i>Abies concolor</i>	5	9	0	0
<i>Pseudotsuga menziesii</i>	34	14	0	0
<i>Arbutus menziesii</i>	1	37	0	0
<i>Lithocarpus densiflora</i>	1	17	0	0
<i>Umbellularia californica</i>	2	45	0	0
Citrus spp.	4	0	0	0
<i>Juglans</i> spp.	13	0	0	0
<i>Malus</i> spp.	7	0	0	0
<i>Prunus</i> spp. <sup>a</sup>	101	0	0	0
<i>Pyrus</i> spp.	84	0	0	0
<i>Quercus</i> spp.	33	61	0	0
<i>Vitis</i> spp.	25	1	0	0
ornamentals <sup>b</sup>	86	2	0	0
other conifers <sup>c</sup>	0	9	0	2
other hardwoods <sup>d</sup>	5	32	1	0
total	401	227	1	2

<sup>a</sup> Various species of orchard trees including apricot, peach, almond, and plum.

<sup>b</sup> Hardwood and conifer genera include *Quercus*, *Rosa*, *Betula*, *Cupressus*, and *Juniperus*.

<sup>c</sup> Includes unknown conifers and the following genera: *Abies* and *Pinus*.

<sup>d</sup> Includes unknown hardwoods and *Acer* spp.



Don Goheen

## Investigation of the *Laetiporus sulphureus* species complex in North America

Harold H. Burdsall, Jr. and Mark T. Banik  
 USDA Forest Service, Center for Forest Mycology Research  
 Forest Products Laboratory, Madison, Wisconsin

**Abstract:** Collections of *Laetiporus sulphureus* from throughout the United States were analyzed for variation in the internal transcribed spacer (ITS) region of the nuclear ribosomal DNA. Analysis of the resulting restriction fragment length polymorphisms (RFLP) identified seven *Laetiporus* restriction groups (LRGs). Fruiting bodies within each LRG had the same color pore layer and occurred on similar host types (conifers vs. hardwoods) in similar positions on the host. Distinctive differences in morphological and ecological characteristics occurred between many of the LRGs. Pairings were conducted between single basidiospore isolates obtained from *Laetiporus* specimens belonging to four LRGs. A change in culture morphology in approximately half of the paired sibling single spore isolates suggests the presence of a bipolar incompatibility system. The system also appears to be multiple allelic. The positive pairings also possessed a combined allozyme pattern indicating nuclear exchange and compatibility. Pairings between four LRGs resulted in a definite thick barrier line between the single spore isolate colonies at their confrontation zone. No nuclear migration was indicated in any of these pairings based on allozyme analysis. The lack of individuals representing heterozygous combinations between the several LRGs suggests that these LRGs are reproductively isolated. Combining the molecular, compatibility, allozyme and morphological, and ecological characters there appear to be four *Laetiporus* taxa in North America, *L. sulphureus*, *L. cincinnatus*, LRG II, and LRG III, the latter two remain unidentified as to species.

### INTRODUCTION

*Laetiporus sulphureus* (Fr.) Murr. (= *Polyporus sulphureus* Fr.) is a common, easily identified member of the Polyporaceae that occurs in most areas of the United States. It is pathogenic, causing a brown cubicle rot of roots, butts, and heartwood of living trees. In the eastern, central, and southwestern United States it occurs almost exclusively on hardwoods, especially *Quercus* spp., but is commonly found on conifers in the Rocky Mountains and Pacific Northwest (Gilbertson and Ryvarden, 1986). It is also a persistent saprophyte and can survive and fruit for many years from a colonized dead substrate (Hepting and Roth, 1950).

Although *L. sulphureus* is easily identified by its bright orange color, morphological diversity within the species has led to the description of a number of varieties. These differences were recently supported by molecular characters (Banik, et al, 1996, 1998). *Laetiporus sulphureus* var. *sulphureus*, the type species of the genus, has basidiocarps with a lemon yellow pore layer and occurs on standing live, trunks, stumps or downed logs. *Polyporus sulphureus* var. *semialbinus* Peck was described to accommodate specimens with white pore layers (Peck, 1906). This same form was more thoroughly described as variety *overholtsii* by Rosen (1927), who included white pored collections, with pink pilei fruiting from the ground in association with *Quercus* species. It also appears this form was described as *Polyporus cincinnatus* Morgan (1885), but recognition at the species level has not been widely accepted (Overholts, 1953, Gilbertson and Ryvarden, 1986). Recently, based on RFLP, morphological and ecological data, this species was recognized as distinct and transferred to the genus *Laetiporus* as *L. cincinnatus* Burdsall, Banik and Volk (Banik

et al, 1998). Specimens occurring on conifers have also been considered as a distinct form and in Europe collections from *Picea* sp. were used to describe the species *L. montanus* Cerny (1989). However, this name appears to lack a Latin diagnosis in the place of original publication and, therefore, is invalid. Molecular studies (Rogers, et al., 1998) suggest that the conifer and hardwood inhabiting *Laetiporus* in Europe may be conspecific.

Using the RFLP data, Banik et al. (1998) identified seven restriction groups within *L. sulphureus*, which were termed *Laetiporus* restriction groups (LRG) I-VII (Table I). It was later determined that three of these belonged to the same taxon, two as homozygous expressions and the other, heterozygous. Thus, five LRGs remain. For one of these, LRG V, no single spore isolates are available. Thus it was not used in this study. *Laetiporus sulphureus* (LRGs I, VI, VII), *Laetiporus cincinnatus* (LRG IV), LRG II, and LRG III were tested for incompatibility in order to test the reliability of the RFLP and ecological correlations. Because *Laetiporus* lacks clamp connections allozyme markers are used as an independent test of nuclear migration and sexual compatibility.

## MATERIALS AND METHODS

Collections of *L. sulphureus* were obtained from many different hosts and locations in the United States and information on host, fruiting position and pore layer color were recorded. Complete collection information is available from the authors upon request.

### Isolate collection and allozyme typing

Tissue isolates were obtained from most of the collections by excising small pieces from the pileus context using aseptic technique, and placing them on 1.5 % malt extract (Difco, Detroit, Mich.) and 2% agar medium (MEA) in Petri plates. All isolates are on deposit in the Center for Forest Mycology Research (CFMR) culture collection maintained at the USDA-FS, Forest Products Laboratory in Madison, WI.

Single spore and tissue isolates were obtained from most specimens. Basidiospores were routinely obtained by suspending sections of the pore surface over oak wood extract medium (OWEM) until basidiospores were deposited on the medium surface. OWEM was prepared by boiling 50 gr red oak sawdust in 1 L water for 1 hour and straining through two layers of cheesecloth to obtain oak wood extract. After autoclaving, 500 mL of the extract was combined with 500 mL water containing 20 gr agar. After 2-4 days incubation at room temperature, germinated single basidiospores were transferred, along with a small piece of underlying medium, to 15 x 45 mm vials containing 2 mL of OWEM. After several months the resulting single spore isolates were transferred to 16 x 125 mm culture tubes containing 1.5 % malt extract and 2 % agar (MEA) for long term storage. Tissue isolates were obtained by excising small pieces of basidiome trama onto MEA.

Tissue isolates from each of the collections were subjected to allozyme analysis for the dimeric enzyme glucose 6-phosphate (GPI) in order to obtain markers for use as aids in interpreting pairing results. A small amount of mycelium was scraped from cultures growing on medium consisting of 4 % potato dextrose agar (Difco), 0.5% agar and 0.25 % gallic acid (PDGal) and ground in a ground glass tissue homogenizer with the addition of 100  $\mu$ L extraction buffer (0.05 M Tris-HCl, pH 7.1). The resulting homogenate was centrifuged at 13800 relative centrifugal force for three minutes in a Eppendorf microcentrifuge, and the supernatant was used for allozyme analysis using cellulose acetate electrophoresis. The procedure followed the instructions provided by the manufacture of the cellulose acetate gel plate electrophoresis apparatus (Helena Laboratories, Beaumont, TX) (Hebert and Beaton, 1993). The running buffer was Tris-glycine (0.25 M Trizma-base, 1.9 M glycine, pH 8.5) and gels

were run for 30 min at 200 volts. Gels were stained for GPI activity using the technique of Richardson et al. (1986), modified by the addition of 2 mL of 1.5 % agar and the use of 0.1 M Tris, pH 7.4 as the stain buffer. Gels were incubated for 10 - 60 min in the dark at room temperature before being photographed and scored for allozyme activity.

#### **Pairings between and within LRGs**

Two single spore isolates were selected at random from each of the collections representing either *L. sulphureus*, *L. cincinnatus*, LRG II or LRG III. These isolates were paired in all possible combinations on PDAgal. Two replicates of each pairing were done, one in 150 x 25 mm and one in 90 x 15 mm plastic Petri plates. Pairings were conducted by placing one agar plug, approximately 5 mm<sup>2</sup> cut from cultures growing on PDAgal, of each of the two isolates to be paired in contact with each other in the center of the plate. A second plug of each isolate was placed 2 cm away from the first plug, such that the four plugs in the plate were in line, with the plugs from one isolate on one side of the plate and the plugs from the other on the opposite side. After incubating at 25 C for 7 to 10 days, the morphologies of the pairings were recorded. Two basic categories of morphologies were observed, one in which the two single spore isolates appeared to fuse and the other in which the two isolates remained distinct.

Allozyme analysis was performed on pairings in which the two single spore isolates remained distinct. Two samples from each of these pairings, one from each side, were analyzed by removing a small amount of mycelium and treating it as described earlier. Allozyme analysis was performed on pairings in which the two single spore isolates appeared to fuse by removing a small amount of mycelium from the center fused area. In all pairings analyzed, the two single spore isolates possessed different allozymes so that the detection of heterodimeric activity could be used as an indicator for nuclear combination.

#### **Pairings within collections**

To determine the mating systems present in *L. cincinnatus* and *L. sulphureus*, all sibling single spore isolates from four collections were paired in all combinations using the protocol described above. The pairings were incubated and scored as described above.

## **RESULTS**

#### **Basidiospore collection and initial allozyme analysis**

Basidiospores of all collections reliably germinated on OWEM with germination percentages ranging from 20 - 80 %. Survival of the germinated basidiospore when transferred to OWEM was close to 100 %.

Four allozyme types, designated A - D were identified in the tissue isolates of *L. sulphureus* and *L. cincinnatus* and LRG III. LRG II had a distinct pattern. Each of the allozyme patterns possessed only a single band, indicating that each collection was homozygous at the GPI locus.

#### **Pairings within and between LRGs**

Pairings between any single spore isolates of *L. sulphureus*, *L. cincinnatus*, LRG II or LRG III all resulted in the formation of a dense, darkly pigmented line separating the two single spore isolates (Table II). Allozyme analysis of pairings between LRGs demonstrated no heterodimeric GPI activity.

#### **Pairings within collections**

Reaction types observed in pairings of single spore isolates from the same fruiting body were the same as those observed in within-LRG pairings. None of the intracollection pairings exhibited a dense dark line as seen between LRGs. Fusion with increased density and pigmentation occurred in approximately

50% of the non-self pairings between sibling single spores. The pattern for this morphology among the pairings fit that expected for a bipolar mating system. Because of the homozygous condition of the GPI locus for each of the fruiting bodies of *L. cincinnatus* from which the basidiospores were isolated, allozyme analysis of the intracollection pairings was not possible.

## DISCUSSION

The use of OWEM facilitated the collection of viable basidiospores from the *Laetiporus* specimens. Previous attempts to obtain single spore isolates using other media had been unsuccessful. With a reliable way to obtain basidiospores a critical assessment of the incompatibility within the genus is now possible.

The occurrence of the heterodimeric GPI activity in pairings between single spore isolates from different collections substantiates the compatibility of these isolates. To confirm that heterodimer formation resulted from nuclear exchange and not mycelial mixing, the mycelia from ten pairs of separately grown single spore isolates were ground together and analyzed for GPI activity. The pairs of single spore isolates chosen had exhibited heterodimeric activity when they were paired during the compatibility tests. None of the ten pairs of separately grown single spore isolates exhibited heterodimeric activity when mixed during grinding. Also, samples taken from five pairings between LRGs exhibited the homodimeric GPI activity of each of the single spore isolates, but no heterodimeric activity was detected. In these cases, invasive growth of mycelia between the two single spore isolates occurred but nuclear exchange did not take place. Thus it appears that heterodimeric enzyme is formed only when the two isotypes are present in a biologically active thallus.

Heterodimeric GPI activity correlates consistently with the morphological change of the cultures to a denser, more pigmented state, thus substantiating that this morphology is indicative of compatibility. This type of dimorphism has been described for other fungi, such as *Armillaria mellea* (Vahl: Fr.) Kummer (Hintikka, 1973). In *Laetiporus*, the dimorphism is comparatively subtle, but by using the pairing protocol described it can be consistently and reliably used to assess compatibility.

The consistent formation of a dark line in all pairings between *L. sulphureus*, *L. cincinnatus*, LRG II, and LRG III confirm that they are incompatible. These results indicate that the delimitation of *L. cincinnatus* (Banik, et al, 1998) is appropriate. For all LRGs, the almost complete compatibility between collections indicates the presence of multi-allelic mating system.

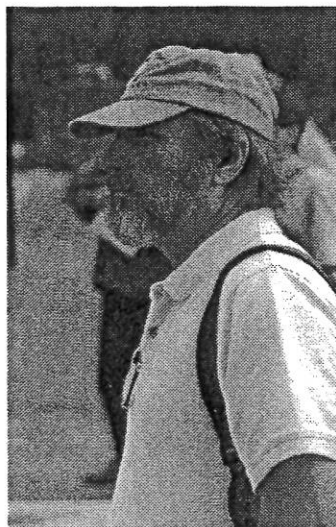
The pattern of compatible reactions in within-fruiting body pairings fits almost exactly that expected for a bipolar mating system for both *L. sulphureus* and *L. cincinnatus*. LRGs II and III are assumed to be the same although there is less data to support this at this time. Incompatible reactions in these crosses appear either as fusions without an increase in density or a separation of the two single spores without the formation of a dark line as seen in pairings between LRGs.

The presence of a bipolar mating system is not unexpected since many other brown rot fungi have this type of mating system (Ryvarden, 1991). Confirmation of the mating system type should be possible if single spores can be obtained from fruiting bodies that are heterozygous at the GPI locus, making allozyme analysis of sibling pairings possible.

Further work is needed to establish absolutely that *L. sulphureus*, *L. cincinnatus*, LRG II, and LRG III are all distinct. However, these initial studies suggest that there are at least four species of *Laetiporus* in North America. Work on proving the existence of these taxa and providing names for them is continuing.

### Literature Cited

- Banik, M. T., H. H. Burdsall, Jr., 1998. Identification of groups within *Laetiporus sulphureus* in the United States based on RFLP analysis of the nuclear ribosomal DNA. *Folia Cryptogamica Estonica* 32: (in press).
- Banik, M. T. and Harold H. Burdsall, Jr., 1999. Incompatibility between *Laetiporus cincinnatus* and *L. sulphureus* in culture. *Mycotaxon* (in press).
- Banik, M. T., H. H. Burdsall, Jr., and T. J. Volk. 1996. Differences between isolates of *Laetiporus sulphureus* in the internal transcribed spacer region of the nuclear ribosomal DNA. *Inoculum; Newsletter of the Mycological Society of America* 47: 14.
- Cerny, A. 1989. *Parazitické Drevokazne Houby*. Prague. 99 p.
- Gilbertson, R. L. and L. Ryvardeen. 1986. North American Polypores. Vol. 1. *Abortiporus-Lindtneria*. Fungiflora, Oslo, Norway. 433 p.
- Hebert, P. D. N., and M. J. Beaton. 1993. Methodologies for allozyme analysis using cellulose acetate electrophoresis. Helena Laboratories. 32pp.
- Hepting, G. H., and E. R. Roth. 1950. The fruiting of heart rot fungi on felled trees. *J. Forestry* 48: 332-333.
- Hintikka, V. 1973. A note on the polarity of *Armillaria mellea*. *Karstenia* 13: 32-39
- Morgan, A. P. 1885. The mycologic flora of the Miami Valley, Ohio. *Cincinnati Soc. Nat. Hist. Jour.* 8: 91-111.
- Overholts, L. O. 1953. The Polporaceae of the United States, Alaska, and Canada. University of Michigan Press. Ann Arbor, Mich. 466p.
- Peck, C. H. 1906. Report of the State Botanist, 1905. N. Y. State Mus. Bull. 105: 34.
- Richardson, B. J., P. R. Baverstock, and M. Adams. 1986. Allozyme electrophoresis a handbook for animal systematics and population studies. Academic Press, Inc. .410pp.
- Rogers, S., O. Holdenrieder, T.N. Sieber. 1998. *Laetiporus sulphureus* from broad-leafed trees and from conifers - a comparison. In Delatour, C., J.J. Guillaumin, and B. Lung-Escarmant, and B. Marçais. 9th Int. Conf. on Root and Butt Rots. p. 439. INRA, Paris
- Rosen, H. R. 1927. A pink-colored form of *Polyporus sulphureus* and its probable relationship to root-rot of oaks. *Mycologia* 19: 191-196.
- Ryvardeen, L. 1991. Genera of Polypores: Nomenclature and taxonomy. *Synopsis Fung.* 5. 363pp.



Hal Burdsall

**Table 1.** Number of collections of original seven *Laetiporus* restriction groups (LRGs) that exhibit a specific morphological, distributional and/or ecological characteristic.

		LRG							
		I	II	III	IV	V	VI	VII	
pore layer color	white	0	4	0	29	5	0	0	
	yellow	24	7	5	0	0	1	19	
host	<i>Quercus</i> sp.	9	20	3	0	26	4	0	11
	other hardwood	9	10	0	4	1	1	7	
	conifer		0	0	8	0	0	0	0
fruiting position	soil from roots		0	0	0	26	0	0	0
	trunks, logs and stumps		27	12	9	3	5	1	16
geographical location	northeastern		5	0	0	0	0	0	1
	southeastern		2	5	0	2	0	0	2
	midwestern		22	0	1	31	5	1	20
	northwestern		0	0	8	0	0	0	0
	southwestern		0	9	2	0	0	0	0

**Table II.** Preliminary data on incompatibility between single spore isolates of *L. sulphureus*, *L. cincinnatus*, LRG II and LRG III haploid cultures.

	I <i>L. sulphureus</i>			II new species?			III new species?		IV <i>L. cincinnatus</i>	
	1	2	3	4	5	6	7	8		
I	1	-F <sup>1</sup>								
	2	+D <sup>2</sup>	-F							
II	3	-L <sup>3</sup>	-L		-F					
	4	-L	-L	+D	-F					
III	5	-L	-L		-L	-L		-F		
	6	-L	-L		-L	-L	+D	-F		
IV	7	-L	-L		-L	-L		-L	-L	-F
	8	-L	-L		-L	-L		-L	-L	+D -F

<sup>1</sup> -F = incompatible reaction with fusion of single spore isolates with no change in colony morphology

<sup>2</sup> +D = compatible reaction with intermingling of single spore isolates and a change in colony morphology to a more dense colored growth in the interaction zone

<sup>3</sup> -L = incompatible reaction with distinctly pigmented thick wall (line) of entangled hyphae formed in the confrontation zone between the single spore isolates.

## Filling Missing Values For Multivariate Data Required By A Landscape Forest Pest Model

Shaoang Zhang<sup>1</sup>  
Matthew J. Oberle<sup>2</sup>  
Judy A. Adams<sup>3</sup>

<sup>1</sup>Biological Statistician, INTECS International, Inc.,

<sup>2</sup>System Ecologist, Autometric Service Company,

<sup>3</sup>Program Manager, Forest Health Technology Enterprise Team, USDA Forest Service

**Abstract.** Modeling forest pests at the landscape scale has been found to be necessary to appropriately represent insect and disease dynamics and to meet the requirements of forest ecosystem management. The shift in the scale and structure of forest insect and disease models from a single stand to a landscape requires comprehensive input data, data that are not completely available from traditional forest inventories and plot surveys. As a result, data availability has become a topic that needs to be addressed and solved in landscape-scale forest pest modeling. This report outlined potential approaches for preparing landscape-level model inputs by statistically filling in missing data. Promising procedures and algorithms associated with filling missing data on a landscape context are summarized and discussed.

### INTRODUCTION

As forest ecosystem management has become a necessary strategy toward sustainable forestry, the focus of forest management has been shifting from the scale of individual forest stands to that of forested landscapes (Unger 1994). A better understanding of disturbances at the landscape level and the interactions between landscape components is now required in ecosystem management decision making (Averill et al. 1994). As a result, the modeling of forest insect and disease dynamics and impacts is also shifting toward the landscape scale, not only due to the new ecosystem management philosophy, but also out of ecological practicality. For example, as common forest disturbances such as insect outbreaks and wildfires are generally triggered by; and impact conditions at; the landscape scale, modeling them at this spatial scale may be more appropriate. Only then can we begin to fully represent and understand their ecological dynamics, allowing better management decisions to be made. However, with the study of landscape ecology still in its infancy, potentially confounding modeling issues, such as spatial and temporal scale dependencies, have been hypothesized and discovered but not fully resolved. Furthermore, adequate ecological data are rarely available for entire landscapes, ultimately requiring some form of quantitative estimation of the important ecological characteristics of unsampled units. This paper provides possible approaches for filling missing values for the multivariate samples required in the operation of landscape-scale models.

In the past few decades, a number of dynamic forest models have been developed. Some of them, such as the Forest Vegetation Simulator (FVS) (Stage 1973, Wykoff et al. 1982, Wykoff 1986, Crookston and Stage 1991, McGaughey 1996, etc.) have been used extensively in forest management. Since its beginning in the early 1970's, FVS has expanded into a large modeling system that includes variants calibrated for many forest types across North America. It would be worthwhile to take advantage of the facilities and experienced users of these single-stand models by using them as the building blocks for landscape-level models. For example, the USDA Forest Service's Forest Health Technology Enterprise Team (FHTET) has been developing a landscape-level WestWide Pine Beetle Model (Beukema et al. 1994) into which FVS's capability to predict stand dynamics is incorporated. However, data availability and scaling effects were found to be problematic in the development of this Model. These issues have not been adequately addressed in forest landscape modeling as traditional

forest sampling approaches are not designed to provide an estimation of landscape characteristics, and large spatial scales frequently involve increased spatial heterogeneity and longer time scales (King 1991, Wiens 1989). So far, little research focused on solving these problems has been reported.

It is out of the scope of this study to investigate all aspects involved in populating a landscape. Instead, it is aimed at introducing some possible approaches to populate a landscape without delving into detailed statistical theories. Although the WestWide Pine Beetle Model is used as the reference model in this study, it is expected that the approaches introduced here can be used in other situations.

## DATA DESCRIPTION

The FVS was designed to use data from conventional forest inventories or other plot surveys. For most cases, only some units<sup>2</sup> within a landscape are sampled, although the proportion of sampled stands in the landscape may vary from survey to survey. In some cases, remote sensing information and/or forest maps of the landscape (e. g. aerial photos) are available. For these reasons, available information for the landscape can be characterized by the two cases illustrated in Figure 1(a) and (b).

## METHODS

In the first case (Figure 1(a)), covariates  $Y$  were observed for all units in the landscape. Design variable  $Z$  is known for all units in the landscape, and has a value of either 0 (if the unit was not surveyed) or 1 (if the unit was surveyed).  $X$ , the key variables whose values are required as input in the landscape forest pest models, were only surveyed partially.  $n_0$  of the total  $n$  units in the landscape were surveyed, the other  $n_1$  units were not surveyed. They are represented by  $X_{inc}$  and  $X_{exc}$ , respectively. The objective to populate a forest landscape discussed in this study is to fill conditional missing values  $X_{exc}$  given  $Y, Z$ , and  $X_{inc}$ . In the second case (Figure 1(b)), no covariate observations are available. Accordingly, the objective of populating a forest landscape is to fill conditional missing values for  $X_{exc}$  given  $Z$  and  $X_{inc}$ . In other words, more information is available in the first case (Figure 1(a)) than in the second case (Figure 1(b)) to fill missing data for units that were not sampled in the ground survey. While the difference in information availability between the first and the second case results in some differences in filling missing values ( $X_{exc}$ ), the principles and approaches for populating a forest landscape in these two cases are similar as we will discuss later.

Some statistical assumptions are needed before going any further in our discussion. First, we assume that the missing data are missing at random (MAR), that is, the probability that an observation is missing may depend on  $X_{inc}$  and  $Y$  but not on  $X_{exc}$ . This assumption is approximately satisfied if the survey for  $X$  is conducted using random sampling. Also, without other specification, we assumed that both  $Y$  and  $X$  are continuous variables from multivariate normal populations. This assumption is reasonable for most cases when the landscape is composed of many units. In addition, the number of units (sample size) surveyed for  $X$  should be large enough to represent stand structures and stand diversity in the landscape. Unless stated otherwise, it is assumed that these assumptions have been met.

<sup>2</sup>A unit can be a stand or a relatively small area in the landscape, depending on what is used as a model grain in the landscape forest pest model

## GENERAL IDEAS TO FILL $X_{exc}$

For the missing data represented by Figure 1(a), covariates,  $Y$ , which are a subset of variables,  $(X', Y)'$ , are measured for all units in the landscape. For this case, the first step to fill  $X_{exc}$  can be seen as performing pattern recognition if variables  $(X', Y)'$  can be represented by a subset of variables  $Y$ . This subset of variables  $Y$  are called feature variables and are denoted by  $Y_f$ .

Under this situation, the following steps can be adopted in filling  $X_{exc}$ :

1. Classify the units with  $X_{inc}$  into  $g$  groups based on the observations for  $(X_{inc}', Y_{inc}')$  or feature variables,  $Y_f$ , where  $g = 1, 2, \dots, n_0$ ;  $n_0$  is the number of observations in  $(X_{inc}', Y_{inc}')$ ; and  $Y_f$  is a subset of  $Y$  which can represent  $(X', Y)'$  under the condition of having  $(X_{inc}', Y_{inc}')$ .
2. Use feature variables  $Y_f$ , and a discriminant rule based on a certain optimal criterion (e.g. Bayesian rule) to classify each units in  $X_{exc}$  into one of the  $g$  groups.
3. Fill missing values for unsurveyed units in each group using one of the potential approaches for filling missing data to be introduced later. Covariance matrix,  $\Sigma_i$ , and mean vector  $\mu_i$  for  $X$  in group  $g_i$  that are needed in missing data filling are initially estimated by the observations of  $X_{inc}^i$ , which are the observations for surveyed units in group  $g_i$ ;
4. Iterate steps 1, 2, and 3 until robust missing value estimates are achieved.

The unit classification is important for populating a forest landscape, since it makes units in the same group as similar as possible and improve the accuracy of filled data. If variables  $(X', Y)'$  can not be well represented by  $Y_f$ , alternate approaches may be used, for example, random assignments of group membership for each unsurveyed unit based on the proportion of units in each group to the total number of units in the landscape can be used for the classification. If stand structures in the landscape are relatively homogenous, the whole landscape can be treated as a population. If this is the case, no unit classification is necessary. For most cases, classifying all units in the landscape into  $g$  groups before applying any of the potential approaches for populating a forest landscape is needed and will be discussed momentarily in this report.

If no observations for covariates  $Y$  are available as illustrated in Figure 1(b), it is not possible to conduct a discriminant analysis to assign group membership for each unsurveyed unit. An approach appropriate for this case is described as follows:

1. Classify the landscape into  $g$  groups based on prior experience or historical observations or  $X_{inc}$ ;
2. Estimate statistics such as  $\mu_i$  and  $\Sigma_i$  for group  $g_i$  and the relative frequency of units in this group,  $f_i$ ;
3. Randomly assign units that were not surveyed into the  $g$  groups based on their relative unit frequency. Such an assignment pledges that more unsurveyed units will be assigned to group  $g_i$  than  $g_j$  if  $f_i$  is larger than  $f_j$ , where  $i \neq j$ ,  $i, j = 1, 2, \dots, g$ .
4. Use missing data filling approaches to generate observations for  $X_{exc}^i$  in group  $i$ ,  $i = 1, 2, \dots, g$ ;
5. Iterate 2, 3, and 4 until robust missing value estimates are achieved.

Some problems exist in the unit classification (clustering surveyed units into groups) and discriminant analysis (group membership assignments for unsurveyed units). For example, in the cluster analysis, determining the optimal number of groups can be problematic. In the discriminant

analysis, the group membership of each unit may change as new members are introduced into the group. An iteration algorithm to mitigate the effects that fluctuating group membership impose on the robustness of the discriminant analysis should be used. The basic idea of the algorithm is to obtain a robust estimation of group mean vectors and covariance matrices by iterative calculation. Discussion on implementing the iteration algorithm will be outlined later in this report.

## OUTLINE OF METHODS

### *Cluster Analysis*

The purpose of cluster analysis is to partition surveyed units into a number of groups or clusters such that units in the same group tend to be similar to each other but as distinct as possible from individuals in other groups. In past decades, "a vast number of clustering methods have been developed in several different fields, with different definitions of clusters and similarity among objects" (SAS Institute Inc. 1989). The hope of the biological application of cluster analysis is that the groups found in cluster analysis will correspond with some "natural" groups occurring in the population studied (the landscape in our case) (Krazanowski and Lai 1988). There is not a single solution toward the most appropriate clustering approaches (Marriott 1971, Evritt 1979), since both grouping criterion and number of groups are problems to which no universally applicable resolutions have been provided. However, based on the multivariate normality assumption, it is possible to suggest a few clustering approaches that would be appropriate for populating a forest landscape. Criteria based on within-group covariance matrix,  $W$ , as well as the number of groups,  $g$ , as reported (Friedman and Rubin, 1967, Marriott, 1971, Arnold, 1979, and Krazanowski and Lai, 1988, etc.) could be used to provide an objective function and evaluate the optimal number of groups. Iteration algorithms that may require great computational power when dealing with a large data set would be needed to implement these approaches in cluster analysis. If the null hypothesis of multivariate normal distribution is skeptical, the alternative approach to determine the number of groups would be the  $k$ th-nearest-neighbor clustering method proposed by Wong and Lane (1983). For technical details regarding these approaches, please refer to Friedman and Rubin (1967), Marriott (1971), Anderberg (1973), Arnold (1979), Wong and Lane (1983), Krazanowski and Lai (1988), and McLachlan (1992).

An alternative to cluster analysis in its empirical application is to group surveyed units using traditional ecological classification approach. This approach is primarily based on ecological community characteristics and geographical attributes, as well as professional experience. The optimal number of groups in such a classification depends on overall variation of ecological types in the landscape. However, such a classification is more or less "subjective" and should be used with caution. It is noted that after the classification, there should be a sufficiently large number of surveyed units in each group to pledge a robustly estimation of population parameters in each group, since each group is treated as a distinct population in filling missing values. For general principles in ecological classification, please refer to text books in Ecology and Forest Ecology such as Kimmins (1987).

### *Discriminant Analysis*

As discussed above, if we have surveyed data as illustrated in Figure 1(a), we may use discriminant analysis to fill missing data in a landscape context. Again, the basic idea is to determine the group membership of each unit based on the observations for feature variables  $Y_f$  which is a subset of covariates  $Y$  and the groups classified based on  $(X'_{inc}, Y'_{inc})$  or  $Y_f$ . It is critical for such a

discriminant analysis to select representative feature variables  $Y_f$  and determine what is the optimal discriminant rule.

### Feature Variable Selection

It has been reported that for a sample of finite size, the performance of a given discriminant rule may not improve with an increase of the number of variables (Boullion, et al. 1975, Jain and Waller 1978, Jain and Chandrasekaran 1982, etc.). This implies that the performance of a given discriminant rule may reach a peak in a range of the number of variables for a given discriminant analysis problem. This phenomenon is called peaking phenomenon (McLachlan 1992). Therefore, the selection of feature variables has been an important topic in discriminant analysis for pattern recognition. In fact, there may be other reasons for using a subset of available feature variables. For instance, in the case illustrated in Figure 1(a), only variables  $Y$  are observed for all units in the landscape, and it is not possible to use variable  $X$  in the discriminant analysis.

The basic idea to evaluate if the selected feature variables is representative is to test the hypothesis that no additional information is provided by the non-selected feature variables. If the hypothesis is true, we can infer that we have selected an appropriate subset of feature variables. Otherwise, other subsets could be more appropriate than the one tested. For theoretical description of this test, please see Rao (1973), McKay and Campbell (1982), and McLachlan (1992). There may be too many combinations for selecting  $k$  variables from  $p$  variables (where  $k < p$ ) to be tested one by one in practice when  $p$  is large. For this reason, some selection procedures have been developed to accelerate the selection process. For example, a canonical analysis that can reflect the relationship between the canonical variates that are, respectively, the linear combination of selected feature variables and the linear combination of unselected variables can be used in this selection process. If the first few pairs of canonical variates are highly correlated, it can be inferred that the selected features are representative. Other approaches such as a stepwise procedure can also be used in feature variable selection (McLachlan 1992). The selection of feature variables can be extremely complicated when the number of groups,  $g$ , is larger than 2. Please see Campbell (1984), Gittins (1985), McLachlan (1992), John et al. (1994), and Aha and Bankert (1994) for technical details.

Empirically, it would be possible to select a subset of available feature variables based on experts' experience and knowledge and achievements of forest remote sensing studies. For example, the basic single tree information required by FVS is tree dimensional measures such as diameter and height that are conceptually related to stand and tree attributes such as total basal area and crown coverage which could be obtained from aerial photometry. Therefore, this empirical selection of feature variables may meet our needs to populate a forest landscape.

### Optimal Discriminant Rules

The optimal discriminant rules for heteroscedastic and homoscedastic models are different. Under the heteroscedastic normal-model, the discriminant function for the optimal rule is a quadratic function of the observations of the feature variables in the unit to be assigned, while under the homoscedastic normal model, the discriminant function is a linear function of the feature variables. The parameters in the discriminant functions are estimated from surveyed units in each group.

For non-normal models (e.g. discrete or non-normal continuous feature variables), it is much more difficult to derive optimal rules, although the quadratic and the linear discriminant functions can still be applicable for some special cases. For example, if the  $i$ th group-conditional density can be

assumed a member of the family of elliptically symmetric multivariate densities, and prior probabilities of the groups are equal, the optimal rule will still be linear for homoscedastic case (Glick 1976). Please see Cox (1972), Glick (1973), Schmitz et al. (1985), Sutradhar (1990), and McLachlan (1994) for details.

Misclassification is inevitable in discriminant analysis regardless of what kind of discriminant rules are used. It is hoped to minimize the error rate for the misclassification. Unfortunately, error rate estimation remains an extremely difficult problem in the application of discriminant analysis. For detailed discussion on this topic, please refer to numerous related publications (Goldstein and Wolf 1977, Glick 1978, Efron 1983, Konishi and Honda 1990, McLachlan 1974, 1986, 1992, etc.)

### ***Filling Missing Values for a Multivariate Sample***

After allocating all units with unknown  $X$  based on  $Y_f$  and established optimal discriminant rules,  $X_{exc}$  is ready to be filled using one of the following approaches to be discussed. Various approaches to fill missing values for a multivariate sample have been developed since 1970's (Little and Rubin 1987).

### **Filling Unconditional and Conditional Means for Missing Values**

The simplest way to fill missing values for a multivariate sample is to impute unconditional means. That is, to estimate missing values  $x_{jk}^i$ , the  $k$ th variable in the  $j$ th units of the  $i$ th group, by the mean estimate of this variable in the same group from observed values of  $\bar{x}_k^i$ . This imputation approach underestimates the variances and covariances of variables  $X$  in each group, although it keeps the average of the observed and imputed values for each variable the same as the estimated mean from surveyed units of this variable. Another similar approach is to impute conditional means given available data if there is a regressional relationship between  $X$  and  $Y$ . Like the first approach, the conditional mean imputation also yields reasonable estimates of means. However, it still underestimates the variances and covariances, although to a less extent as compared to the unconditional mean approach. In fact, the second approach has been extensively applied in forestry while making inference from forest sampling (e.g. Hamilton 1984).

Ideal approaches for filling missing values should not only provide reasonable estimates of means, but, more importantly, also retain the full range of variation. Therefore, an alternative strategy to select imputations of missing values randomly from a predictive distribution for  $X$  rather than from the center of this distribution has been suggested. Approaches that meet this strategy were classified into two categories, the quasi-randomization inference approach and the model-based approach (Little and Rubin 1987). Of these two approaches, the nearest neighbor that is in the first category and the multiple imputation that falls in the second category are promising for populating a forest landscape. These two approaches are outlined as follows. For other approaches and the details of these two approaches, please see Rubin and Schenker (1986), Little and Rubin (1987), Rubin (1987), Schreuder et al. (1993), Moeur and Stage (1995), and Schafer (1997).

### **The Nearest Neighbor Imputation**

The nearest neighbor analysis is one of the *hot deck* imputation (see Little and Rubin (1987) for a definition) methods in which  $n_1$  missing observations of  $X_{exc}$  are drawn from  $n_0$  observations of  $X_{inc}$ . In the nearest neighbor analysis, the missing observation of an unsurveyed unit is substituted by

the observation of its nearest neighbor that was surveyed. Therefore, an index to measure the similarity or distance between two units in each group, based on the values of covariates (e.g. variables  $Y$  in Figure 1(a)), are defined. Mahalanobis distance are usually used to serve this purpose. For cases where the covariates are independent of each other and standardized, Minkowski distance can also be appropriate..

The implementation of this approach is relatively straightforward. While imputing a missing observation for an unsurveyed unit, it is suggested to use a few units that are the nearest neighbors of this unsurveyed unit and then average the observations of  $X$  in these neighboring units to impute the missing observation. The application of the nearest neighbor imputation in forest sampling inference was shown by Moeur and Stage (1995). In their research, the correlation between the linear combinations of  $X$  and the linear combination of  $Y$  was introduced to improve the estimation of the distance between two units.

Compared to conditional or non-conditional mean imputation approaches, the nearest neighbor imputation may retain the variation of missing observations in some extent. However, this approach still underestimates the variation of missing observations, since this approach draws the imputations from  $X_{inc}$  and assumes that the variation of  $X$  is fully represented by  $X_{inc}$ . Some improvements to this approach such as Bayesian bootstrap imputation and adaptive nearest neighbor approach may better retain the variation of missing observations (Rubin 1981, Rubin and Schenker 1986, Hastie and Tibshirani 1994).

An approach that may retain the full variation of missing observations is to first draw parameters from its posterior distribution and then drawing  $X_{exc}$  from its conditional posterior distribution with the drawn parameters (Rubin and Schenker 1986). Single random imputation and multiple imputation to be introduced in the next paragraphs are two specifications of this approach.

### Single Random Imputation

Suppose the data for variables  $X$  in the  $i$ th group are iid observations from a multivariate normal distribution  $N(\mu_i, \Sigma_i)$ . If  $\mu_i$  and  $\Sigma_i$  can be well estimated by  $\mu_i^*$  and  $\Sigma_i^*$  based on observed observations of  $X$  in the  $i$ th group,  $n_1^i$  components of  $X_{exc}$  in the  $i$ th group are then randomly drawn as iid sample from  $N(\mu_i^*, \Sigma_i^*)$ . If the normality assumption is in question, it is desirable to use the components of  $X_{inc}$  that fell in the  $i$ th group to adjust the shape of the distribution of missing observations imputed for the  $n_1^i$  components of  $X_{exc}$  in the  $i$ th group. This can be accomplished by integrating the hot deck imputation and the normal imputation approaches together (Rubin and Schenker 1986). Single random imputation infers to that only one random draw from  $N(\mu_i^*, \Sigma_i^*)$  is conducted for each missing observation.

### Multiple Imputation

Multiple imputation is a method to replace each missing observation with  $m$  ( $m > 1$ ) imputations drawn from a representative distribution as proposed by Rubin (1978, 1987). This approach creates more than one complete data set and allows valid estimates of the variance for missing observations using standard complete data analysis methods (Little and Rubin 1987). The uncertainty about both the parameters of the missing data model and the randomness of missing values given the parameters is taken into consideration in the multiple imputation. Therefore, it overcomes

the shortcomings of conditional mean and single random imputation (Little and Rubin 1987, Schafer and Schenker 1997, Rubin 1987, 1996). For most cases, a small  $m$  (3-5) could achieve a satisfactory imputation result (Rubin and Schenker 1986, Rubin 1996).

In the multiple imputation, the  $m$  imputations of  $X_{exc}^i$  ( $M \geq 2$ ) for the  $i$ th group are  $m$  repetitions from the posterior predictive distribution for this group, each repetition corresponding to an independent drawing of the parameters and missing values (Little and Rubin 1987). Then the standard complete data analysis methods are applied to each complete data set, and the results are combined in a way to include the variance across imputation that was summarized by Schafer (1997). For details regarding this approach, please refer to Rubin (1981, 1987, 1996), Little and Rubin (1987), Schafer (1997), and Schafer and Schenker (1997).

### **Trend Surface Analysis**

For many cases, data of geographic units are tied together by spatial autocorrelation. If this is the case, trend surface analysis could be an appropriate approach to fill missing data for non-responding units in the landscape. In trend surface analysis, map data of  $X$  is separated into two components—that of regional nature (large scale variation) and local fluctuations (small scale variation) (Cressie 1991, Davis 1986). For our purpose, if covariates  $Y$  are observed for all units in the landscape and  $X$  and  $Y$  are correlated, the large scale variation of  $X$  could be better described by  $Y$  rather than by just geographic variables. The small scale variation is then estimated by kriging or cokriging approaches if it is not caused by random variates. Kallas (1997) and Metzger (1997) reported that this approach is promising for modeling small scale variation of forest stand structure and root disease. For details in spatial analysis, please see Cressie (1991). Due to the error term for the regression between  $X$  and  $Y$  in this case it is no longer a random normal variate vector, and a strategy other than ordinary least square (OLS) are needed for regression parameter estimation.

### **Algorithm**

Without looking in depth into the theories and soundness of the statistical assumptions on which the methods outlined above are based, it is not difficult to perform these methods with the use of the facilities provided by some powerful statistical packages such as SAS (SAS Institutes Inc. 1989) and some software packages available on this topic.

All multiple analyses outlined above are based on an initial reduction of the data in each group to its sample mean vector and sample covariance matrix. As each unclassified unit is assigned to one of these groups and missing values are imputed, the group sample mean vector and sample covariance matrix may change. The changes of group sample mean vector and sample covariance matrix may result in the changes of clustering and discriminant rules and missing data imputation. In other worlds, in the process of clustering and discriminant analysis and filling missing data, the estimates of population parameters would need to be updated. For this reason, a computing strategy using iteration algorithms is usually needed.

A popular iterative algorithm used for pattern recognition and missing data problems is the Expectation-Maximization (EM) algorithm. It is a method relating to the maximum likelihood (ML) estimation of parameters of the predictive distribution to the ML estimation based on the complete data likelihood (Little and Rubin 1987). The EM algorithm is composed of two steps, the E step and the M step. For our case, the E step perform the maximum likelihood estimation of the parameters (mean vector and covariance matrix for each group if multivariate normal distributions are assumed) of the

population that each group represents based on observations (and also imputation when they are available). The M step finds the conditional classification of the "groups" and the conditional expectations of the "missing data" in each group given the observations and current estimated parameters. The E step and the M step are iterated until convergence.

While using this approach in populating a landscape, the iterative algorithm can be outlined as follows:

***For data availability illustrated in Figure 1(b)***

1. Conduct a cluster analysis for the surveyed units and classify them into  $g$  groups; randomly assign each unsurveyed unit into one of the groups based on relative frequency of group members in each group; estimate parameters of the predictive distribution for each group;
2. Impute missing observations by randomly drawing samples from the predictive distribution with estimated parameters;
3. Re-estimate parameters of the predictive distribution for each group after filling missing values;
4. Reevaluate group membership of each unit and re-estimate the missing values given new parameter estimates;
5. Iterate steps 3 and 4 until convergence.

***For data availability illustrated in Figure 1(a)***

1. Select feature variables based on the observations for both main variables and covariates; conduct cluster analysis for the surveyed units and classify them into  $g$  groups based on variables  $(X', Y')$  or the feature variables  $Y_f$ ; conduct discriminant analyses for non-responding units and assign them into one of the  $g$  groups based on the feature variables and the clustering results; iterate the cluster and discriminant analyses until the assigned group membership of each unsurveyed unit does not change; estimate parameters of the predictive distribution for each group;
2. Impute missing observations based on the given predictive distribution with estimated parameters;
3. Re-estimate parameters of the predictive distribution for each group after filling missing values;
4. Iterate steps 3 and 4 until convergence.

The EM algorithm has been extensively used since the 1970's to provide robust parameter estimation (Little and Rubin 1987). Programs for performing EM algorithm can be found in related statistical literature and on the Internet.

## DISCUSSION

Pattern recognition, missing data analysis, and spatial statistics are branches of statistics that are undergoing rapid development. Also, quantitative analysis in landscape ecology is still in its infancy. It can be expected that with the development and the growth of these scientific branches, more mature and applicable approaches for populating a forest landscape will be developed.

The approaches and associated theories for populating a landscape are complicated as knowledge of several disciplines, including several branches of statistics, forest sciences, ecology, remote sensing, and pattern recognition need to be integrated. With this integration, some formidable problems in statistics and in ecology and the cost of computation arise. For example, in statistics a good solution for populating a landscape may involve the complex distribution theories, Bayes statistics, multivariate analysis, and the integration of spatial auto-correlation and conventional missing

value filling approaches. Many problems remain unsolved in both theory and application. However, with the computation facilities that are currently available, it is possible to develop some practical approaches to address the problem of populating a forest landscape as we reported.

Notice should be taken while understanding the approaches outlined above. The premises of these approaches are normality, ignorable missing-data mechanism, large sample availability, continuous variables, and feature variables that are a subset of the covariates. Such strict conditions may not always be satisfied in applications. For instance, if discontinued variables such as categorical variables are involved in the analysis, approaches other than those introduced here will be more appropriate. They will be addressed in the future.

As an initiation of the effort to fill missing values in a landscape context, this report is meant to summarize promising approaches rather than to provide technical details in the theories methodologies. However, problems, ideas, feasibility, and even algorithms to address the problem of populating a landscape are discussed. After reviewing these approaches and the references provided, it should not be difficult to design and computerize one or two approaches that could be applicable in the practice of populating a landscape.

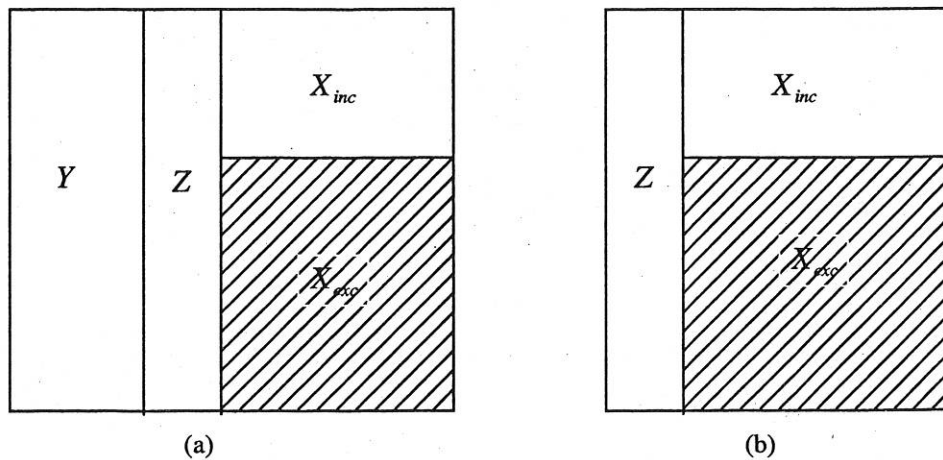


Figure 1. Illustration of data availability of a landscape survey, where  $X$  denotes key variables of interest;  $Y$  denotes the covariates of  $X$  which are observed for all units in the landscape; and  $Z$  is a design variable with value 1 or 0 to represent if a unit is surveyed or not for the key variables  $X$ ;  $X_{inc}$  and  $X_{exc}$  represents values of  $X$  for  $n_0$  responding units and  $n_1$  non-responding units in the landscape, respectively; and subscript *inc* means that observations are included and *exc* means that observations are missing.

- Aha, D. W., and R. L. Bankert. 1994. Feature selection for case-based classification of cloud types: an empirical comparison. *In Proceedings of the AAAI-94 Workshop on Case-Based Reasoning.*
- Anderberg, M. R. 1973. *Cluster Analysis for Applications.* New York: Academic Press, Inc.
- Arnold, S. J. 1979. A test for cluster. *J. Marketing Research* 16:545-551.
- Averill, R. D., L. Larson, J. Saveland, P. Wargo, and J. Williams. 1994. Disturbance processes and ecosystem management. The paper was charted by the Director of Forest Filre and Atomospheric Sciences Research, Fire and Aviation Management, Forest Pest Management, and Forest Insect and Disease Research in Response to an action item identified in the National Action Plan for Implementing Ecosystem Management.
- Beukema, S. J., D. C. E. Robinson, J. A. Greenough, W. A. Kurz, and P. J. McNamee. 1994. Westwide pine beetle model: detailed description. Prepared by ESSA Technologies Ltd., Vancouver, B. C. for US Forest Service, FPM/MAG, Fort Collins.
- Boullion, T. L., P. L. Odell, and B. S. Duran. 1975. Estimating the probability of misclassification and variate selection. *Pattern Recognition* 7:139-145.
- Campbell, N. A. 1984. Canonical variate analysis-a general model formulation. *Austral. J. Statist.* 26:86-96.
- Cox, D. R. 1972. The analysis of binary multivariate data. *Appl. Statist.* 21:113-120.
- Cressie, N. 1991. *Statistics for Spatial Data.* John Wiley & Sons, Inc. New York.
- Crookston, N. L. and A. L. Stage. 1991. User's guide to the parallel processing extension of the prognosis model. General Research Report INT-281, USDA Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah.
- Davis, J. C. 1986. *Statistics and Data Analysis in Geology.* 2<sup>nd</sup> Ed. John Wiley & Sons, New York.
- Efron, B. 1983. Estimating the error rate of a prediction rule: improvement on cross validation. *J. Amer. Statist. Assoc.* 78:316-331.
- Everitt, B. S. 1979. Unsolved problems in cluster analysis. *Biometrics* 35:169-181.
- Friedman, H. P. and J. Rubin. 1967. On some invariant criteria for grouping data. *J. Amer. Statist. Assoc.* 62:1159-1178.
- Gittins, R. 1985. Canonical analysis. A review with applications in ecology. *Vol. 12 in Biomathematics.* Springer-Verlag, New York.
- Glick, N. 1973. Sample-based multinominal classification. *Biometrics* 29:241-256.
- Glick, N. 1976. Sample-based classification procedures related to empirical distributions. *IEEE Trans. Inform. Theory* IT-22, 454-461.
- Glick, N. 1978. Additive estimators for probabilities of correct classification. *Pattern Recognition* 10:211-222.
- Goldstein, M. and E. Wolf. 1977. On the problem of bias in multinominal classification. *Biometrics* 33:325-331.
- Hamilton, D. A., Jr. 1984. Sampling and estimation of conifer mortality using large-scale color aerial photography. *For. Sci.* 30:333-342.
- Hastie, T., and R. Tibshirani. 1994. Discriminant adaptive nearest neighbor classification. Technical Report, Dept. of Statistics, Stanford University, Stanford, California.
- Jain, A. K., and B. Chandrasekaran. 1982. Dimensionality and sample size considerations in pattern recognition practice. *In Handbook of Statistics (Vol. 2),* P. R. Krishnaiah and L. Kanal (Eds.) Amsterdam: North-Holland, pp. 835-855.
- Jain, A. K., and W. G. Waller. 1978. On the optimal number of features in the classification of multivariate Gaussian data. *Pattern recognition* 10:365-374.
- John, G. H., R. Kohavi, and K. Pfaeger. 1994. Irrelevant features and the subset selection problem. *In Cohen, W. W., and Hirsh, H. (eds.), Machine Learning: Proceedings of the Eleventh International Conference,* 121-129, Morgan Kaufmann Publishers, San Francisco, CA.
- Kallas, M. 1997. Armillaria root disease on the Black Hills National Forest. M.Sc. Thesis, College of Natural Resources, Colorado State University.

- Kimmins, J. P. 1987. *Forest Ecology*. Macmillan Publishing Company, New York.
- King, A. W. 1991. Translating models across scales in the landscape. In Turner M. G. and Gardner, R. H. (editors). *Quantitative Methods in Landscape Ecology*. Springer-Verlag, New York. Pp479-516.
- Konishi, S. and M. Honda. 1990. Comparison of procedures for estimation of error rates in discriminant analysis under nonnormal populations. *J. Statist. Comput. Simul.* 36:105-115.
- Krazanowski, W. J. and Y. T. Lai. 1988. A criterion for determining the number of groups in a data set using sum-of-squares clustering. *Biometrics* 44:23-34.
- Little, R. J. A. and D. B. Rubin. 1987. *Statistical Analysis with Missing Data*. John Wiley & Sons, Inc. New York.
- Marriott, F. H. C. 1971. Practical problems in a method of cluster analysis. *Biometrics* 27:501-514.
- McGaughey, R. J. 1996. Stand visualization system. USDA Forest Service Pacific Northwest Research Station.
- McKay, R. J., and N. A. Campbell. 1982. Variable selection techniques in discriminant analysis, I. Description. *Br. J. Math. Statist. Psychol.* 35:1-29.
- McLachlan, G. J. 1974. An asymptotic unbiased technique for estimating the error rates in discriminant analysis. *Biometrics* 30:239-249.
- McLachlan, G. J. 1986. Assessing the performance of an allocation rule. *Comput. Math. Applic.* 12A:261-272.
- McLachlan, G. J. 1992. *Discriminant Analysis and Statistical Pattern Recognition*. John Wiley & Sons, Inc. New York.
- Metzger, K. 1997. Modelling forest stand structure to a ten meter resolution using landsat TM data. M.Sc. Thesis, College of Natural Resources, Colorado State University.
- Moeur, M. and A. R. Stage. 1995. Most similar neighbor: an improved sampling inference procedure for natural resource planning. *For. Sci.* 41:337-359.
- Rao, C. R. 1973. *Linear Statistical Inference and Its Applications*. 2<sup>nd</sup> Edition. Wiley, New York.
- Rubin, D. B. 1978. Multiple imputations in sample surveys. *J. Amer. Statist. Assoc.* 1978, Proceedings of the Survey Research Methods Section, pp. 20-34.
- Rubin, D. B. 1981. The Bayesian bootstrap. *The Annals of Statistics*. 9:130-134.
- Rubin, D. B. 1987. *Multiple Imputation for Non-response in Survey*. Wiley, New York.
- Rubin, D. B. 1996. Multiple imputation after 18+ years. *J. Amer. Statist. Assoc.* 91:473-489.
- Rubin, D. B. and Schenker, N. 1986. Multiple imputation for interval estimation from simple random samples with ignorable nonresponse. *J. Amer. Statist. Assoc.* 81:366-374.
- SAS Institute Inc. 1989. *SAS/STAT User's Guide*. Version 6, Fourth Edition, Vol. 1 and 2, Cary, NC: SAS Institute Inc.
- SAS Institute Inc. 1989. *SAS/IML Software: Usage and Reference*. Version 6, First Edition, Cary, NC: SAS Institute Inc.
- Schafer, J. L. 1997. *Analysis of Incomplete Multivariate Data*. Chapman & Hall, London.
- Schafer, J. L. and N. Schenker. 1997. Inference with imputed conditional means. Technical Report, Department of Statistics, Pennsylvania State University.
- Schmitz, P. I. M., J. D. F. Habbema, and J. Hermans. 1985. A simulation study of the performance of five discriminant analysis methods for mixtures of continuous and binary variables. *J. Statist. Comput. Simul.* 23:69-95.
- Schreuder, H. T., T. G. Gregoire, and G. B. Wood. 1993. *Sampling Methods for Multiresources Forest Inventory*. John Wiley & Sons, Inc., New York.
- Stage, R. A. 1973. Prognosis model for stand development. USDA Forest Service Research Paper INT-137, USDA Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah.
- Sutradhar, B. C. 1990. Discrimination of observations into one of two t populations. *Biometrics* 46:827-835.

- Unger, D. G. 1994. The USDA Forest Service perspective on ecosystem management. Symposium on Ecosystem Management and Northeast Area Association of State Foresters Meeting, Burlington, Vermont.
- Wiens, J. A. 1989. Spatial scaling in ecology. *Functional Ecology* 3:385-397.
- Wong, M. A. and T. Lane. 1983. A *kth* nearest neighbor clustering procedure. *J. Royal Statistical Association*. 77:841-847.
- Wykoff, W. R., N. L. Crookston, and A. L. Stage. 1982. User's guide to the stand prognosis model. General Research Report INT-133, USDA Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah.
- Wykoff, W. R. 1986. Supplement to the user's guide for the stand prognosis model - version 5.0. General Research Report INT - 208, USDA Forest Service Intermountain Forest and Range Experimental Station, Ogden, Utah.



Shaoang Zhang and Judy Adams

## Preliminary Report on the Ecology of *Armillaria* in Utah and the Inland West

Geral I. McDonald,  
 USDA Forest Service, Rocky Mountain Research Station,  
 1221 South Main Street,  
 Moscow, Idaho 83843, USA.  
 E-mail: gimcdon@forest.moscowfsl.wsu.edu

### Introduction

Shoestring root rot of conifers, caused by species of the basidiomycetous genus *Armillaria*, damages conifers in forests throughout the western United States. Most conifers are hosts to one or more species of *Armillaria*. Host range, aggressiveness, and other ecological behaviors of this fungus vary with locality. In coastal forests of western Oregon and Washington, occasional damage to Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) is not significant. In the wet inland forests of northern Idaho, eastern Washington, and western Montana, Douglas-fir and grand fir (*Abies grandis*) mortality can be severe in size classes ranging from seedlings to mature trees. In higher elevation forests, damage to subalpine fir (*Abies lasiocarpa*) and Englemann spruce (*Picea engelmannii*) can be significant. The fungus is seldom found in dry forests dominated by ponderosa pine (*Pinus ponderosa*). Is ecological behavior and occurrences of *Armillaria* predictable or unpredictable at specific locations in conifer forests of the western United States?

In 1983, a study of the ecological genetics of the *Armillaria* - conifer pathosystem was initiated to answer this question. First, 120 plots (0.04 hectares) were established at random on 15 national forests within a 300-mile radius of the Intermountain Research Station Laboratory located at Moscow, Idaho (McDonald and others 1987). Habitat type of each plot was determined to associate occurrence and behavior of *Armillaria* with plant communities (McDonald and others 1987). Data from these investigations suggested that *Armillaria* behavior and occurrence could be mapped (predicted) over large geographic areas, if the number of map units were reduced by combining habitat types into ecologically similar Potential Vegetation Groups (PVGs). This idea was given an initial test with the establishment of 48 plots randomly located on national forests in Utah.

### Phytosociology: the ecological context

Davis and others (1980) combined habitat types expected to exhibit similar fire behavior into fire behavior ecoclasses. We reasoned a similar tactic should facilitate the understanding of ecological aspects of *Armillaria* behavior. If ecosystem roles of *Armillaria* were to be understood, a less subjective method of combining habitat types would be needed. Thus, a system to group defined habitat types was constructed on the premise that conifer climax species indicate a temperature gradient and that shrubs and herbs indicate a moisture gradient (McDonald 1991). This idea was recently expanded to encompass all the conifer forests of Utah, Idaho, Oregon, Washington, and Montana (McDonald unpublished data). Before discussing this new classification effort, we need to define plant association and habitat type. A plant association is simply an abstract taxonomic unit described by the ecologist who has formulated a specific classification system based on distribution of native plants (Pfister 1989). After the associations are defined, a dichotomous key can be constructed to define potential climax communities (plant associations) at a particular site – the habitat type (Pfister 1989).

To obtain an ecologically consistent west-wide classification of habitat types into PVGs, we used the classification of north Idaho forest vegetation (Cooper and others 1991) as a model for defining temperature and moisture gradients. We reasoned that the mix of heterogeneous mountainous topography and climate of north Idaho has created environments representative of most of the forested environments in the west. There were notable exceptions in that the dry and warm ponderosa pine and pinyon-juniper communities were missing. Nevertheless, the dichotomous keys to habitat types in northern Idaho (Cooper and others 1991) were constructed to reflect a moisture gradient in a heterogeneous environment. We hypothesized that under-story plants presented in the north Idaho classification defined water availability bands. Further, when augmented with additional plants found in other regions, moisture bands could be extended over the total range of annual soil temperatures found in conifer forests of the west (Figure 1). Since temperature and moisture interact to limit niches, not all indicators extend over the complete range of temperatures (Figure 1). The idea applied to this

classification is that the maximum drought tolerance of the indicators defines the moisture band in question over the entire temperature gradient (Figure 2). For example, *Clintonia uniflora* was hypothesized to define 30 to 35 inches of annual water availability in cold environments and *Polystichum munitum* defines this same amount of water in a warmer environment. Although indicator species tend to occur in wetter ecosystems (Figure 2), their explicit dry limit could be determined by appropriate drought tolerance experiments. Amounts and pattern of water input, evapotranspiration, and storage capacity of the soil profile also influence the dry limit. Application

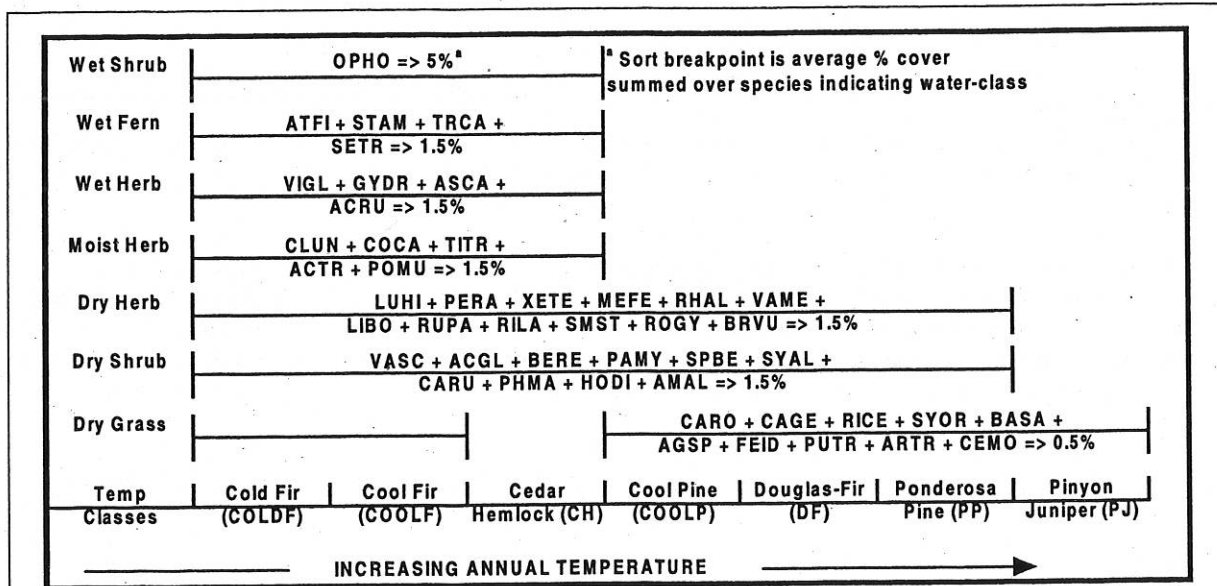


Figure 1. Distribution of water-class indicator species over a temperature gradient defined by climax conifer species

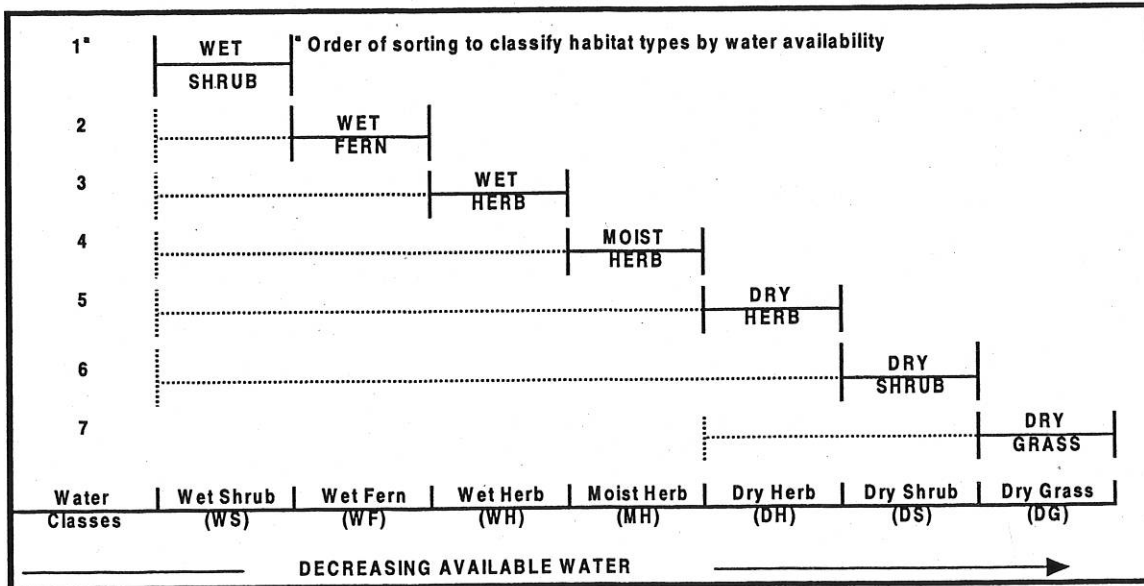
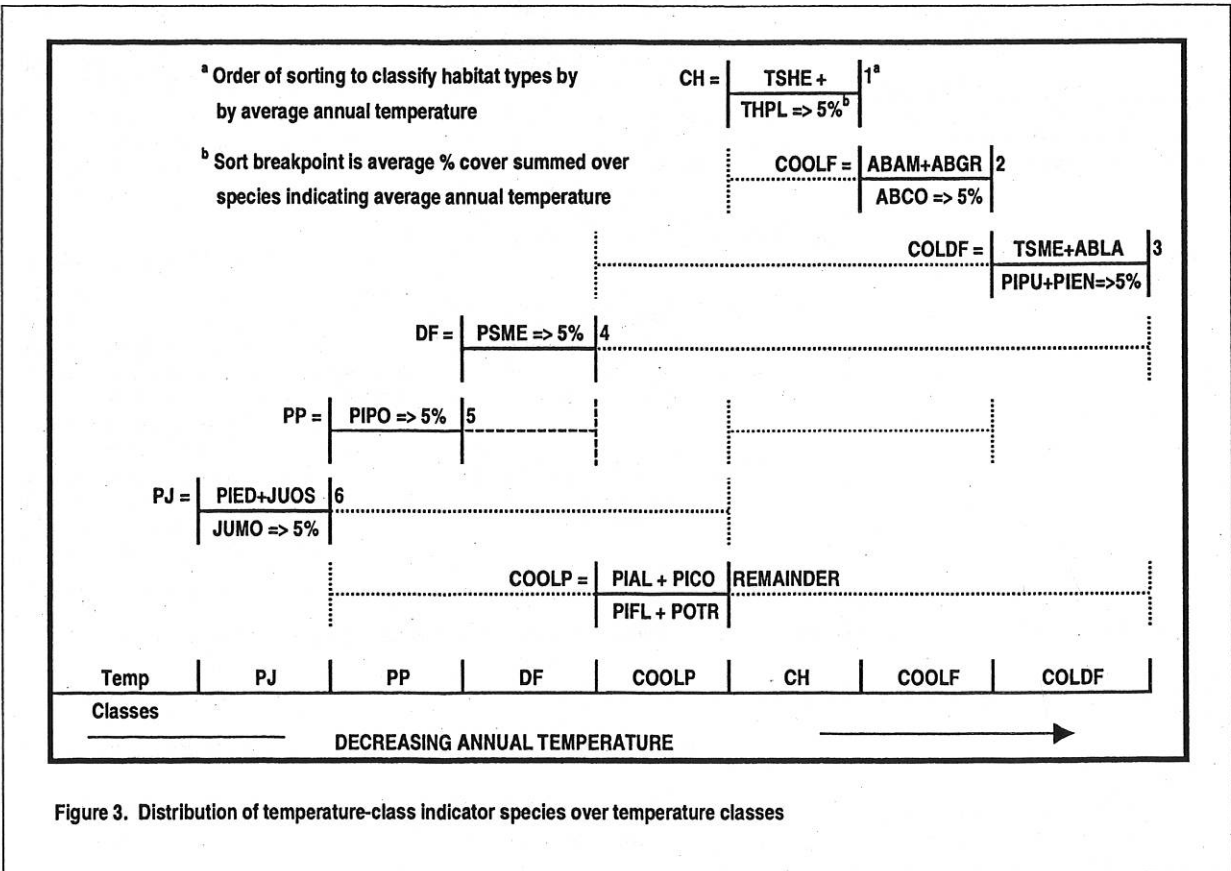


Figure 2. Distribution of water-class indicator species over water-classes

of this approach also requires the assumption that populations of assumed ecological synonyms do not exhibit geographic variation of their ecophysiological traits. We know that this assumption may not hold with some plants. Nevertheless, the assumption can be tested for important indicator plant species.

Inspection of the dichotomous keys to habitat types produced seven moisture-class groups. These groups were Wet Shrub (WS), Wet Ferns (WF), Wet Herbs (WH), Moist Herbs (MH), Dry-Herbs (DH), Dry-Shrubs (DS), and Dry-Grass (DG) (see Table 1 for list of species in each group). In all, 12 habitat type manuals covering the states of Oregon and Washington east of the crest of the Cascade Mountains, all of Montana, all of Idaho, and all of Utah were utilized. Next, these groups of assumed ecological synonyms (indicators) were used to classify habitat types and phases. Average cover, as given in constancy tables published in the 12 classifications, were extracted to produce a matrix of 631 habitat types (records) x 61 species (fields). Coverage was summed across fields for all members of an indicator group to produce a moisture index for each habitat type. Then all records having an index above a threshold value were removed to form each respective moisture class in an order from wet to dry (Figure 2). Index threshold was set at 1.5% for each class, except the first and last. The threshold for the wettest class (WS) was set at 5% because the class was based on a single relatively large shrub. The threshold for the most dry class (DG) was set at 0.5% because plant coverage is uniformly low at low levels of available soil moisture. In this fashion, each of the 631 habitat types was assigned to a moisture class.

The same logic was applied for establishing a temperature gradient defined by conifer climax species (Figure 3). The association of climax species with temperature is widely accepted but not well proven. However, this assumption can be tested by measuring soil temperature at each plot at a depth of 50cm. A single measurement at 50cm anytime throughout the year gives the average annual temperature of the first meter of soil depth (USDA Soil Conservation Service, 1975). The conifer climax species at any location will be the species exhibiting the most shade tolerance at a specific temperature x moisture intersection. Climax species were grouped into COLD Fir (COLDF), COOL Fir (COOLF), Cedar-Hemlock (CH), COOL Pine (COOLP), Douglas-Fir (DF), Ponderosa Pine (PP), and Pinyon-Juniper (PJ) (see Table 1).



The average-cover matrix was sorted with group removal as described above, except removal was based on a temperature index obtained by summing the average cover values for each climax group. Order of removal from the matrix was decreasing shade tolerance and increasing cold tolerance, then by increasing shade and heat tolerance (Figure 3). The accumulated average-cover threshold for these sorts was 5%. Finally, habitat types that did not reach the summed 5% average-cover index were placed into the remainder class, COOLP (Figure 3). In this fashion, each of the 631 habitat types was assigned to one of seven temperature-class designations. The moisture-class and temperature-class designations were combined to produce 31 distinct PVGs. The 631 habitat types defined in the 12 habitat type manuals were reduced to 30 PVGs (Table 2). One PVG, COOLF/WS, was not represented in the 631 defined habitat types, but it has theoretical existence (the classification is available from the author).

WET SHRUB	DRY SHRUB	CEDAR-HEMLOCK
OPHO <i>Oplopanax horridum</i> (Devil's Club)	VASC <i>Vaccinium scoparium</i> (Grouse whortleberry)	TSHE <i>Tsuga heterophylla</i> (Western hemlock)
	ACGL <i>Acer glabrum</i> (Rocky Mountain maple)	THPL <i>Thuja plicata</i> (Western red cedar)
	BERE <i>Beberis repens</i> (Creeping Oregon grape)	
WET FERN	PAMY <i>Pachistima myrsinites</i> (Myrtle boxwood)	COOL PINE
ATFI <i>Athyrium filix-femina</i> (Ladyfern)	SPBE <i>Spiraea betulifolia</i> (Shiny-leaf spiraea)	PIAL <i>Pinus albicaulis</i> (Whitebark pine)
STAM <i>Streptopus amplexifolius</i> (Twisted-stalk)	SYAL <i>Symphoricarpos albus</i> (Common snowberry)	PICO <i>Pinus contorta</i> (Lodgepole pine)
TRCA <i>Trautvetteria carolinensis</i> (False bugbane)	CARU <i>Calamagrostis rubescens</i> (Pinegrass)	PIFL <i>Pinus flexilis</i> (Limber pine)
SETR <i>Senecio triangularis</i> (Arrowleaf groundsel)	PHMA <i>Physocarpus malvaceus</i> (Ninebark)	POTR <i>Populus tremuloides</i> (Quaking aspen)
WET HERB	HODI <i>Holodiscus discolor</i> (Ocean-spray)	
VIGL <i>Viola glabella</i> (Pioneer violet)	AMAL <i>Amelanchier alnifolia</i> (Serviceberry)	DOUGLAS-FIR
GYDR <i>Gymnocarpium dryopteris</i> (Oak fern)		PSME <i>Pseudotsuga menziesii</i> (Douglas-fir)
ASCA <i>Asarum caudatum</i> (Wild ginger)	DRY GRASS	
ACRU <i>Actaea rubra</i> (Baneberry)	CARO <i>Carex rossii</i> (Ross sedge)	PONDEROSA PINE
	CAGE <i>Carex geyeri</i> (Elk sedge)	PIPO <i>Pinus ponderosa</i> (Ponderosa pine)
	RICE <i>Ribes cereum</i> (Squaw current)	
MOIST HERB	SYOR <i>Symphoricarpos oreophilus</i> (Mountain snowberry)	PINYON-JUNIPER
CLUN <i>Clintonia uniflora</i> (Queen cup beadlily)	BASA <i>Balsamorhiza sagittata</i> (Arrowleaf balsamroot)	PIED <i>Pinus edulis</i> (Pinyon pine)
COCA <i>Cornus canadensis</i> (Bunchberry dogwood)	AGSP <i>Agropyron spicatum</i> (Bluebunch wheatgrass)	JUOS <i>Juniperus osteosperma</i> (Utah juniper)
TITR <i>Tiarella trifoliata</i> (Coolwart foamflower)	FEID <i>Festuca idahoensis</i> (Idaho fescue)	JUMO <i>Juniperus monosperma</i> (One-seed juniper)
ACTR <i>Achlys triphylla</i> (Vanilla leaf)	PUTR <i>Purshia tridentata</i> (Bitterbrush)	
POMU <i>Polystichum munitum</i> (Western swordfern)	ARTR <i>Artemisia tridentata</i> (Mountain big sagebrush)	
DRY HERB	CEMO <i>Cercocarpus montanus</i> (Alderleaf mountain mahogany)	
LUHI <i>Luzula hitchcockii</i> (Smooth woodrush)	COLD FIR	
PERA <i>Pedicularis racemosa</i> (Sickle-top lousewort)	ABLA <i>Abies lasiocarpa</i> (Subalpine fir)	
XETE <i>Xerophyllum tenax</i> (Beargrass)	TSME <i>Tsuga mertensiana</i> (Mountain hemlock)	
MEFE <i>Menziesia ferruginea</i> (Mock azalea)	PIEN <i>Picea engelmannii</i> (Engelmann spruce)	
RHAL <i>Rhododendron albiflorum</i> (White rhodoendron)	PIPU <i>Picea pungens</i> (Blue spruce)	
VAME <i>Vaccinium membranaceum</i> (Big huckleberry)	COOL FIR	
LIBO <i>Linnaea borealis</i> (Twinflower)	ABAM <i>Abies amabilis</i> (Pacific silver fir)	
RUPA <i>Rubus parviflorus</i> (Western thimbleberry)	ABGR <i>Abies grandis</i> (Grand fir)	
RILA <i>Ribes lucustre</i> (Prickly current)	ABCO <i>Abies concolor</i> (White fir)	
SMST <i>Smilacina stellata</i> (Starry Solomon-seal)		
ROGY <i>Rosa gymnocarpa</i> (Baldhip rose)		
BRVU <i>Bromus vulgaris</i> (Columbia brome)		

Table 3. List of moisture class and temperature class indicator plants used to classify habitat types

**Armillaria distribution and behavior in the Inland Northwest**

The 120 plots installed in 1983 were classified by PVG and the results (Table 3) show some clear patterns. First, although sampling was sparse in the DG moisture band, 17 plots fell into the DS band and none supported *Armillaria* (Table 3). The next wettest band was DH, which included 54 plots. Of these, 65% supported only *A. ostoyae* (McDonald unpublished data). The remainder of the 1983 plots fell into the more moist bands. Forty-four of 46 plots (96%) supported both *A. ostoyae* and North American Biological Species

(NABS) X (McDonald unpublished data). Only two plots were located in the COLDF/WF PVG and none supported *Armillaria*. This may indicate an upper limit of soil moisture for the genus.

These findings support the following three hypotheses. First, DG and DS moisture classes are not suitable habitats for any *Armillaria* species. Second, *A. ostryae* has at least a 0.65 probability of occurring on DF or cooler /DH.PVGs. Third, the probability of finding the two *Armillaria* species on 0.04-hectare plots in MH or WF ecosystems is 0.96. These data also indicate that wetter ecosystems may not support *A. ostryae* and NABS X.

Temp Classes	Water Classes						
	Dry Grass	Dry Shrub	Dry Herb	Wet Herb	Wet Herb	Wet Fern	Wet Shrub
PJ	1						
PP	24	29	1				
DF	19	101	35	2			
COOLP	13	11	11	1			
CH			4	24	10	8	5
COOLF	2	18	45	24	6	8	0
COLDF	30	43	110	13	5	27	1

**Table 2 Distribution of 631 inland west habitat types**

Temp Classes	Water Classes						
	Dry Grass	Dry Shrub	Dry Herb	Wet Herb	Wet Herb	Wet Fern	Wet Shrub
PJ	0						
PP	0/1	0	0				
DF	0	0/8	6/9	0			
COOLP	0	0	0	0			
CH			0	14/14	7/7	4/4	0
COOLF	0	0/1	18/25	11/12	4/4	0	0
COLDF	0	0/8	11/20	4/5	0	0/2	0

**Table 3 Fraction of inland northwest plots with *Armillaria***

Variation of genet behavior in the CH/WH PVG was demonstrated by results from an intensive sampling study on the Priest River Experimental Forest in northern Idaho (McDonald and others 1998). About 1300 isolates were collected from a 2-acre site. These isolates sorted into 7 genets belonging to *A. ostryae* and NABS X. One NABS X genet dominated the site, occurring as more than 900 isolates. *A. ostryae* genets varied in their ecological behavior. One genet was found as fans on 114 of 129 trees, while 77% of the occurrences of another genet appeared as epiphytic rhizomorphs. Nearly 100% of the isolates belonging to NABS X were obtained from epiphytic rhizomorphs. After 10 years of observation, none of the NABS X genets have produced basidiomata and only one of the *A. ostryae* genets has. These multiple individuals also exhibit variation in rhizomorph production, pathogenic aggressiveness, frequency of basidiome production, and potentially, host specificity. Based on these findings, we can hypothesize that highly variable multiple genets of *A. ostryae* are present in wet ecosystems. The idea of multiple genets is further supported by the initial delineation of genets obtained from the 120 random Inland Northwest plots (McDonald and Martin 1988).

**Armillaria in Utah**

In 1992, 16 plots were established during a preliminary inspection of Utah forests. These plots were established by stratification of forest type and without regard for expression of disease. Plots were inspected for *Armillaria* signs and symptoms and indicator plants as previously described (McDonald and others 1987). In 1993, 32 plots were established at random on four national forests (8 plots per forest) as previously described (McDonald and others 1987). A few nonrandom collections made by others augmented the random plots. Our complete collection of plots (Figure 4) are representative of most of the conifer forest ecosystems in Utah. Preliminary determination of genets and their species affiliation shows one genet per plot and all Utah collections belong to *A. ostoyae* (McDonald unpublished data).



Figure 4. Locations of Utah *Armillaria* plots

Temp Classes	Water Classes						
	DG	DS	DH	MH	WH	WF	WS
PJ	0/3						
PP	0/4	0	0				
DF	0	0/5	0	0			
COOLP	0/2	0/1	0	0			
CH			0	0	0	0	0
COOLF	0/1	1/6	1/1	0	0	0	0
COLDF	1/7	5/12	3/6	0	0	0	0

Table 4. Fraction of Utah plots with *Armillaria*

Temp Classes	Water Classes						
	DG	DS	DH	MH	WH	WF	WS
PJ	0/3						
PP	0/5	0	0				
DF	0	0/13	6/9	0			
COOLP	0/2	0/1	0	0			
CH			0	14/14	7/7	4/4	0
COOLF	0/1	1/7	19/26	11/12	4/4	0	0
COLDF	1/7	5/20	14/26	4/5	0	0/2	0

Table 5. Fraction of all Inland plots with *Armillaria*

With regard to distribution across ecosystems, Utah *Armillaria* shows both similarities with and differences from the Inland Northwest experience (Table 4). Seventeen randomly located plots fell within the DG moisture band in the PJ, PP, COOLF, and COLDF temperature bands. One of 7 COLDF plots supported *A. ostoyae*. This finding mostly agrees with the Inland Northwest findings. In the case of the DS band, a statistically significant difference (Table 6) may exist, since 5 of 20 COLDF/DS plots supported *A. ostoyae*. On the other hand, in ecosystems one step wetter (COLDF/DH) and one or two steps warmer (DF and COOLF/DS), a regional difference is not apparent (Tables 3, 4, and 6). Distributions across ecosystems for the total data are intriguing (Table 5). *Armillaria* appears to inhabit a band of environments bordered by parallel lines from COLDF/DG to CH/WH and from COLDF/MH to CH/WF.

**Armillaria behavior: Utah vs. Inland Northwest**

Are disagreements in distribution by ecosystem in the two regions due to sampling variation or are they due to ecotypic variation of *A. ostoyae*? In light of demonstrated variation among genets at the Priest River Experimental Forest, it seems prudent to consider that ecotypic variation can cause differences in ecological behavior across PVGs. A genetic hypothesis could include genet by genet variation caused by selection for specific environments from preexisting gene pools via spore-rain, phenotypic plasticity, or classic mutation and

recombination. This hypothesis can be tested by measuring reaction norms, which are graphs of environment vs. genotype (Stearns, 1989). They allow visualization of population x treatment interaction, tendency for similar patterns of plasticity, amount of environmental sensitivity of traits, and amount of additive genetic variation (Figure 5). A reaction norm can be measured for any quantitative trait. Some potential *Armillaria* traits are

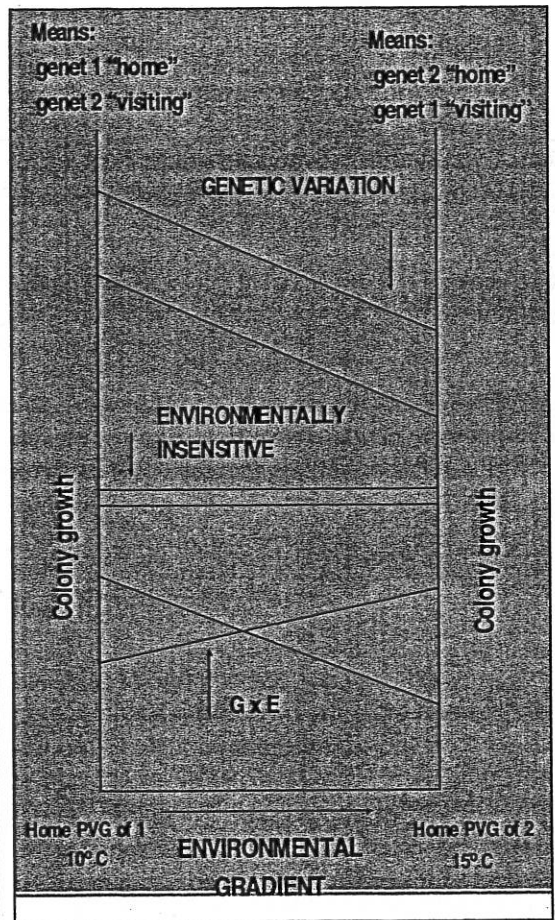


Figure 5. Interpretation of a phenotypic plasticity experiment

Potential Veg Group	Location	Armillaria Present			Fisher's Chi SQ
		yes	no	% Present	
DF/DS	NW	0	8	0	no test
	Utah	0	5	0	
COLDF/DS	NW	0	8	0	0.1
	Utah	5	7	42	
COLDF/DH	NW	11	9	55	1
	Utah	3	3	50	

Table 6. Comparison of *Armillaria* occurrence in overlapping northwest and Utah PVGs (Fisher's exact chi Square)

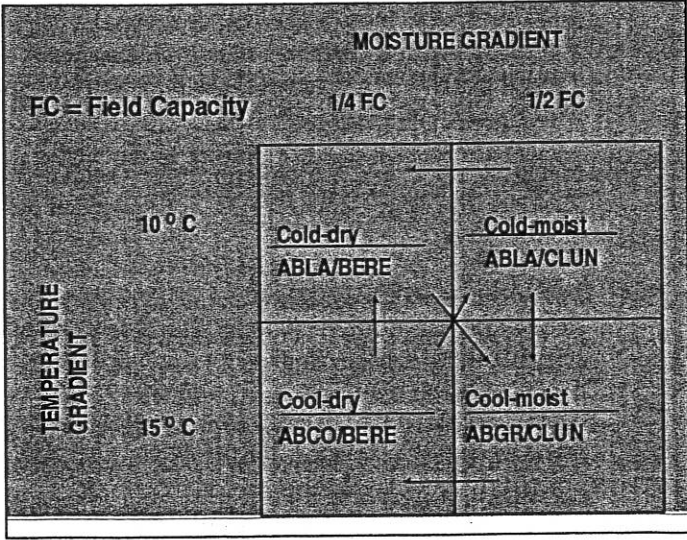


Figure 6. A possible phenotypic plasticity experiment designed to assess ecological genetics of *Armillaria*

respiration, colony growth, rhizomorph production, germ tube growth rate, percent of germination, cold tolerance, heat tolerance, pH tolerance, and nutrient requirements. A potential experiment (Figure 6) could be performed with the addition of soil temperatures taken at a 50cm depth on plots where the *Armillaria* was collected.

**Conclusions**

This preliminary analysis comparing *Armillaria* populations raises some interesting questions. First, does the limited data collected so far accurately show the true distribution of this important genus over western conifer ecosystems? If it does, then mapping of ecosystems (PVGs) will provide an accurate baseline for managing the fungus – whether to lessen disease impacts or to insure ecosystem function. If distribution is sufficiently limited by environmental constraints, then mapping of current distributions will provide reliable information for the future. On the other hand, if the fungus is expanding its range, explicit knowledge about that expansion will be needed. The suggested genetic experiment is the first step toward obtaining such an understanding of the biology of *Armillaria*. Finally, we have discussed potential new distribution only into more dry ecosystems.

But, new distribution may be similarly limited or mediated into more wet ecosystems. For example, we have observed *A. cepistipes* (*A. sinapina*?) behaving as an aggressive pathogen on dominant Sitka spruce (*Picea sitchensis*) in very wet ecosystems on the Oregon coast (McDonald unpublished data). In addition, *A. ostoyae* was observed causing mortality in Douglas-fir in a wet ecosystem near Lake Quinault on the Washington coast (McDonald unpublished data). Do these instances represent the limited occurrence of relatively rare pathogenic variants that have fitness for unusual environments? Effective management of forested ecosystems will require answers to these questions.

#### Literature cited

- Cooper, S. V., K. E. Neiman, R. Steele, and D. W. Roberts. 1991. Forest Habitat Types of Northern Idaho: a Second Approximation, Gen. Tech. Rep. INT-236. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 143p.
- Davis, K. M., B. D. Clayton, and W. C. Fischer. 1980. Fire ecology of Lolo National Forest habitat types. Gen. Tech. Rep. INT-79. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 75p.
- McDonald, G. I. 1991. Connecting forest productivity to behavior of soil-borne diseases. In Harvey, A. E. and L. F. Neuenschwander, ed. Proceedings—Management and productivity of western-montane forest soils. Gen. Tech. Rep. INT-280. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 129-144.
- McDonald, G. I., and N. E. Martin. 1988. *Armillaria* in the Northern Rockies: Delineation of isolates into clones. Res. Pap. INT-385. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 13 p.
- McDonald, G. I., N. E. Martin, and A. E. Harvey. 1987. Occurrence of *Armillaria* spp. in forests of the Northern Rocky Mountains. Res. Pap. INT-381. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 7 p.
- McDonald, G. I., N. B. Klopfenstein, and M.-S Kim. 1998. Ecology of *Armillaria* in a 16-year-old northern Idaho white pine plantation. *Phytopathology* 88: S60.
- Pfister, R. D. 1989. Basic concepts of using vegetation to build a site classification system. In Ferguson, D. E., P. Morgan, and F. D. Johnson eds. Proceedings—Land Classification based on Vegetation Applications for Resource Management. Gen. Tech. Rep. INT-257. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 22-28.
- Stearns, S. C. 1989. The evolutionary significance of phenotypic plasticity. *Bioscience* 39 (7): 436-445.
- USDA Soil Conservation Service. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. U. S. Department of Agriculture. Agricultural Handbook No. 436. Washington, D. C. 743p.

**Reflections on the epidemiology and damage caused by *Elytroderma deformans* in the South Lake Tahoe Basin, California, 1971-1998**

Robert F. Scharpf  
Placerville, CA

Studies were initiated in the Lake Basin in 1971 the year following an epidemic outbreak of *Elytroderma deformans* (ED) on Jeffrey pine, *Pinus jeffreyi*. Results of these studies (Scharpf and Bega 1981, 1988; and Scharpf 1989) have shown that epidemic outbreaks occur when rain occurs in spring when mature fruiting and new foliage are present. These results are further confirmed with studies on a similar disease, *Lirula abietis-concoloris* on white fir, *Abies concolor*. Laboratory tests were conducted using mature fruiting bodies to study spore discharge and dispersal, and field tests involving overhead irrigation to simulate the effect of rain in the infection process. (McCain, Arthur H. And Robert F. Scharpf 1987, Scharpf 1988).

My current thoughts about the moisture requirement for infection during these sporadic outbreaks include more than the presence of rain. I believe that any conditions, including rain, fog, clouds and dew, that allow for free moisture to accumulate on young needles when inoculum is present, allows for both spore dispersal, germination and infection. It appears that a period as short as 24 hours is sufficient for these processes to occur. Because the disease in the Lake Tahoe Basin is most heavily concentrated in the lower lakeshore areas rather than on the upper slopes, I feel that specific micro climatic conditions such as lakeshore fogs or prolonged dew formation may be responsible for the periodic outbreaks.

Observation on the damage caused by ED in the 6 plots established by Scharpf and Bega 1981, show the gradual, but continued loss of Jeffrey pines in the plots with a steady encroachment of white fir. The more shade tolerant white fir has become the dominant species on several plots, that were nearly pure pine stands in 1971. It is highly doubtful in my view that white fir will maintain it's dominance for long periods. Periodic droughts of 3 years or more have created extreme moisture stress conditions on many fir stands predisposing them to attack by bark beetles which often results in heavy mortality. Thus the stands, represented by the study plots, appear to be extremely fragile and subject to changes that effect the health and survival of either pines or true firs.

My opinion is that these particular stands on these sites historically have fluctuated back and forth in composition among pines, firs and desert brush species depending on the particular environmental and ecological stresses placed upon the stands.

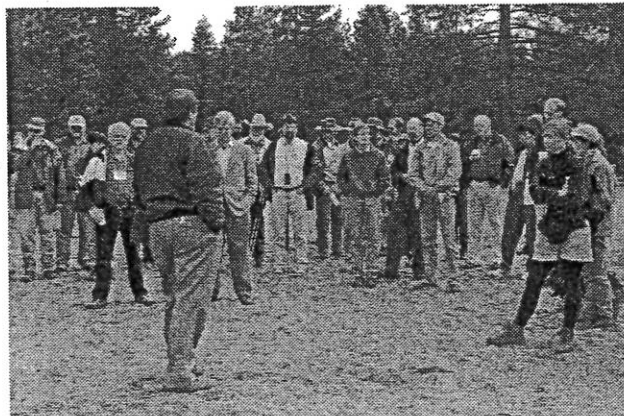
Certainly mans activities have been partially if not primarily responsible for some of these changes. Before the area was severely disturbed by logging and other activities about a century ago, the area apparently supported stands of widely spaced, open grown, old growth Jeffrey pine and fir. Clear-cutting these stands allowed for regeneration of fairly heavily stocked stands of young pines. It is in these stands of young pines, I believe, that ED had built up over the years to cause the mortality and damage we see following outbreak years. Our tests in 1988 (Scharpf and Bega) indicate that ED is capable of intensifying to damaging levels in young, planted Jeffrey pines in just 13 years.

In conclusion, I would like to make the following points about how we should look at the effects of ED and similar persistent, "slow acting" forest diseases.

1. The epidemiology and infection process of ED, I believe is well known, but the climatic and ecological conditions that regulate outbreaks of the disease probably vary in different areas. For example, the timing and frequency of outbreaks on pines in Oregon and elsewhere probably differs from that in South Lake Tahoe.
2. Trying to determine the long term affects of the diseases based on 1 or 2 year observations is doomed to failure, (or at least erroneous information.) For instance, low levels of mortality or growth reduction may appear insignificant in any one year, but cumulative losses over just a few decades could be dramatic.
3. Diseases such as ED that may appear to be relatively insignificant when viewed at any given period of time, may in the long term have a more serious effect than anticipated on forest health and management of a given stand.

Literature Cited:

- Scharpf, Robert F. 1989. Life cycle and epidemiology of Elytroderma disease reduces growth and vigor, increase mortality of Jeffrey pines at Lake Tahoe Basin, California Res. paper PSW155 6 p. illus, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California.
- Scharpf, Robert F. and Robert V. Bega. 1988. Elytroderma Disease in young planted Jeffrey Pine, South Lake Tahoe, California. Research Notes PSW-399. 2 p. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California.
- McCain, Arthur H. and Robert F. Scharpf 1987. Control of needle cast of white fir. California Plant Pathology No. 78 - December 3 p.
- Scharpf, Robert F. 1988. Epidemiology of *Lirula abietis-concoloris* on white fir in California. Plant Disease 72:855-858.



## **PANEL: WOOD DECAY, SOIL ORGANISMS AND THEIR ROLE IN FORESTED ECOSYSTEMS**

**Bob Edmonds - Moderator**

### **Decay Mechanisms of Basidiomycetes**

Barbara Illman  
USDA Forest Service  
Forest Products Laboratory  
Madison, WI

An understanding of the role of wood decay in the forest ecosystem requires knowledge about the decay mechanisms of wood decay fungi, which are determined by the chemical composition of wood. More than 65% of wood consists of carbohydrates, cellulose, and hemicellulose; lignin constitutes approximately 25%. Some wood extractives are chemicals that are part of the plants defense system against insects and fungi.

Most wood decay is caused by two groups of basidiomycetes: brown-rot and white-rot fungi. These fungi are distinguished by their residues, which reflect differential decay mechanisms. Brown-rot fungi primarily degrade cellulose, leaving a typical brown residue. White-rot fungi degrade both lignin and cellulose. Because lignin is degraded at a faster rate than is cellulose, the decay residue is typically white.

The mechanisms of decay have an impact on ecosystem structure and function. The residue from brown-rot fungi crumbles into powder when dry, making an unsuitable habitat for most animals. In contrast, the residue from white-rot fungi often takes the form of spongy mats of cellulose fibers, which are suitable for nesting sites for many animal species.

Knowledge about the requirements for expression of decay mechanisms is prerequisite to using decay as a component of forest ecosystem management. Mechanisms of decay evolve under particular environmental conditions. Decay optimally occurs between 10°C and 32.2°C. The decay process is slow when the temperature is above or below this optimum range; decay essentially stops when the temperature drops as low as 1.7°C and accelerates when the temperature rises as high as 37.8°C. Decay requires moisture, with an optimum of 30% wood fiber saturation. Wood with moisture content below 20% will typically not decay, and decay already present in the wood will not progress.

Several general statements can be made about brown- and white-rot fungi, and all of these generalities have exceptions:

- Brown-rot fungi are typically saprophytes, and white-rot fungi are typically pathogens.
- Decay occurs in heartwood more than sapwood in living trees, whereas decay occurs more in sapwood than in heartwood of dead trees and wood products.
- Most pathogens that attack trees cease activities after the tree dies or has been cut.

This panel will address specific roles of decay in the forest ecosystem. Each role is predicated on the expression of decay mechanisms: from how wood decay interacts with wildlife, as Catharine Park will describe in her work on using wood decay to establish wildlife habitat; to how biological

decomposition can offset fire, the approach Al Harvey uses to actively manage fuel load; to how heart rot creates small-scale disturbance by creating gaps in the forest, as Paul Hennon will describe.

In summary, wood decay plays a major role in forest ecosystems. We need more information about the decay mechanisms of basidiomycetes to understand and manage forested ecosystems.



Barbara Illman and Hal Burdsall enjoying the choices at the ice cream social.



Paul Hennon

## Heart rot and other causes of small-scale disturbance in the temperate rain forests of southeast Alaska

Paul E. Hennon and Michael H. McClellan

USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory,  
2770 Sherwood Lane, Suite 2A, Juneau, Alaska 99801 USA,  
E-mail: phennon/r10@fs.fed.us and mmclellan/r10@fs.fed.us

### Introduction

The forests of southeast Alaska differ from other forests in western North America in that fire is not an important disturbance factor (Harris and Farr 1974, Alaback 1988). Indeed, they are often described as temperate rain forests because of the rarity and unimportance of fire. Wind has received the most attention as a disturbance force in the region (Harris 1989, Swanston *et al.* 1996) and is assumed by many to be driving change at both large and small spatial scales.

But recent studies and our observations in old-growth forests challenge this view, particularly at the small spatial scale. In this paper, we consider other factors of small-scale disturbance, especially heart rot disease, and describe preliminary results from a large effort to measure how trees die in unmanaged, old-growth forests of southeast Alaska. This ecosystem is an excellent setting to explore processes of natural disturbance because large areas of forest still exist that have not been altered by timber harvesting, fire suppression, or other forest management activities.

### Forest disturbance in southeast Alaska

Various disturbance forces appear to be operating at different scales of time and space in the forests of southeast Alaska (Fig. 1). Glaciers are relatively infrequent but can cause complete disturbance at nearly a regional scale. Landslides and floods occur on particular portions of the landscape favorable for their development (i.e., steep slopes and riparian areas, respectively) and most often function at temporal and spatial mid-scales. Two insect species, black-headed budworm and hemlock sawfly, flare up every few decades, defoliating large forested areas. Typically, however, they do not cause tree mortality and should not be considered disturbance agents even though their role in nutrient cycling and sources as bird prey may be important. Spruce beetle kills dominant trees in groups, and thus is a legitimate disturbance agent, but its outbreaks are only common in the eastern and northern parts of the region which have a transitional continental-maritime climate. Wind is thought to function at a range of scales; attempts to map blowdown typically yield patches of 2 to 10 hectares, but larger events have been documented (Harris 1989, Nowacki and

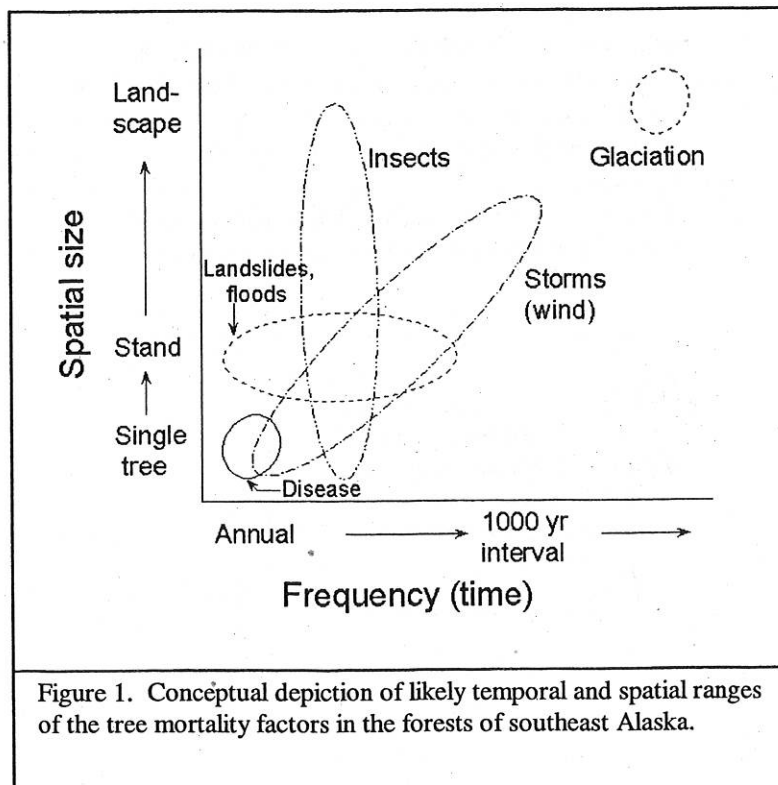


Figure 1. Conceptual depiction of likely temporal and spatial ranges of the tree mortality factors in the forests of southeast Alaska.

Kramer 1998). The return interval of wind and other stand-replacing factors is not known over most of the landscape because there is little available information on the age structure of forests in southeast Alaska. Age structure analysis of a randomly-selected subset of old-growth timber inventory plots showed that 74% of the stands had three or more age classes (Farr and McClellan, in review), illustrating the preponderance of small-scale disturbance. It is conceivable that catastrophic storm events are rare in protected areas (Nowacki and Kramer 1998), or even that they have not occurred at all since glaciation some 9000 years ago. If that is the case, then small-scale events have shaped and maintained these forests for long periods of time. Small-scale forces, such as wind and disease, would operate at the single-tree or several-tree spatial level, killing scattered trees each year (i.e., frequent time scale).

### Small-scale disturbance--mode of tree death

Research by ecologists on small-scale disturbance frequently focuses on the recovery of vegetation, sometimes ignoring the cause or mechanism of tree death that leads to disturbance. When tree death is measured, it is often classified as uprooting, bole breakage (sometimes called windbreak or stem snap), and dead standing. High winds, water-saturated soils, snow and ice loading, and shallow root systems lead to increased susceptibility for tree uprooting (Alaback 1988). Until recently, uprooting was the only small-scale disturbance process that has received much attention in these forests. Two studies in the Juneau and Sitka areas have attempted to evaluate gap-level or small-scale disturbance by measuring gap sizes and documenting tree mortality (Hocker 1990, Ott 1997). Both concluded that most tree death that gives rise to canopy gaps is in the form of bole breakage (99% and 76%, respectively, for these two studies) and both recognized the associated role of heart rot. Sampling was limited in these studies, however, and their results on different forms of tree mortality appear to confuse trees that die by bole breakage with those that die standing and subsequently deteriorate.

In order to understand the mechanisms and consequences of small-scale disturbance, we believe it is essential to accurately determine how trees die. These distinctions are important ecologically because different forms of tree mortality lead to different vegetation recovery and conditions on the site. Whether trees die by uprooting, bole breakage, or standing, their type of death will influence

Table 1. Decay fungi of living Sitka spruce and western hemlock in forests of coastal Alaska listed in descending order of importance for white rot and brown rot species (modified from Kimmey (1956)).

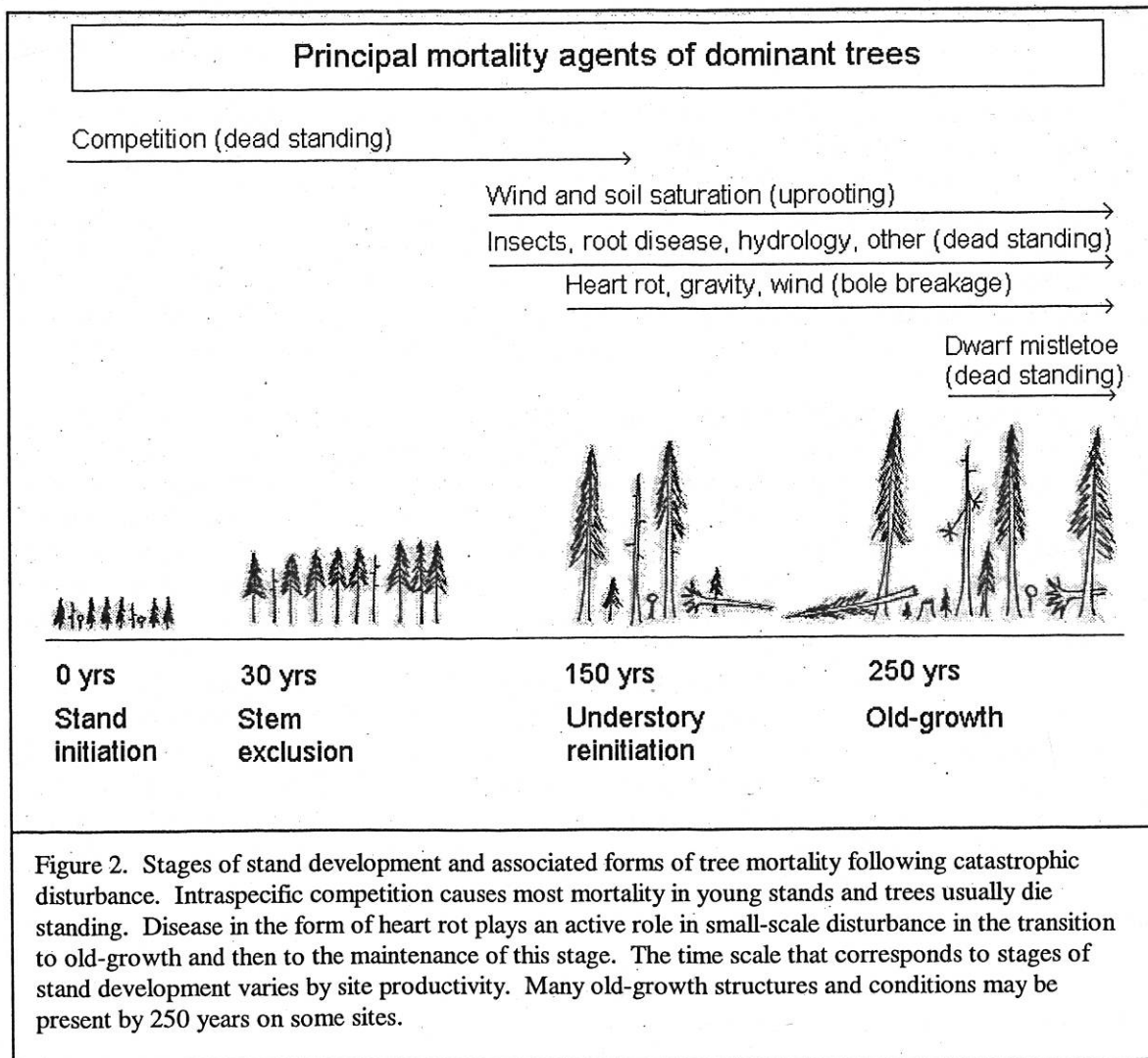
Sitka spruce	
<u>White rot fungi</u>	<u>Brown rot fungi</u>
<i>Phellinus pini</i> (Thore:Fr.) Pilat	<i>Fomitopsis pinicola</i> (Schwartz:Fr.) Karst.
<i>Armillaria</i> spp.	<i>Phaeolus schweinitzii</i> (Fr.) Pat.
<i>Heterobasidion annosum</i> (Fr.) Bref.	<i>Laetiporus sulphureus</i> (Bull.:Fr.) Murr.
<i>Merulius</i> sp.	<i>Antrodia heteromorpha</i> (Fr.) Donk.
<i>Phellinus nigrolimitatus</i> (Rom.) Bourd. & Galz.	<i>Lentinus kaufmanii</i> A.H. Smith
Western hemlock	
<u>White rot fungi</u>	<u>Brown rot fungi</u>
<i>Armillaria</i> sp.	<i>Fomitopsis pinicola</i>
<i>Heterobasidion annosum</i>	<i>Laetiporus sulphureus</i>
<i>Pholiota adiposa</i> (Fr.) Kumm.	<i>Phaeolus schweinitzii</i>
<i>Phellinus hartigii</i> (Allesch. & Schnabl) Bond.	<i>Hericius</i> sp.
<i>Phellinus pini</i>	
<i>Ganoderma applanatum</i> (Pers.:Wallr.) Pat.	

the response of understory vegetation, conifer regeneration, wildlife habitat, nutrient cycling, and soil

processes that affect site productivity (Hennon 1995). Mixing of organic and inorganic layers of soil occurs when trees uproot but not when trees die standing or by bole breakage. This mixing reverses podzolization which, if left unchecked, could lead to reduced soil drainage and immobilization of nutrients (Ugolini and Mann 1979; Borman *et al.* 1995).

**Heart rot and the interaction of large- and small-scale disturbance**

Every important tree species worldwide is invaded and decayed by one or more species of heart rot fungi. A considerable body of literature on commercial loss by heart rot has been developed since Hartig (1874) described the causal role of fungi, but the ecological role of heart rot fungi as disturbance factors in forests has received surprisingly little attention (Hennon 1995). The dominant species of heart rot fungi of western hemlock and Sitka spruce in southeast Alaska (Table 1) are well known to mycologists and pathologists; all are found in conifers throughout the Pacific Northwest of North America. Brown and white rot species are well represented in both hosts. Many of the fungi responsible for the considerable level of heart rot are spread by infectious spores that colonize large wounds. One such fungus, *F. pinicola*, is extremely common and causes an estimated 73% of cull in Sitka spruce and 22% of cull in western hemlock in southeast Alaska (Kimmey 1956). In British Columbia, wounding is associated with up to 65% of decay in live western hemlock trees (Buckland *et al.* 1949). Causes of bole wounds on trees in Alaska include porcupines, bears, beavers, logging, and road building, but falling trees and limbs appear to be the most common form of natural bole injury in



western hemlock old-growth forests (Kimmey 1964). Hennon and DeMars (1997) recently determined the rate of wood decay that occurs in wounded western hemlock and Sitka spruce. More than a century would probably elapse between the time that a tree was wounded and enough heart rot developed for tree failure through bole breakage to occur.

These fungi contribute to an estimated 31% defect in the gross volume of live trees in old-growth forests in southeast Alaska (Farr *et al.* 1976). Several factors probably give rise to such a high rate of wood decay including hemlock and spruce's susceptibility to decay, long life spans, their thin bark that is easily wounded, and the wet, mild climate favorable for the development and spread of fungi.

Time may also be a critical factor. Many forests in coastal Alaska are composed of old trees because of the apparent infrequency of large-scale catastrophic disturbance. Interactions occur among large-scale disturbance and the agents and processes of small-scale disturbance (Fig. 2). In particular, large stand-replacing events, such as wind storms or clearcuts and the resulting stand structures, greatly influence the levels of important tree diseases. Early stages of stand development are almost devoid of two key diseases, hemlock dwarf mistletoe and the heart rots. Tree mortality is generally caused by competition for light and nutrients in these dense young stands, and most trees die standing. We do not know when dwarf mistletoe recolonizes a forest after a catastrophic disturbance, but birds or mammals are responsible for transporting inoculum (i.e., seeds). Forests may first have to reach the old-growth stage where canopy height ceases to expand and gap-level mortality operates, conditions that favor the short-range seed dispersal mechanism of the parasite.

Our observations in stands of different ages and reports in the literature indicate that heart rot returns at an earlier stage than does dwarf mistletoe. Conifers less than 100 years old have little decay, but by 200 years, 65% of western redcedar, 50% of western hemlock, and 20% of Sitka spruce trees contain decay (Kimmey 1956). Farr *et al.* (1976) reported a significant correlation between tree age and the percentage of decayed wood volume in live trees. Heart rot fungi may facilitate the change from the maturing even-aged stage (i.e., understory reinitiation, to use Oliver and Larson's (1990) terminology) as it is in transition to the old-growth stage (Fig. 2). Mortality of dominant trees may be necessary for this transition or perhaps it speeds the rate of change.

The age of a stand when decay losses exceed annual increment was dubbed the "pathological rotation age" by Meinecke (1916). This age varies widely for different tree species and for a single species in different regions. Western hemlock, for example, reaches pathological rotation at stand ages of 225 to 275 years in western British Columbia (Buckland *et al.* 1949) and 100 to 120 years in Idaho and Montana (Weir and Hubert 1918). Many old-growth forests in southeast Alaska are probably at this stage where the wood produced annually is in equilibrium with that which is lost to heart rot decay and mortality. Such forests may reach a relatively high degree of stability.

#### **Silvicultural Alternatives to Clearcutting Study: patterns of tree death**

A large multi-disciplinary study, known as *Silvicultural Alternatives to Clearcutting in the Old-Growth Forests of Southeast Alaska*, has provided the resources for us to conduct detailed sampling of vegetation, including tree mortality, in old-growth forests. The main objective of this study is to determine to what extent structures and functions that occur in old-growth forests can be maintained under different intensities and spatial arrangements of timber harvesting. One of our specific objectives is to address several concerns that managers have with partial harvests: logging damage during harvest and excessive windthrow and dwarf mistletoe spread after harvest. Tree damage during logging operations may add to an even higher level of heart rot decay than occurs before harvest. Our approach to address these concerns is to measure patterns of tree mortality and associated factors before harvest (i.e., natural conditions) and contrast any changing conditions after harvest with this baseline.

Thus, the pretreatment or baseline sampling allows us to study patterns of tree mortality that are unaffected by human activities. This study is conducted at three sites in southeast Alaska: Hanus Bay on northern Baranof Island and adjacent Catherine Island, Portage Bay on Kupreanof Island, and Lancaster Cove on Prince of Wales Island. Each site has nine treated stands 15 to 20 ha (40 to 50 ac) in size. Each stand contains 20 1/5 ac permanent plots. Thus, we have 540 plots established to sample vegetation before and after harvest. Among a myriad of measurements that we and other scientists make on the living vegetation and other conditions, we collect the following data on dead trees: species, mode of death, diameter, height-to-break (if broken), decay class, amount of decay, and direction of tree fall.

Figure 3 displays our sample population of live and dead trees at the three study sites. Note that western hemlock dominates our sample populations as it does regionally. The forests of southeast Alaska are composed by volume of approximately 61% western hemlock, 33% Sitka spruce, and 6% cedars and other species (Harris and Farr 1974). For snags and logs, it is difficult to distinguish species of hemlock even with microscopic examination of wood. Most of the dead trees noted as "TSHE (+TSME)" are assumed to be western hemlock because this species is so common in our plots. With the abundance of western hemlock in our sample population of dead trees and in the region, understanding the tree mortality process for western hemlock is clearly essential to knowledge about small-scale disturbance.

In evaluating dead trees that would give rise to a canopy gap and subsequent growing space for a mature tree, we omitted any small dead trees from analysis. We queried our sample of live trees and found that tree diameter (DBH) of 45 cm was an approximate division between classes of codominant and intermediate trees at each of our three sites. We could not collect data on crown dominance for many dead trees (i.e., many were down); thus, we included any dead trees 45 cm DHB or larger in the analyses, which presumably would capture codominant and dominant trees.

Figure 4 depicts the percentage of dead trees of dominant and codominant size, regardless of species or snag/log class, that were found killed in four different ways at the three study sites. By this simple analysis, the most common form of tree mortality appears to be by broken bole, followed by dead

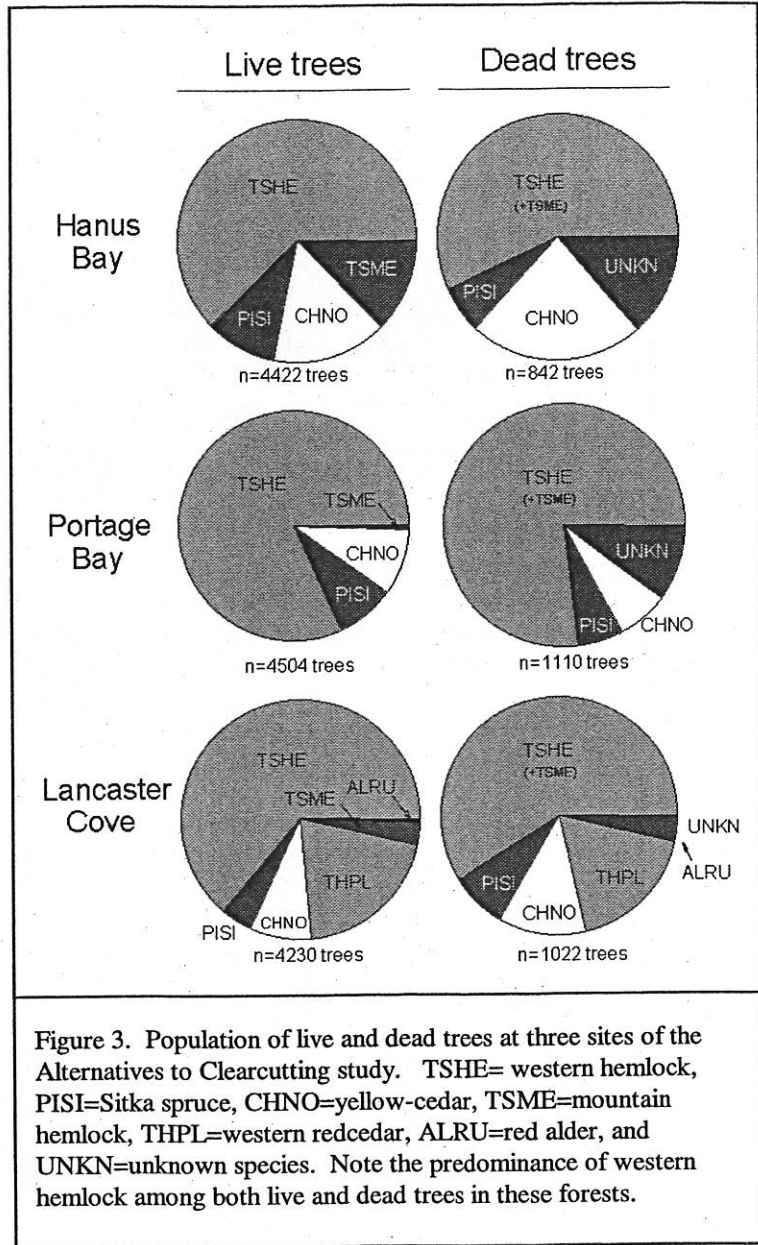


Figure 3. Population of live and dead trees at three sites of the Alternatives to Clearcutting study. TSHE= western hemlock, PISI=Sitka spruce, CHNO=yellow-cedar, TSME=mountain hemlock, THPL=western redcedar, ALRU=red alder, and UNKN=unknown species. Note the predominance of western hemlock among both live and dead trees in these forests.

standing and uprooting. Few large trees were killed by being knocked over by other trees. More trees were found uprooted at the Lancaster site than the other sites, but, even here, over 77% of trees died in some other manner.

We also use these data to investigate differences in the mode of tree death for the various tree species. Figure 5 illustrates the percentage of canopy-level trees of each species that appeared to die by each type of mortality at the three study sites. Note that western redcedar (THPL) is present only at the Lancaster Cover study site. Western hemlock displayed the greatest percentage of tree death by broken bole at all sites. The decay-resistant yellow-cedar and western redcedar were more evenly distributed among the three main types of tree death. Uprooting was the most common form of tree death in only one species-site combination:

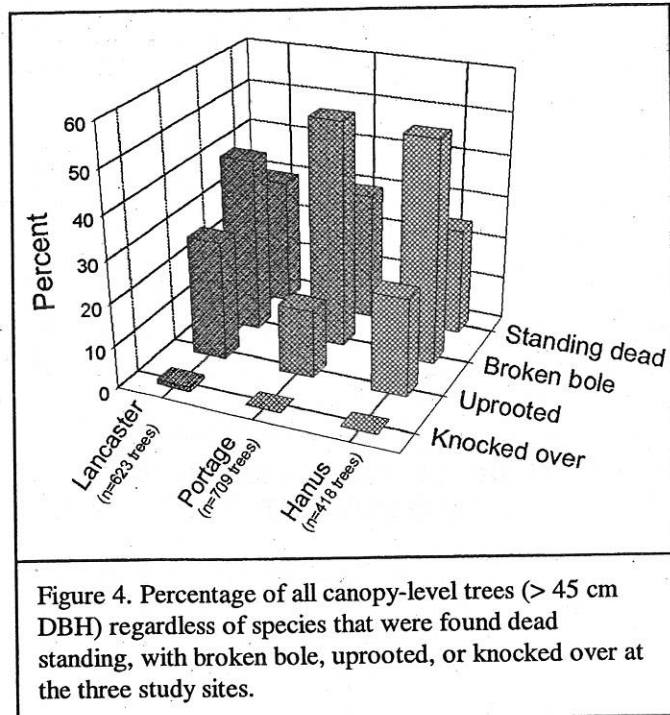


Figure 4. Percentage of all canopy-level trees (> 45 cm DBH) regardless of species that were found dead standing, with broken bole, uprooted, or knocked over at the three study sites.

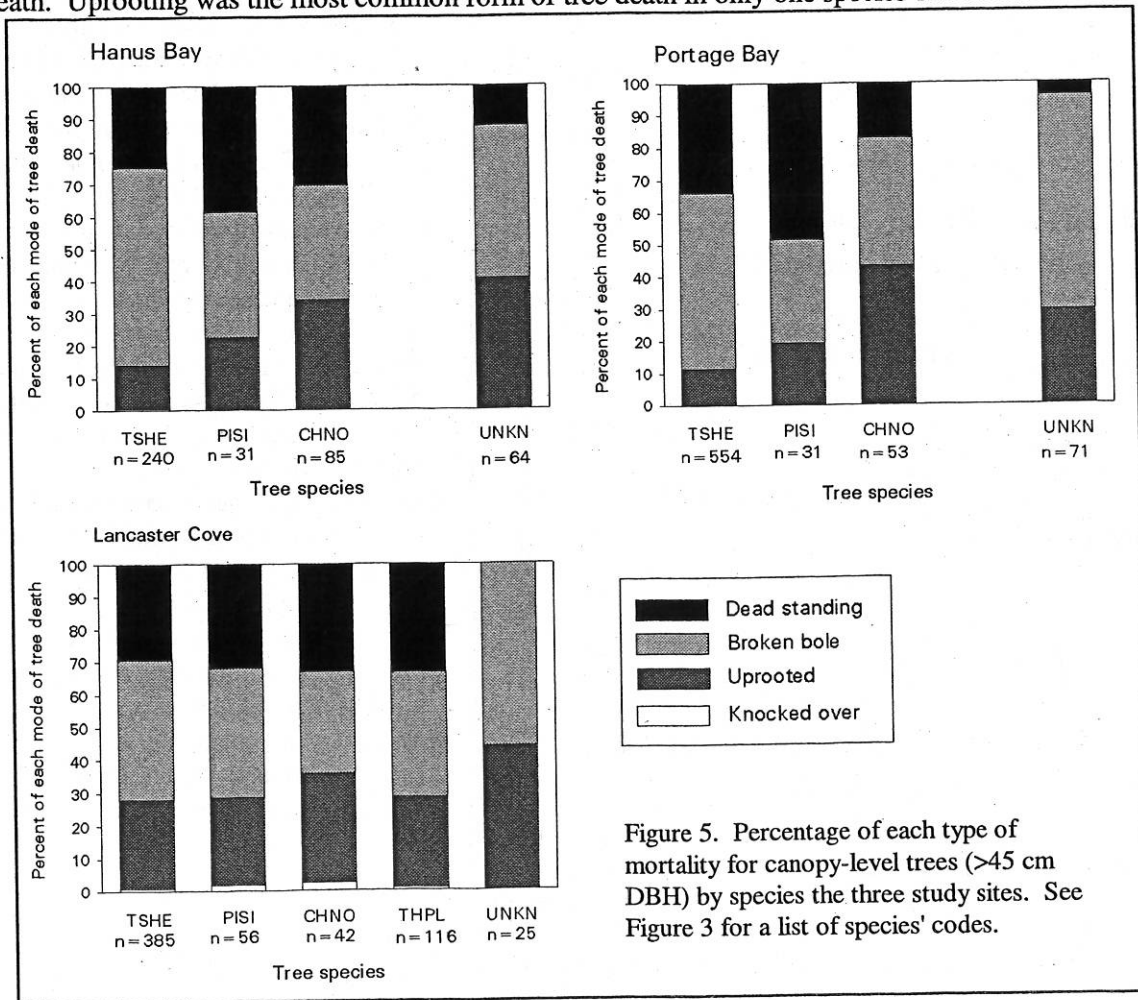


Figure 5. Percentage of each type of mortality for canopy-level trees (>45 cm DBH) by species the three study sites. See Figure 3 for a list of species' codes.

yellow-cedar (CHNO) at Portage Bay. The relatively high frequency of dead standing Sitka spruce at Portage Bay suggests a host-specific agent occurs there, such as spruce beetle. The trees that could not be identified to species (UNKN) were typically old mortality without bark present and were often found with broken boles or had been uprooted, but were not commonly found standing. Many of these trees were probably western hemlocks, known to be susceptible to decay and to not persist for many decades as a standing snag (Hennon and Loopstra 1991).

We recognize that including older mortality in these analyses confuses trees that die through bole breakage with those that die standing and subsequently deteriorate to the point where they have broken boles. Eventually, trees that die in either fashion will have a broken bole and extensive wood decay. We are confident that we can distinguish death by uprooting from other forms of tree mortality long after death because of the presence of the tipped-up root system. We find that few standing snags uproot after tree death. We are developing a method to determine how a tree died when we encounter an old broken off tree. This involves comparing when a tree died (by stem ring analysis on the downed log and other trees in the stand) to when it fell (by dating wounds on adjacent trees). When these dates coincide, we assume that trees died suddenly through bole breakage. When tree fall occurs later than death, we assume that the tree died standing, deteriorated, and then fell.

For the purpose of preliminary analysis in this paper, however, we chose to examine the mode of tree

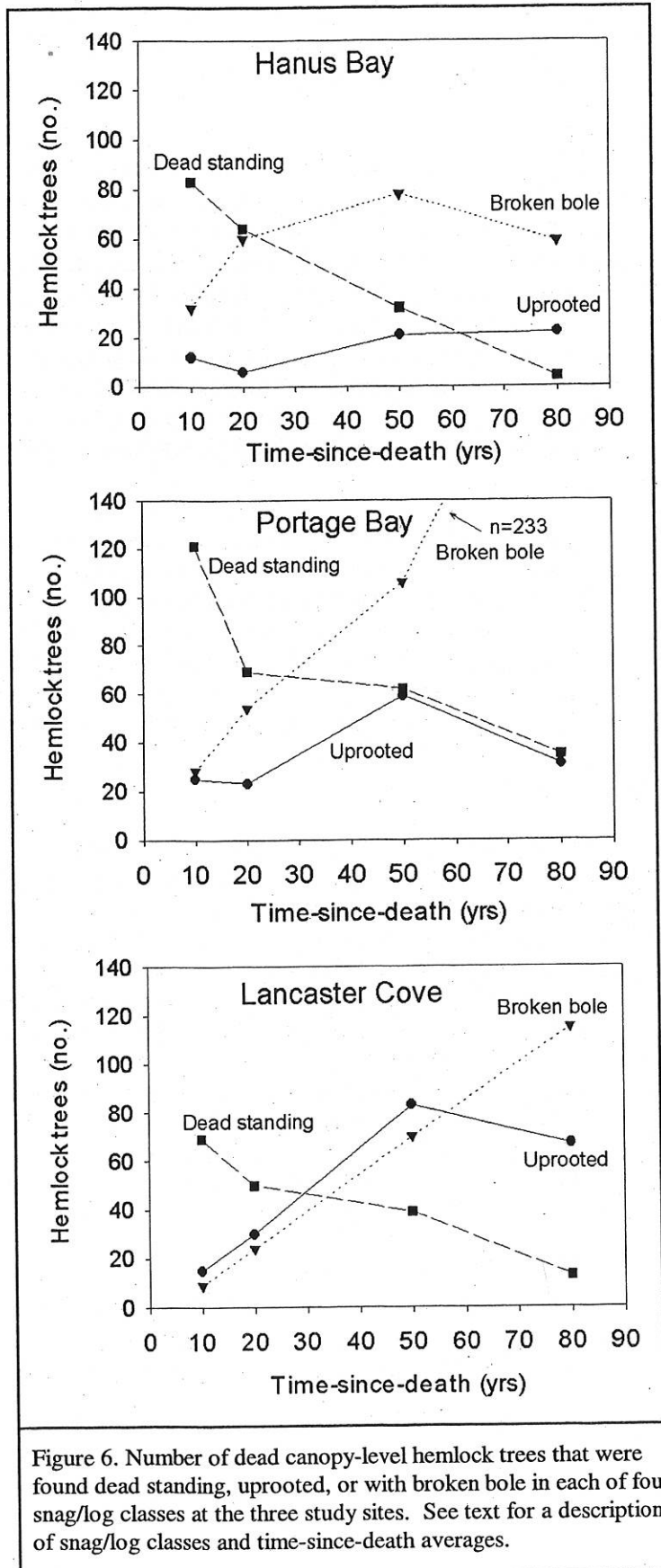


Figure 6. Number of dead canopy-level hemlock trees that were found dead standing, uprooted, or with broken bole in each of four snag/log classes at the three study sites. See text for a description of snag/log classes and time-since-death averages.

death by snag/log class (Fig. 6). We report preliminary time-since-death estimates for each class based on a retrospective study (P. Palkovic, Pers. Comm). Snag/log classes are: 1) twigs retained, 10 yr, 2) secondary or long primary branches retained, 20 yr, 3) short primary branches retained, 50 yr, and 4) all branches gone, logs slumping, 80 yr.

Accounting for time-since-death reduces the likelihood of overestimating the proportion of trees that die by bole breakage. Over time, trees that die standing will deteriorate and break, leading to fewer standing trees and more broken boles with increasing time-since-death. For hemlocks at each of the three sites (Fig. 6), dead standing trees dominated our class of most recent mortality (i.e., dead, twigs retained). The number of dead standing hemlocks diminished through time with each successive snag/log class. Broken boles showed the reverse trend with increasing numbers through time, indicating that many hemlock trees die standing and eventually deteriorate to appear as broken boles. Our sampling demonstrates that the most common form of tree mortality for canopy-level hemlocks at these three sites is dead standing, followed by broken boles and uprooting. Of the three types of tree mortality, wind probably has a less causal role in dead standing tree death than bole breakage or uprooting.

Future analyses will be directed at learning more about causal factors of tree mortality. We will associate bole breakage for trees in the early snag/log classes with measurements of decay that we made in these dead trees. Comparing the azimuth of tree fall for each of the forms of tree mortality will help distinguish the effects of wind and gravity on trees that die through bole breakage and uprooting. We will evaluate the other tree species as we have done here for western hemlock by examining mode of tree death by snag/log class (i.e., time-since-death). This may enable us to find historic pulses of mortality at the stand or site level that would suggest effects of wind or some other mid-scale disturbance event.

### **Conclusions**

Wind is not the only force that contributes to small-scale disturbance in the forests of southeast Alaska. The preliminary results from our sampling at three sites indicate that many or most canopy-level trees die standing. Clearly, we need to learn more about the mortality factors that lead to trees dying standing if we hope to thoroughly understand the mechanisms of small-scale disturbance. Heart rot also plays a role in tree mortality by predisposing tree death through bole breakage. This form of mortality is more common in some forests than uprooting, the latter being primarily a physical process. Research has documented the correlation between stand age and heart rot levels. We now need information on the age structure of forests throughout the region in order to evaluate large- and mid-scale disturbance that has occurred historically and how much of the landscape is in an old-growth condition functioning under small-scale processes. Besides adding to our understanding of the mechanisms of natural disturbance, the study of tree mortality in these forests will yield an interesting perspective of what levels and types of tree death may be desirable in managed forests.

### **Acknowledgements**

This paper is a contribution from the study, 'Silvicultural Alternatives to Clearcutting in the Old-Growth Forests of Southeast Alaska', a joint effort of the USDA Forest Service Pacific Northwest Research Station and the Alaska Region, implemented on the Tongass National Forest. We thank the many workers who assisted in the Herculean task of collecting field data at our study sites.

**Literature Cited**

- Alaback, P. B. 1988. Dynamics of old-growth temperate rainforests in southeast Alaska. Proceedings of Glacier Bay Science Symposium 2: 150-153.
- Borman, B.T.; Spaltenstein, H.; McClellan, M.H.; Ugolini, F.C.; Cromack, K.; Nay, S.M. 1995. Rapid soil development after windthrow disturbance in pristine forests. *Journal of Ecology* 83: 747-757.
- Buckland, D.C., Foster, R.E.; Nordin, V.J. 1949. Studies in forest pathology. VII. Decay in western hemlock and fir in the Franklin River area, British Columbia. *Can. J. For. Res. Sect. C* 27: 312-331.
- Farr, W.A., LaBau, V.J.; Laurent, T.H. 1976. Estimation of decay in old-growth western hemlock and Sitka spruce in southeast Alaska. USDA For. Ser., Pac. Northwest For. and Range Exp. Sta., Portland OR. Research Paper PNW-204. 24p.
- Farr, W.A.; McClellan, M.H. Size and age structure of trees in the old-growth forests of southeast Alaska. In review.
- Harris, A.S. 1989. Wind in the forests of southeast Alaska and guides for reducing damage. USDA For. Ser., Pac. Northwest Res. Sta., Portland, OR., Gen. Tech. Rep., PNW-GTR-244. 63p.
- Harris, A.S.; Farr, W.A. 1974. The forest ecosystem of southeast Alaska. 7. Forest ecology and timber management. USDA For. Ser., Pac. For. Res. Sta., Portland, OR., Gen. Tech. Rep. PNW-25. 109p.
- Hartig, R. 1874. Wichtige Krankheiten der Waldbäume. Beiträge zur Mycologie und Phytopathologie für Botaniker und Forstmänner. Berlin, Springer. 127p.
- Hennon, P.E. 1995. Are heart rot fungi major factors of disturbance in gap-dynamic forests? *Northwest Science*. 69: 284-293.
- Hennon, P.E.; DeMars, D.J. 1997. Development of wood decay in wounded western hemlock and Sitka spruce in southeast Alaska. *Can. J. For. Res.* 27: 1971-1978.
- Hennon, P. E.; Loopstra, E.M. 1991. Persistence of western hemlock and western redcedar trees 38 years after girdling at Cat Island in southeast Alaska. USDA For. Ser., Pac. Northwest Res. Sta., Portland, OR. Res. Note PNW-RN-507. 5p.
- Hocker, K.M. 1990. Influence of canopy gaps on forest dynamics in southeast Alaskan hemlock-spruce forests. Cambridge, MA: Harvard University. 43 p. Senior thesis.
- Kimmey, J.W. 1956. Cull factors for Sitka spruce, western hemlock and western redcedar in southeast Alaska. USDA For. Ser., Alaska For. Res. Cent., Juneau, AK. Station Paper No. 6. 31p.
- Kimmey, J.W. 1964. Heart rots of western hemlock. USDA For. Ser., Washington. For. Pest Leaflet 90. 7p.
- Meinecke, E.P. 1916. Forest pathology in forest regulation. USDA Bull. 275: 1-63.
- Nowacki, Gregory J.; Kramer, Marc G. 1998. The effects of wind disturbance on temperate rain forest structure and dynamics of southeast Alaska. Gen. Tech. Rep. PNW-GTR-421. Portland, OR: U.S. Dep. Agric., Forest Ser., Pac. Northwest Res. Sta. 25 p.
- Oliver, C.D.; Larson, B.C. 1990. Forest stand dynamics. McGraw Hill, New York. 467p.
- Ott, R.A. 1997. Natural disturbance at the site and landscape levels in temperate rainforests of southeast Alaska. Fairbanks, AK: University of Alaska. Ph.D. dissertation.
- Swanston, Douglas N.; Shaw, Charles G. Shaw III; Smith, Winston P. and others. 1996. Scientific information and the Tongass Land Management Plan: key findings from the scientific literature, species assessments, resource analyses, workshops, and risk assessment panels. Gen. Tech. Rep. PNW-GTR-386. Portland, OR: U.S. Dep. Agric., Forest Ser., Pac. Northwest Res. Sta. 30 p.
- Ugolini, F.C.; Mann, D.H. 1979. Biopedological origin of peatlands in southeast Alaska. *Nature* 281: 366-368.
- Weir, J.R.; Hubert, E.E. 1918. A study of heart-rot in western hemlock. U.S. Dep. Agr. Bull. 722:1-37.

## Wildlife and Wood Decay Interactions

Catherine Parks  
USDA Forest Service  
Pacific Northwest Research Station  
La Grande, Oregon

Fungal initiated wood decays are very important to the wildlife component of the forest system. In general, decayed wood offers **substrate** that provides critical niches for feeding--up and down the food chain, and **structure** that provides important habitat for nesting, denning, resting, hunting, courtship, and communication--such as the drumming used by some woodpeckers.

I believe that there is evidence to suggest that some of these fungal decay/wildlife interactions are quite **specialized** in some cases. Although there are many examples of these interactions, I will outline a couple of them in more detail.

The first example is the Vaux's Swifts (*Chaetura vauxi*). These swifts are Neotropical migrants that nest in the coniferous forest of the Pacific Northwest after wintering in Mexico or Central and South America. The swifts nest in hollow trees and, rarely, in chimneys. They must have this structure for successful reproduction. All of the tree nest sites documented in the Blue Mountains of Oregon have been in extensively decayed or hollow trees, both living and dead. Large true fir (*Abies* spp.) with broken tops, hollowed by the fungus *Echinodontium tinctorium* are frequent nest sites (Bull and Hohmann 1993). Standing dead trees of any species that contain heartrot, or a living tree hollowed out by fire, may be important structures for swifts and other wildlife dependent on hollow trees. The more flammable decayed heartwood may be incinerated by the fire, while the living sapwood super-heats, forming a case-hardened shell. These trees typically stand for a long time and may be used year after year by returning swifts or other dependent wildlife.

Another example of perhaps a more specialized relation is linked to research we conducted on western redcedar trees used by Pileated woodpecker (*Dryocopus pileatus*) on the Olympic Peninsula (Parks et al. 1997). These trees are huge, old, living remnant trees used not for nesting but as roost sites by the Pileateds. Pileateds, like most woodpeckers, are tied to wood decay as a precursor for cavity excavation. They excavate 1 or more nests each year as part of their breeding ritual, but non-nesting birds will repeatedly return to use existing cavities in roost trees. Telemetry research shows that genetically related individuals will commonly use the same trees for roosting generation after generation. In our study we distinguished the decay fungi associated with trees previously identified as roost trees (Aubry and Raley 1990). The fungus we found associated with 8 of 10 trees was *Oligoporus sericeomollis*. We weren't able to culture basidiomycetes from 2 trees although the decay looked very similar to the other trees from which *O. sericeomollis* was cultured. It is interesting that the decay caused by *O. sericeomollis* reportedly causes rot column that is tubular in shape, can extend 25 or more meters up the bole of the tree, and can spread out into large branches (Buckland 1946). The decay columns produced by *O. sericeomollis* may create optimal roosting conditions in western redcedar for Pileateds. Pileated woodpeckers often roost in large longitudinal tree cavities having multiple openings that provide a means of escape from potential predators. During the telemetry study, woodpeckers were observed entering redcedars at one opening but exiting from another opening some distance away.

To close, I'll briefly outline and update some of the studies I am involved in that deal with wood decay and wildlife interactions:

Inoculation. Field trials continue in inoculating living trees around the West to produce heartrot decay for cavity nesters. We are beginning a plan of destructive sampling of a sub-sample of trees to evaluate the presence and extent of decay in trees inoculated longer than 4 years ago.

Bear Tree Work. Two years ago, I did some initial work with Oregon Department of Fish & Wildlife to characterize trees associated with black bear (*Ursus americanus*) dens (Parks et al. 1996). Briefly, we found radio-collared bears denning both in the base and high above the ground in large hollow trees with butt rot or heart rot. Most of the trees were living. One of the dens was a cull tree felled about 20 years ago and left just off the stump.

Current work being done by our research team in La Grande includes efforts by Evelyn Bull to select trees large enough to contain a basal bear den and that have good indications of butt rot. A chain saw is used to fashion an entry. Thirty den trees have been altered and will be checked for use during the spring of the next few years.

Other studies of the relation of wood decay and wildlife include the characterization of trees used by bats, and the collection of data on all types of "snag creation" projects in a series of retrospective studies that evaluate the efficacy of various ways to wound or kill trees to make suitable decay for cavity nesters.

#### References

Aubry, K. B. and C. M. Raley. 1990. Northwest Env. J. 6:432

Buckland, D. C. 1946. Can. J. Res. C. 24:158.

Bull, E.L. and J. E. Hohmann.1993. West. Birds 24:38-42.

Parks, C.G. 1996. Bear trees---An eastern Oregon landscape legacy. [Brochure]. U.S. D.A., For. Serv., P.N.W. Res. Stat.

Parks, C.G., C.M. Raley, K.B. Aubry, and R.L. Gilbertson. 1997. Plant Disease 81:551.



Dave Johnson

## Can We Harness Biological Decomposition to Offset the Effects of Fire as a Primary Carbon Recycling Agent?

Alan E. Harvey, Michael J. Larsen and Russel T. Graham  
Supervisory Plant Pathologist, Principal Research Mycologist and Research Forester respectively,  
U.S.D.A., Forest Service, Forestry Sciences Laboratory, Moscow, Idaho,

### Abstract

Human settlement-driven reductions in fire frequency have seriously altered accumulations of all types of woody debris in most north temperate forest ecosystems, especially in the interior west. Many are now sufficiently laden with fuel that fires, either wild or prescribed, are likely to cause excessive carbon loss and related soil damage. Many of the most problematical situations are located in, or proximal to, valuable properties and people where smoke or harvest removals are generally frowned upon and application of planned burning is expensive, risky and likely to be extremely unpopular. Public, private and corporate forest operations are faced with circumstances where available methodologies to manage fuels are often not practical or acceptable and fuels will continue to accumulate until the inevitable worst-case fire events occur.

Applications of modest-impact harvest or preharvest removals, accompanied by treatment of slash to accelerate decomposition, should provide helpful alternatives to more traditional methods. Accelerating biological decomposition in ecosystems where the process is normally both temperature and moisture limited is not a trivial problem. However, management of forest structure to raise (or lower) temperatures and to improve available moisture, in combination with modifying resulting slash in ways that enhance activities of endemic (or introduced) decomposers, holds considerable promise as an approach to improving the long-term fire situation in high fuel forests.

### Fire-Biological Decomposition Interactions

Perhaps one of the most notable characteristics of western forests is their tendency to accumulate carbon over time (Olsen 1981). The photosynthetic (carbon fixation) process is less limited by the environment than is respiration-driven biological decomposition. Thus, fuel accumulates and eventually must be removed or it will burn.

#### *Current status of western forests:*

Success with fire control this century has placed most short-fire-cycle interior forests in the high fuel accumulation category (Sampson and Clark 1995). These forests are now in a condition where lack of fire has created overly dense, successional advanced forests with high stress and high mortality. Dry season wildfires now often put both soils and vegetation, including root systems, at high risk (Harvey 1994a, Swezy and Agee 1991). Soils subjected to high severity fires can lose not only surface reserves of organic matter and nutrients, but also those incorporated deep within the soil profile. An undesirable situation from the standpoint of long-term sustainable forestry (Harvey et al. 1994c). The unpopularity of harvesting, fire and/or salvage operations adds a political dimension, particularly in or around high value land developments where clear air and quality vistas are extremely valuable.

#### *Fire cycles:*

Fire events in the western U.S. vary from a few years to several centuries and weather patterns provide enough lightning to eventually cause ignitions, with or without the help of humans (Olsen 1981). In the absence of fire, nutrients are sequestered in accumulating organic debris and turnover is slow. Certain specific benefits of charcoal in forest soils (pH control, detoxification/adsorption of

phenolic derivatives, enhanced microbial activity) may also be reduced and ecosystem development is eventually impaired (Zackrisson *et al.* 1996, Harvey 1994a,c, Harvey *et al.* 1976). Historical fire cycles interrupted this fuel accumulation processes. If the accumulation persists over excessively long time periods, fire events can be extreme (Sampson and Clark 1995).

#### *Global carbon considerations:*

The endemic high fuel situation in interior western forests has made it increasingly difficult to suppress fires during the last decade. As a result, fires have become larger, more extreme, more difficult to control and more environmentally damaging since the late 1980s. More lives, property, timber and soils have been at higher risk than ever before. The costs of this situation are adding up, and likely to continue doing so (Clark and Sampson 1995, Sampson and Clark 1995). Rather than a natural and positive process in the development of ecosystems, fires can become a significant threat to the soils and biological systems of fuel laden forests (Harvey 1994a,c). Western interior forests were a substantial and globally significant carbon sink prior to the early 1980s. However, wildfires have released more carbon than sequestered for most of the last decade. So, regional forest health and carbon cycling problems now have global ramifications (Sampson and Clark 1995, Harvey 1994b).

#### Traditional Slash Treatment and the Need for Wood

Where creation of mineral soil seedbeds have been important for reliable regeneration, especially where woody residue accumulations have been high, use of windrow- or pile-and-burn methods of slash disposal have often been the management options of choice (Gutzwiler 1976). Although we are increasingly aware of the importance of decomposing slash to forest ecosystems (Harvey 1994a, Harmon *et al.* 1986, Harvey *et al.* 1979), low impact broadcast burning methodologies are frequently unreliable and expensive. So, despite a potential for high soil damage, piling or windrowing and burning may be the only effective short term methods available that comply with 5 year reforestation requirements. It may also help comply with regulations concerning wildfire hazard abatement and the requirement to prevent accumulating slash from becoming inoculum sources or brood sites for pathogen or insect pests (Fellin 1980, Hubert 1920), especially where slash accumulations are high. Alternatively, it may take 30 years, or more, for fuels in slash piles to be neutralized by biological decomposition (Wagener and Offord 1972) and 300 years, or more, for large logs to decompose (Grier 1978).

Unfortunately, because of soil damage from burning variously piled fuel or damage from excessive soil scarification and/or compaction between piles or windrows, we have observed many cases where sites so treated show good, sustained performance for regeneration only in narrow bands surrounding the variously concentrated fuels. Therefore, methods to avoid the necessity for a seedbed (i.e., planting) or improving early debris dispersal by partial piling (Harvey *et al.* 1979) have been recommended. Enhancing decomposition rates of assorted, scattered slash, through improved invertebrate and microbial action, could also facilitate the use of low impact site preparation methodology while reducing probability for soil damage.

#### Effective Environments for Biological Decomposition

Decomposition is an ongoing, ever-present process in both living and dead woody materials (Lowell *et al.* 1992, Wagener and Offord 1972, Buchanan 1940). A myriad of microorganisms, including auto- and heterotrophic fungi, bacteria, streptomycetes, protozoa and invertebrates, individually and/or collectively, contribute much to the decay process. Climatic weathering and interactions of the substrates with existing flora and fauna are critical (Torgerson and Bull 1995, Moldenke and Lattin 1990, Edmonds and Eglitis 1989).

*End products of decay:*

There are two major types of decay in woody plants, white- and brown-rot. Typically, white-rot fungi depolymerize carbohydrates and lignin at somewhat similar rates. Brown-rot fungi depolymerize carbohydrates and leave the lignin essentially unchanged (Highley and Kirk 1979, Highley *et al.* 1979, see also these proceedings). There are indications that the extractive content of heartwood, particularly in conifer wood (live or dead), exerts a limiting or selective influence on the activities of both brown- and white-rot fungi (Pearce 1996, Levy 1979). The end products are a function of the interaction between lignin-type, temperature-moisture regime, pH and associated decay organisms (Highley and Kirk 1979). In the interior region of the western United States, the principal decay process for large dimensional, dead, coniferous woody materials is of the brown-rot type (Larsen *et al.* 1980) which is typical of conifer ecosystems (Gilbertson 1981).

The products from these two decay processes function quite differently in forest ecosystems. Brown-rot end products are rich in nutrients and water and in some situations can substitute for forest humus (Ponge *et al.* 1998, Larsen *et al.* 1980). They are also very persistent and form unique deposits in and on forest soils (or streams) that support a number of highly specific functions (Ponge *et al.* 1998, Harmon *et al.* 1986, Harvey 1994a, Larsen *et al.* 1980). In contrast, white-rot end products do not tend to be rich in resources, are rapidly incorporated into soil humus and function primarily as such (Boddy 1991, Hintikka 1970, see also these proceedings).

*Moisture and temperature requirements:*

Moisture and temperature regimes are the primary controlling factors for microbial actions driving wood decay processes (Edmonds 1990, Erickson *et al.* 1985). The effects of both are critical to the survival of primary fungal decomposers, especially at two critical phases of their life-cycles, 1) the spore germination-colonization phase and 2) the vegetative-colonization and growth phase. Requirements are not the same for these two phases! Spore germination, followed by substrate colonization, operates within much narrower limits than the colonizing vegetative growth phase of soil inhabiting fungi.

Most decay fungi are mesophiles, unable to grow vegetatively above 40°C. They usually have temperature optima between 25-30°C. Jensen (1967) indicated that minor temperature fluctuations stimulate growth. For many fungi, minimum temperatures for growth are below 0°C (Pechmann 1966). Many wood decay fungi can be expected to extend their vegetative thallus to a considerable degree during the winter. Additionally, exposure to cold stimulates growth when temperatures do become optimal (Pechmann 1966).

Temperature extremes and moisture deficits have been reported as decay limiting by Kimmey (1955), Childs and Clark (1953), Buchanan (1940) and Hubert (1920), among others. Lohman (1965) indicated that unfavorable temperature-moisture regimes were the principal limiting factors to the onset and continuation of decay in lodgepole pine (*Pinus contorta* Dougl.) slash. He reported that temperatures in the upper 5 cm of slash pieces favored heat-tolerant fungi. Aho (1974) reported that few heat-tolerant fungi are found in the middle and lower portions of slash piles, where decay is most active.

Moisture extremes can also limit the rates of wood decay (Yoneda 1980). Pechmann *et al.* (1967), reported that substrates with moisture contents below 30 or above 120 percent were not colonized readily by decay fungi. Ethridge (1958) noted that moisture content of heartwood is dependent on species and site and is generally less than that of sapwood. He also noted that even minor changes in moisture had significant effects on decay rates. Wood in close proximity to or in contact with soil readily absorbs moisture and nutrients from it. Substrates in such a location generally decay much faster than variously suspended material (Edmonds *et al.* 1986, Erickson *et al.* 1985, Levy 1979, Aho 1974). Other factors likely to affect moisture in woody materials include shading, aspect, elevation, compaction, stratification, amount of soil organic horizons and anything else that

influences microsite moisture/temperature. Conditions under which wood was formed (e.g., bark thickness, sapwood/heartwood areas and ratios, diameter, growth rate, etc. [Lowell *et al.* 1992, Aho and Cahill 1984]) can also have significant effects on moisture content and decomposition.

*Forest structure and proximity to soil:*

Obviously, manipulation of above-ground forest structure to control temperature and moisture in woody debris, through shading and/or regulating air movement, has potential to increase base decomposition rates, as does regulating slash species, diameters, lengths, quantities and arrangements. The latter improves proximity of slash to the soil surface which will enhance the environment for decomposition. It can also improve conditions for rapid colonization of slash by soil-borne decomposers (Bollen 1974). Since fungi penetrate along the grain of wood much faster than across it (Levy 1979), frequent sectioning of long pieces will improve accessibility of the materials to fungal action.

*Stump treatment and decomposition:*

There has been increasing interest in encouraging rapid colonization and decomposition of conifer stumps with aggressive saprophytic decay fungi as a means of biological control for root pathogens (Rayner 1978). Considerable success in preventing or inhibiting stump invasion and decomposition by *Heterobasidion annosum* Fr. has been achieved through artificial inoculations of stump surfaces immediately after harvest with several fungi, most notably with *Phlebiopsis gigantea* (Fr.:Fr.) Jul., *Hirschioporus abietinus* (Fr.) Donk. and *Resinicium bicolor* (Alb. et Schw.: Fr.) Parm. (Holmer and Stenlid 1993, Negrutsky 1983). There has also been some success in discouraging development of *Armillaria* sp. in pine stumps by inoculating with *Ganoderma*, *Laccaria*, and *Hypholoma* (all white-rotters), among others (Gallet *et al.* 1993, Pearce and Malajczuk 1990). Chemical treatments of the stumps can either enhance or impair this process (Rayner 1978).

These successes indicate artificial inoculations of stump tissues have promise for providing rapid colonization and aggressive decay in this type of forest debris, irrespective of any potential for control of pathogens. It also suggests the possibility that these or other organisms may work with other large woody materials as well.

*Chemical treatment of slash to enhance decomposition:*

Lack of nitrogen is one of the primary factors governing rates of invasion and decomposition of woody materials (Cowling and Merrill 1966, Bollen and Glennie 1961). Infusing stem sections with nitrogen can greatly enhance decomposition rates under laboratory conditions (Merrill and Cowling 1965). Thus, it follows that applying nutrients (fertilizers, sludge, fire retardants, etc. [Bollen 1974]) to woody litter might bring about more rapid decomposition in the forest. However, historic attempts to apply nutrients, with or without added fungal inoculum, have not been encouraging with either chips or intact woody litter (e.g., Bollen and Glennie 1961, Lohman 1959). Sufficient penetration of nutrients into the substrates is apparently a problem, as are high application rates where off-site movement can easily occur, with either chips or slash (Bollen 1974). Direct applications of several nutrients to the forest floor can induce fruiting of some fungi in soil litter and humus (e.g., see Sagara and Hamada 1965), but it is not clear whether such treatments can enhance decomposition rates without causing unwanted offsite movement or undesirable side-effects.

*Converting slash to chips for enhancing decomposition:*

There has been considerable interest in the use of chips, including sawdust, as a means of dealing with excess or non-merchantable woody residue (fuel), or as a site amelioration treatment, since at least the early 1960s (Bensen 1982, Allison 1965, Bollen and Glennie 1961). However, leaving slash on site in the form of chips or sawdust to accelerate biological disposal has not worked well. The stubborn persistence of sawdust piles at old mill sites serve as graphic examples. Also, if

chips or sawdust are incorporated into the soil, there is an immediate immobilization of all available nitrogen and phosphorous to support the resulting microbial decomposition of the chips. Good for decomposition of the wood but not for growth of vegetation (Allison 1965, Bollen and Glennie 1961).

In our experience, rapid decomposition of chips on or in soil is also short-lived. They soon absorb an excess of moisture and decomposition is slowed. Decomposition soon becomes driven by bacteria and soft rot fungi! When placed uniformly on the soil surface as a shallow layer, chips act as an insulator insuring cool temperatures, along with limited oxygen, as the chips absorb moisture. On sites we examined near Dubois, Wyoming in the late 1970s at approx. 3,000 m elevation, where a uniform layer of chips (ca. 15-20 cm) was returned to the site, soils were still frozen under the chip layer in early August (“Styrofoam effect”)! Further, moisture collecting in low spots had visible brown discoloration from wood leachates (“extractive effect”) even five years after the treatment. Additionally, after bleaching in the sun, these chips provided a highly efficient reflective surface.

Lodgepole pine seedlings planted in this treatment could not produce root systems in the cold soils, were killed directly by water soluble phenolic toxins or suffered extensive cambium damage from reflected sunlight. Not a very successful regeneration approach in a cold, high ultra-violet environment! On the other hand, non-symbiotic nitrogen fixation rates in the chips, particularly in piles, were some of the highest that we have measured (Jurgensen *et al.* 1979).

Although these results were not encouraging from the standpoint of any practical application for forest residue reduction, the high levels of nitrogen fixation were encouraging. Also, information was then available indicating that mixed communities of fungi or fungi in association with other organisms, including heterotrophic bacterial nitrogen-fixers, might accelerate the decomposition process (Aho 1974). Shortly thereafter, experiments on inoculations of chip piles with pure and mixed cultures of fungal decomposers, and various bacteria and yeasts, were carried out by Blanchette and Shaw (1978a,b) at Washington State University in Pullman. Results of these experiments were encouraging, showing substantial increases in early chip pile decay rates with inoculations (up to 40% wt. loss compared to less than 1% for controls), especially with mixed culture inoculations (Blanchette and Shaw 1978a).

Following these leads, we initiated a small study in 1995, in cooperation with Dr. R. Powers (PSW-Redding, CA). This study is located adjacent to the University of California's Blodgett Experimental Forest at approximately 1,400 m in a mixed conifer stand near Placerville, CA. Small, elongated chip piles (2mx1mx25m, not to exceed 30% soil coverage to avoid the styrofoam~ effect and to minimize problems with the “extractive” effect) were inoculated with pure cultures of several aggressive decomposer isolates available from the Forest Products Lab collection, including *Postia placenta* (Fr.) M. Lars. et Lomb., a brown rotter which had proven itself in Blanchette and Shaws (1978a) work. It was assumed that the endemic microbial flora would provide helper organisms if required. Despite several inoculation attempts, the inoculants were not able to capture a significant portion of the substrate available and at this point do not appear to have significantly accelerated decomposition. In this environment, again, accumulation of excess moisture appears to have caused even these small chip piles to become anaerobic, resulting primarily in fermentation (inferred from the strong odor of acetic acid). Back to the drawing board!

In Alberta, Canada, the Northern Forestry Center is currently reexamining the return of mixed aspen and conifer slash to forest sites as layers of chips, with and without the application of external nutrients<sup>1</sup>. Applications of chipped aspen wood are also being evaluated for feeder root effects on residual, suckering aspen stumps (Visser *et al.* 1998). Past attempts at increasing decomposition of wood waste material, including chips, by adding nutrients have not been encouraging (Bollen and Glennie 1961).

<sup>1</sup>Contact Dr. David McNabb, at dhmcnabb@arc.ab.ca. or Doug Maynard, Soil Research Scientist, Can. For. Serv., Northern Forestry Centre, Edmonton, Alberta.

*Redefining chips:*

The current approach to this problem at the Rocky Mountain Research Station in Moscow, ID is to redefine "chips" to include much larger material than would be traditional. Our view of what these would look like can more appropriately be termed "chunks" and include material more the size of golf balls, or even basketballs, rather than coins. That type of material should provide relatively "natural" environments for both white- and brown-rot fungi and maximize colonization surfaces for saprophytic decays, thus discouraging "problematical" pathogens. This substrate size should allow for progressive water leaching of extractives, permit rapid penetration of microbes through end cut conductive tissues and, if in contact with or in proximity to soil surfaces, can provide for protected thermal, nutrient, moisture and inoculum enhanced environments. These chunks should remain moist and relatively intact, even if the site burns (soil protection) but, if appropriately arranged, should drain excess moisture well, providing for gradual export of extractives to the soil. They should not be as quick to accumulate excess moisture as small materials are prone to do and they should be less limiting to longitudinal fungal movement through wood vessels than variously crushed materials.

Several studies will be installed at the Priest River Experimental Forest in northern Idaho, beginning this fall. These will include managing woody debris as the "chunks" described above. They will also include a preharvest rendering of understories into such chunks, and their arrangements on the soil surface, as a means of pretreating (dispersing/reducing) a major source of slash prior to commercial harvesting operations. Targeted stands have forest health problems and high fuel accumulations typical of the region. At this point we are not intending to include artificial inoculations of these materials (logistical limitations) and will be depending on endemic organisms. However, we are hoping to initiate active work in this arena (inoculation) when we see who the major (fungal) players are in the decomposition communities that develop.

#### Wood Decay Fungi as Targets for "Management"

The use of wood inhabiting fungi to ameliorate accumulations of residues, whether in whole-log form, as chips or as "fines", is a process that has seen relatively little work and modest success. It has been documented for the most part by casual observations of the activities of wild-type organisms.

*Small residues:*

With regard to fresh logging slash, primarily in the form of foliage and fine branches, Larsen *et al.* (1981) observed differences between heavily infested and uninfested materials in western Montana by *Aethelia epiphylla* Pers. (one of several "snow molds" common to the region) and concluded that infested material lost much of its biomass and substantial portions of bound nutrients after even a single winter. This suggests rapid downward movement of nutrients into the soil, along with the accompanying reduction in "flash" fuels. It also indicates such fuels will be dispersed rapidly where snow is an effective force for compressing this material onto or in the proximity of the soil. Self pruned branch materials are frequently up to 40% decayed, even before they arrive on the ground (Boddy 1991). For the most part, branches and twigs or small residues are completely decomposed, primarily by white rot fungi, in most forest ecosystems in less than 20 years, often within the first 4 or 5 years (Rayner and Boddy 1988, Aho and Cahill 1984). Fine fuels, although temporarily dangerous as a source of ignition, are a short-term problem.

*Large residues:*

Large branches and logs, in contrast, can remain a fuel problem for perhaps a century or more, especially on sites where decomposition is severely limited (cold, dry). Brown-rot fungi are usually the predominant decomposers of large residues in conifer ecosystems, especially those with developed heartwood (Boddy 1991, Gilbertson 1981, Larsen *et al.* 1980, Levy 1979). This, despite the fact that

brown-rot fungi are very much in the minority, when compared to white-rots, at least in terms of numbers of species available (Boddy 1991, Gilbertson 1981).

In the California trial described above we inoculated conifer wood chips in the small windrows ("simulated" logs) with three aggressive brown rot fungi, e.g. *Gleophyllum seapiarium* (Pers.:Fr.) Murr., *Serpula himantiodes* (Fr.:Fr.) Karst. and *Postia placenta*, at regular intervals along their length. Inoculum form was as aliquots of liquid cultures or well-colonized wood dowels. Subsequent monitoring, through attempts to reisolate, demonstrated low survival rates for the inoculants. However, observations confirmed that other cord-forming basidiomycetes were active, but only in the top-most few centimeters. Deeper in the windrows, the chips were saturated with water and smelled of fermentive activity. Several of the active surface fungi were captured in culture.

In an earlier effort to define the principal decayers in all sizes of residues, in both disturbed and undisturbed stands of the subalpine fir type in northwestern Montana (Larsen *et al.* 1980), approximately 15,000 isolates from on-site woody debris were obtained and identified, in as far as possible. Although not all isolates were basidiomycetes, most were. The principal brown-rot fungi were *Postia placenta* and *Fomitopsis pinicola* (Sw.:Fr.) Karst. It should be noted that despite the frequent isolation of *Postia*, occurrences of fruiting bodies of this genus were extremely rare. Presence of fruiting bodies is often not a good indicator of relative decay activities (see also Buchanan, 1940). White-rot fungi were also common, the most frequently encountered was *Acanthophyseum lividocoeruleum* (Karst.) Pouz., but in total they occurred far less often than the brown-rotters cited above.

Some other fungi that can be considered good candidates ("targets") for manipulation to accelerate brown rot decomposition of woody debris are *Neolentinus lepideus* (Fr.:Fr.) Redh. et Ginns., *Antrodia carbonica* (Overh.) Ryv. et Gilbsn., *Fomitopsis cajanderi* (Karst.) Kotl. et Pouz., and several species of the genus *Pholiota*. Many others, both brown- and white-rotters, have been mentioned in the literature available regarding the decomposition of logging slash, and variously windthrown, insect or fire-killed timber, particularly in western ecosystems (e.g., Lowell *et al.* 1992, Edmonds and Eglitis 1989, Erickson *et al.* 1985, Aho and Cahill 1984, Wagener and Offord 1972, Wright and Harvey 1967, Kimmey 1955, Buchanan 1940, and others).

Although brown-rot fungi have many advantages in conifer ecosystems (Boddy 1991, Gilbertson 1981, Larsen *et al.* 1980), we should not overlook the potential of white-rot fungi as slash decomposers, especially since they have shown promise with conifer stumps and sapwood (Edmonds 1990, Holmer and Stenlid 1993, Pearce and Malajczuk 1990). Our isolation work in northwestern Montana indicated that the undersides of 4-6" sized slash in contact with the soil surface were often colonized by white-rot fungi, while the exposed, upper sides were usually colonized exclusively by brown-rot fungi only three years after harvesting.

#### *Assessment by decay type:*

Any discussion with regard to fungi targeted as potentially useful for inoculation of slash, or for manipulating microenvironments to encourage activities of specific natural populations, is necessarily generalized and, at this point speculative. But, there is enough information on the ecology of several, including both white- and brown-rot fungi, to indicate fertile areas for investigation of specific organisms and environments that could lead to significant progress in accelerating biological decomposition of excess fuel. Early capture of substrates will be critical for introduced white rotters to establish themselves effectively, especially in large materials (Rayner and Boddy 1988, Rayner and Todd 1979). Our observations suggest, however, that brown-rotters most often overwhelm white-rot fungi in problematic interior ecosystems, if the captive substrates and environments are suitable. Thus, the environmental requirements of organisms like *Postia placenta* and *Fomitopsis pinicola*, among others, especially in natural substrates and ecosystems, needs attention.

### Prognosis

Considering the lessons learned, it is probable that intelligent break-up of and physical arrangements for slash in forest ecosystems, with or without supplemental inoculations, can be helpful in accelerating decomposition and reducing the fire hazard of accumulating woody debris in appropriately managed forests. Thus, it seems probable that significant offsets can be achieved, particularly in moderate ecosystems. Further, it also seems probable that harnessing specific fungi (perhaps different ones [or mixes] with different environments and substrates) for aiding this process has considerable potential. The promise shown by *Postia placenta* in chips, with or without "helper" organisms (Blanchette 1978a), its widespread occurrence in natural forest residues (Larsen et al. 1980) and at least occasional operation as a heart rot (Highley and Kirk 1979) serves as a specific example of a potent, perhaps manageable force in the carbon cycle of western forests.

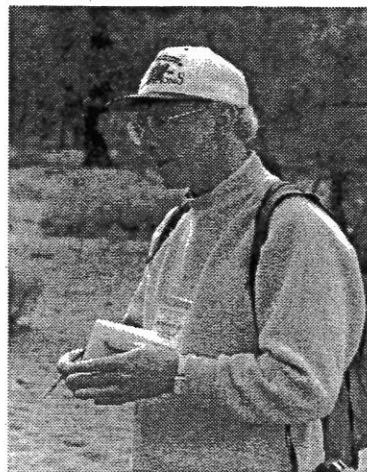
### Literature Cited

- Aho, P.E. 1974. Decay. pp Q1-Q17, In: Cramer, O.P. (Tech. ed.), Gen. Tech. Rep. PNW-24, Environmental effects of forest residues management in the Pacific Northwest. USDA, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland:OR.
- Aho, P.E. and M. Cahill. 1984. Deterioration rates of blown down timber and potential problems associated with product recovery. Gen. Tech. Rep. PNW-167, USDA, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland:OR, 11pp.
- Allison, F.E. 1965. Decomposition of wood and bark sawdusts in soil, nitrogen requirements, and effects on plants. Tech. Bull. 1332, USDA, Agricultural Research Service, Washington, D.C., 58 pp.
- Benson, R.E. 1982. Management consequences of alternative harvesting and residue treatment practices-lodgepole pine. GTR-INT-132, USDA, Forest Service, Intermountain Forest and Range Experiment Station, Ogden:UT, 58 pp.
- Blanchette, R.A. and C.G. Shaw. 1978a. Associations among bacteria, yeasts, and basidiomycetes during wood decay. *Phytopathology* 68:631-637.
- Blanchette, R.A. and C.G. Shaw. 1978b. Management of forest residues for rapid decay. *Can. J. Bot.* 56:2904-2909.
- Boddy, L. 1991. Importance of wood decay fungi in forest ecosystems. pp. 507-540. In: Arora, D.K., et al. (eds.), Handbook of Applied Mycology, Vol. I: Soil and Plants, Marcel Dekker, Inc., New York, NY. 720 pp.
- Bollen, W.B. 1974. Soil microbes. pp. B1-B41, In: Cramer, O.P. (Tech. ed.), Gen. Tech. Rep. PNW-24, Environmental effects of forest residues management in the Pacific Northwest. USDA, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland:OR.
- Bollen, W.B. and D.W. Glennie. 1961. Sawdust, bark and other wood wastes for soil conditioning and mulching. *Forest Prod. J.*, Jan., pp. 38-46.
- Buchanan, T.S. 1940. Fungi in wind-thrown northwest conifers. *J. Forest.* 38:276-281.
- Childs, T.W., and J.W. Clark. 1953. Decay of windthrown timber in western Washington and northwestern Oregon. USDA, Forest Path. Spec. Release 40, Washington D.C., 20 pp.
- Clark, L.R. and R.N. Sampson. 1995. Forest ecosystem health in the Inland West: a science and policy reader. American Forests, Forest Policy Center, Washington D.C., 37 pp.
- Cowling, E.B. and W. Merrill. 1966. Nitrogen in wood and its role in wood deterioration. *Can. J. Bot.* 44:1539-1554.

- Edmonds, R.L. 1990. Organic matter decomposition in western United States forests. pp. 118-128, In: Proceedings-Management and productivity of western-montane forest soils. Harvey, A.E. and Neuenschwander, L.F. (compilrs.), GTR-INT-280, USDA, Forest Service, Intermountain Research Station, Ogden:UT, 254 pp.
- Edmonds, R.L. and A. Eglitis. 1989. The role of the Douglas-fir beetle and wood borers in the decomposition of and nutrient release from Douglas-fir logs. *Can. J. Forest. Res.* 19:853-859.
- Edmonds, R.L., D.J. Vogt, D.H. Sandberg and C.H. Driver. 1986. Decomposition of Douglas-fir and red alder wood in clear-cuttings. *Can. J. For. Res.* 16:822-831.
- Erickson, H.E., R.L. Edmonds and C.E. Peterson. 1985. Decomposition of logging residues in Douglas-fir, western hemlock, Pacific silver fir, and ponderosa pine ecosystems. *Can. J. For. Res.* 15:914-921.
- Etheridge, D.E. 1958. The effects of variation in decay of moisture content and rate of growth in subalpine spruce. *Can. J. Bot.* 36:187-206.
- Fellin, D.G. 1980. A review of some interactions between harvesting, residue management, fire and forest insects and diseases. pp. 335-414, In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests. GTR-INT-90, USDA, Forest Service, Intermountain Forest and Range Experiment Station, Ogden:UT, 526 pp.
- Gallet, J.P., B. Lung-Escarmant, P. Bracciano and B. Taris. 1993. Biological control of *Armillaria* root rot (*Armillaria ostoyae*) in pine forests in the south-west of France. Screening *in vitro* of wood decay fungi. pp. 696-711, In: Johansson, M. and J. Stenlid (eds.), Proceedings of the Eighth International Conference on Root and Butt Rots, International Union of Forestry Research Organizations, Swedish University of Agricultural Sciences, Uppsala, Sweden. 778 pp.
- Gilbertson, R.L. 1981. North American wood-rotting fungi that cause brown rots. *Mycotaxon* 12:372-416.
- Grier, C.C. 1978. A *Tsuga heterophylla*-*Picea sitchensis* ecosystem of coastal Oregon: Decomposition and nutrient balances of fallen logs. *Can. J. For. Res.* 8:198-200.
- Gutzwiler, J.R. 1976. Mechanical site preparation for tree planting in the Inland Northwest, pp. 117-142, In: Proceedings, tree planting in the Inland Northwest, Washington State University Extension Service, Pullman, WA.
- Harmon, M.E. *et al.* 1986. Ecology of coarse woody debris in temperate ecosystems. *Adv. Ecol. Res.* 15:133-302.
- Harvey, A.E. 1994a. Integrated roles for insects, diseases and decomposers in fire dominated forests of the Inland Western United States: Past present and future forest health. *J. Sustain. For.* 2:211-220.
- Harvey, A.E. 1994b. Interactions between forest health and the carbon cycle: inland northwestern American and global issues. pp. 86-91, In: Proceedings, Society of American Foresters and the Canadian Institute of Forestry, Anchorage, AK., SAF-95-02, Society of American Foresters, Bethesda, MD: 543 pp.
- Harvey, A.E., J.M. Geist, G.I. McDonald, *et al.* 1994c. Biotic and abiotic processes in east side ecosystems: the effects of management on soil properties, processes, and productivity. Gen. Tech. Rep. PNW-GTR-323, USDA, Forest Service, Pacific Northwest Research Station, Portland, OR. 71 pp.
- Harvey, A.E., M.J. Larsen and M.F. Jurgensen. 1979. Fire-decay: Interactive roles regulating wood accumulation and soil development in the Northern Rocky Mountains. Res. Note INT-263, USDA, Forest Service, Intermountain Forest and Range Experiment Station, Ogden:UT, 4 pp.
- Harvey, A.E., M.J. Larsen and M.F. Jurgensen. 1976. Distribution of ectomycorrhizae in a mature Douglas-fir/larch forest soil in western Montana. *For. Sci.* 25:350-358.
- Highley, T.L. and T.K. Kirk. 1979. Mechanisms of wood decay and the unique features of heartrots. *Phytopathology* 69:1151-1157.

- Highley, T. L., S.S. Bar-Lev, T.K. Kirk and M.J. Larsen. 1979. Influence of O<sub>2</sub> and CO<sub>2</sub> on wood decay fungi in sapwood and heartwood by four heart-rot fungi. *Phytopathology* 69:1151-1157.
- Hintikka, V. 1970. Studies on white-rot humus formed by higher fungi in forest soils. *Comm. Inst. For. Fenn.* 69:1-68.
- Holmer, L. and J. Stenlid. 1993. Biological control of *Heterobasidion annosum* by cord-forming basidiomycetes. pp. 686-692, Johansen, M. and J. Stenlid (eds.), Proceedings of the eighth international conference on root and butt rots, International Union of Forestry Research Organizations, Aug. 9-16, 1993, Wik, Sweden and Haikko, Finland, 778 pp.
- Hubert, E.E. 1920. The disposal of infected slash on timber sale areas in the northwest. *J. For.* 18:34-56.
- Jensen, K.F. 1967. Oxygen and carbon dioxide affect the growth of wood decaying fungi. *Forest Sci.* 13:344-389.
- Jurgensen, M.F., S.F. Arno, A.E. Harvey, M.J. Larsen and R.D. Pfister. 1979. Symbiotic and nonsymbiotic nitrogen fixation in Northern Rocky Mountain forest ecosystems. pp. 294-308, In: Symbiotic nitrogen fixation in the management of temperate forests. Gordon, J.C., et al. (eds.), Oregon State University, Corvallis:OR, 501 pp.
- Kimme, J.W. 1955. Rate of deterioration of fire-killed timber in California. Circular 962, Washington, D.C.: U.S. Department of Agriculture. 22 p.
- Larsen, M.J., A.E. Harvey and M.F. Jurgensen. 1980. Residue decay processes and associated environmental functions in Northern Rocky Mountain forests. pp. 157-194, In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests. GTR-INT-90, USDA, Forest Service, Ogden:UT, 526 pp.
- Larsen, M. J., M. F. Jurgensen, and A. E. Harvey. 1981. *Athelia epiphylla* associated with colonization of subalpine fir foliage under psychrophilic conditions. *Mycologia* 73:1195-1202.
- Levy, J.P. 1979. The place of basidiomycetes in the decay of wood in contact with the ground. pp. 161-178, In: Frankland, J.C. and J.N. Hedger (eds.), Decomposer basidiomycetes: their biology and ecology. Symposium of the British Mycological Society, London: UK, Cambridge University Press, Cambridge, UK, 355 pp.
- Lohman, A.A. 1965. The lethal effect of periodic high temperatures on certain lodgepole pine slash decaying basidiomycetes. *Can. J. Bot.* 43:334-338.
- Lohman, A.A. 1959. Deterioration by decay of lodgepole pine logging slash near Strochan, Alberta. Interim Rep. Canada Agricultural Research Branch, Forest Biology Lab, Calgary, Alberta, Canada.
- Lowell, E.C., S.A. Willits and R.L. Krahmer. 1992. Deterioration of fire-killed and fire-damaged timber in the western United States. PNW-GTR-292, USDA, Forest Service, Pacific Northwest Research Station, Portland:OR, 27 pp.
- Merril, W. and E.B. Cowling. 1965. Effect of variation in nitrogen content of wood on rate of decay. *Phytopathology* 55:1067-1068.
- Moldenke, A.R. and J.D. Lattin. 1990. Dispersal characteristics of old-growth soil arthropods: the potential for loss of diversity and biological function. *Northw. Environ. J.* 6:408-409.
- Negrutsky, S.F. 1983. Wood-destroying fungi--inhibitors of *Fomitopsis annosa* and their use for biological control. pp. 325-331, In: Kile, G.A. (ed.), Proceedings of the Sixth International Conference on Root and Butt Rots of Forest Trees, International Union of Forestry Research Organizations, CAIRO, Melbourne, Australia. 430 pp.
- Olsen, J.S. 1981. Carbon balance in relation to fire regimes. pp. 377-378, In: Mooney, H.A., et al. (coords.), Fire regimes and ecosystem properties. GTR-WO-26, USDA, Forest Service, Washington, D.C.
- Pearce, M.H. and N. Malajczuk. 1990. Inoculation of *Eucalyptus diversicolor* thinning stumps with wood decay fungi for control of *Armillaria luteobubalina*. *Mycol. Res.* 94:32-37.
- Pearce, R.B. 1996. Antimicrobial defenses in the wood of living trees. *New Phytol.* 132:203-233.

- Pechmann, H. Von. 1966. Der einfluss der Temperatur auf das Wachstum van Blavepilzen. *Mat. Org.* 1:237-250.
- Pechmann, H. Von., A. Foess, H. Von. Liese and V. Amer, 1967. Untersuchungen uber die Rotstreifigkeit des fichtenholzes. *Forstwissench. Forsch.* 27:1-12.
- Ponge, J.F., *et al.* 1998. The forest regeneration puzzle: Biological mechanisms in the humus layer and forest vegetation dynamics. *Bioscience.* 48:523-530.
- Rayner, A.D.M. 1978. Internal spread of fungi inoculated into hardwood stumps. *New Phytol.* 82:505-517.
- Rayner, A.D.M. and L. Boddy, 1988. Fungal communities in the decay of wood. *Adv. Microb. Ecol.* 10:115-166.
- Rayner, A.D.M. and N.K. Todd. 1979. Population and community structure and dynamics of fungi in wood. *Adv. Bot. Res.* 7:333-420.
- Sagara, N. and M. Hamada. 1965. Responses of higher fungi to some chemical treatments of forest ground. *Trans. Mycol. Soc. Japan* 6:72-74.
- Sampson, N.R. and L.R. Clark. 1995. Wildfire and carbon emissions: a policy modeling approach. American Forests, Forest Policy Center, Washington D.C., 23 pp.
- Swezy, D.M. and J.K. Agee. 1991. Prescribed-fire effects on fine-root and tree mortality in old-growth ponderosa pine. *Can. J. For. Res.* 21:626-634.
- Torgerson, T. and E. Bull. 1995. Down logs as habitat for forest-dwelling ants--the primary prey of pileated woodpeckers in northeastern Oregon. *Northw. Sci.* 69:294-303.
- Visser, S., D. Maynard, and R.M. Danielson. 1998. Response of ecto- and arbuscular- mycorrhizal fungi to clear-cutting and the application of chipped aspen wood in a mixedwood site in Alberta, Canada. *Appl. Soil Ecol.* 7:257-269.
- Wagener, W.W. and H.R. Offord. 1972. Logging slash: it's breakdown and decay at two forests in northern California. Res. Pap. PSW-83, USDA, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkely:CA, 11 pp.
- Wright, K.H. and G.M. Harvey. 1967. The deterioration of beetle-killed Douglas-fir in western Oregon and Washington. Res. Pap. PNW-50, USDA, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland:OR, 20 pp.
- Yoneda, T. 1980. Studies on the rate of decay of wood litter on the forest floor. III. Effect of moisture content on CO<sub>2</sub> evolution from decaying wood. *Jap. J. Ecol.* 30:55-62.
- Zackrisson, O., M.C. Nilsson and D.A. Wardle. 1996. Key ecological function of charcoal from wildfire in the Boreal forest. *Oikos* 77:10-19.



Bob Edmonds

## Brown versus white rot in forest ecosystems: Does it matter?

Robert L. Edmonds and Michelle Isaacson  
 College of Forest Resources  
 University of Washington  
 Seattle, WA

### Introduction

There has been considerable recent interest in the role of coarse woody debris (CWD) in forest ecosystems (Kohm and Franklin 1997). In the Pacific Northwest CWD is arbitrarily defined as logs and standing dead trees (snags) greater than 15 cm in diameter (Harmon et al. 1986), although there is a considerable amount of material on the forest floor that is smaller than this. In terrestrial ecosystems CWD functions as a site for tree and shrub regeneration, habitat for wildlife, a long-term source of soil organic, a source of biodiversity for fungi, bacteria and invertebrates, and a site for N fixation (Franklin et al. 1989, Edmonds and Lebo 1998). In addition, it stabilizes sites against erosion. In streams and rivers logs function to prevent stream bed and bank erosion and provide dams for creating pool and riffle habitats for fish. CWD used to be removed during forest harvesting operations, but it is now being retained. In fact millions of dollars have been spent placing logs in streams. Many are tied down with cables so they won't move.

A Douglas-fir (*Pseudotsuga menziesii*) tree in an old-growth forest in the Pacific Northwest might live to be 600 years-old, but once it dies it could have a further "life" as a log on the forest floor for another 600 years (Dr. Jerry Franklin, College of Forest Resources, University of Washington, personal communication). Thus the functional life of a Douglas-fir tree could be 1200 years. This second life, however, is related to how long it takes the log to decay and it can only last for 600 years if it is rotted by brown rot fungi. If it is rotted by the other major group of fungi, the white rotters, its life will be much shorter. The structural chemicals in wood are hemicellulose, cellulose and lignin. Brown rot fungi decay the cellulose and hemicellulose leaving the lignin, which decays very slowly. White rot fungi, on the other hand, decay cellulose, hemicellulose and lignin, resulting in a more complete decomposition process (Kaarik 1974). Thus CWD with white rot will have a shorter residence time than CWD with brown rot.

Decay also occurs in the wood in living trees. Obviously this causes timber losses, but decay in living trees also provides habitat for certain species of wildlife, e.g., cavity nesting birds, bats and bears (Bull et al. 1997). Here the type of and rate of decay is also important. In fact, live trees are now being inoculated with wood decay fungi to hasten habitat development. These trees may function for a longer time period than snags.

Many of the common root and butt rot organisms in Pacific Northwest forests are white rotters (Allen et al. 1996). For example, *Phellinus weirii*, *Heterobasidion annosum*, *Armillaria* spp., and *Perenniporia subacida*. Only a few are brown rotters, e.g., *Phaeolus schweinitzii*. Many of the bole decay organisms are brown rotters (Hennon 1995), but most seem to live on large diameter boles. Some occur on living trees, some occur on both living and dead trees, while the ecological niche for others is mostly dead wood (e.g., *Fomitopsis pinicola*). Forest management has changed the proportions of these organisms in Pacific Northwest ecosystems because of changes in substrates and the production of smaller diameter trees. Hollow logs are an example of an important structural category of CWD. However, logs do not become hollow on the ground because they result from the action of heart rot fungi while they are still alive (Bull et al. 1997). Hollow logs will rarely develop in smaller diameter trees.

Because so much CWD has been removed from managed forests and the fact that tree sizes in managed forests are much smaller than those in old-growth forests it has been difficult to exactly recreate the "old-growth environment" in managed stands. Thus, experiments are now being conducted, particularly by USDA Forest Service scientists, to group small diameter wood into structures resembling and hopefully functioning as large logs, particularly for small mammals and salamanders. Stumps are also components of managed forests that do not exist in natural forests and we know very little about their decomposition or functional roles.

As mentioned before CWD is also important in the aquatic and riparian environment. Red alder is the dominant tree in riparian areas in areas that have been harvested and it is known that red alder logs decompose much more rapidly than conifer logs in streams. However, there is little riparian conifer wood available for placement in streams. Conversion of riparian alder stands to conifer stands has been proposed, and although some conversion has started, it will take a long time before any large logs are available for streams. Small diameter conifer logs tied together in a structure are now being placed in streams.

If small diameter wood is to function properly it is important to understand its decay dynamics, especially with respect to brown and white rots. The objectives of our research were to: (1) determine the relationship between conifer log diameter and the type of decay, i.e., brown or white rot, and (2) answer the question posed by the title -- brown versus white rot in forest ecosystems: does it matter?

## Methods

### Study sites

Four study sites were located in western Oregon and Washington. The first site was located in Seward Park, in Seattle, Washington in a second-growth stand dominated by Douglas-fir with Pacific madrone (*Arbutus menziesii*) and western redcedar (*Thuja plicata*) as understory trees. The second site was also in Seattle at Discovery Park. It was in a second-growth forest dominated by hardwoods, mainly big leaf maple (*Acer macrophyllum*) and red alder (*Alnus rubra*), but Douglas-fir and western redcedar were also present. The third site was located on Tiger Mountain, near Issaquah, Washington. It was a second growth forest dominated by Douglas-fir. The fourth site was in the Siskiyou Mountains of southern Oregon. It was an old-growth stand including Douglas-fir, big leaf maple, Port-Orford-cedar (*Chamaecyparis lawsoniana*) and red alder.

### Measurements

The lengths and diameters at the base end of a total of 146 conifer logs were determined. A few stumps and snags were also measured. Logs were classified in four diameter classes 10-20, 21-30, 31-40 and >41 cm. Each log was classified as having white or brown rot with the dominant rot type being used. Some logs were classified with both types of rot. Logs represented a variety of decay classes.

## Results and Discussion

Table 1 shows the number of logs in each study location relative to diameter class and the type of decay. A similar number of logs were examined at each of the study sites; 43, 36,

Table 1. Number of conifer logs in four study locations in western Oregon and Washington containing white and brown rot or both in relation to diameter class and length ranges.

Study site	Diameter class (cm)	Decay type			Length range (cm)
		White	Brown	Both	
Seward Park, Seattle, WA	10-20	14	0	0	166-610
	21-30	6	4	2	24-780
	31-40	4	4	0	80-1098
	>41	4	5	0	73-762
	Total	28	13	2	
Discovery Park, WA	10-20	9	6	0	52-365
	21-30	4	8	0	46-2134
	31-40	4	4	0	80-1889
	>41	0	1	0	1219
	Total	17	19	0	
Tiger Mt, WA	10-20	10	6	0	46-1158
	21-30	12	5	0	90-1800
	31-40	0	1	0	805
	>41	0	2	0	122-3048
	Total	22	13	0	
Siskiyou Mts, WA	10-20	7	4	0	85-1588
	21-30	2	1	0	95-762
	31-40	0	6	0	217-2088
	>41	3	8	0	122-1110
	Total	12	21	0	

35, and 33 logs at Seward Park, Discovery Park, Tiger Mountain and the Siskiyou Mountains. There were more white rotted logs than brown rotted logs at the Seward Park and Tiger Mountain sites, but the opposite pattern occurred at Discovery Park and in the Siskiyou. In general, however, the two smallest diameter classes had the greatest number of white rotted logs at all sites, while the brown rotted logs were more evenly distributed across diameter classes. This is well illustrated in Table 2 which shows the total of all the logs at the four study sites; 81 percent of all the white rotted logs were in the 10-20 and 21-30 cm diameter classes, but only 52 percent of the brown rotted logs were in these classes. In general, logs tended to be dominated by one type of rot or the other, although two of the logs in the 21-30 cm class at Seward Park had both types of rot well represented (Table 1). Log lengths ranged from 24-3048 cm. However, there was no strong relationship between log diameter and log length as we expected.

Table 2. Total numbers and percentages of white and brown rotted stumps at the four study sites.

Diameter class (cm)	Numbers of logs			Percentage of logs		
	Decay type			Decay type		
	White	Brown	Both	White	Brown	Both
10-20	40	16	0	51	25	0
21-30	24	18	2	30	27	100
31-40	8	15	0	10	23	0
>41	7	16	0	9	25	0
Total	79	65	2	100	100	100

The three stumps we examined ranged in diameter from 36 to 112 cm; two had brown rot and one had white. We also examined three snags ranging in diameter from 25 to 45 cm; two had brown rot and one had both.

Table 3 shows that 71 percent of the logs in the smallest diameter class were decayed by white rot organisms while only 29 percent were decayed by brown rot organisms. The opposite pattern occurred in the largest diameter class. It appears that logs greater than approximately 30 cm in diameter are rotted predominantly by brown fungi, while logs less than 30 cm in diameter are rotted by predominantly white rot fungi (Table 3).

Table 3. Percentage of white and brown rotted logs in each diameter class

Diameter class (cm)	Decay type		
	White	Brown	Total
10-20	71	29	100
21-30	57	43	100
31-40	35	65	100
>41	30	70	100

This is no doubt due to changes in wood chemistry, the sapwood/heartwood ratio, and surface to volume ratios. Insects are also important in the wood decay process. Larger diameter wood may favor wood boring insects which could carry brown rot fungi (Edmonds and Eglitis 1989). In terms of biodiversity brown rot fungi tend to harbor a higher numbers and species of invertebrates than white rotted wood perhaps because of a more favorable moisture environment (Edmonds and Marra in press).

The list of fungi recorded on CWD in the study is shown in Table 4. Most are white rot fungi. Root disease organisms, such as Phellinus weirii and Armillaria spp. occupy stumps and lower bole of living trees, but usually do not exploit the bole after the tree dies. The dominant brown rotter was Fomitopsis pinicola. Is this a keystone or indicator species for the functioning of ecosystems and in maintaining brown rotted logs? What will happen if its population is reduced and white rotted wood becomes predominant? We know that white rotted wood does not contribute as much to soil organic matter as brown rotted wood (Hennon 1995).

It appears that the proportion of brown rot and white rot in CWD forest ecosystems is important to their functioning. If we want CWD to function in managed stands as it does in old-growth stands then we must be sure that wood is at least 30 cm in diameter. Smaller diameter wood bundled together to simulate a large log will not function in the same way as a large log in terrestrial or aquatic environments.

---

Table 4. Fungi found on coarse woody debris in this study.

---

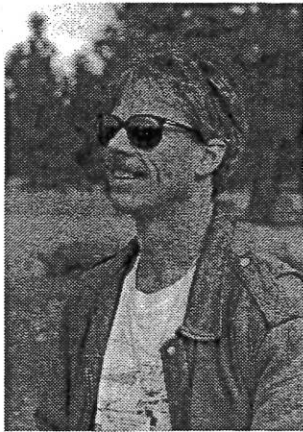
Taxa	Type of decay caused
<u>Armillaria</u> spp.	white
<u>Chondrostereum purpureum</u>	white
<u>Cryptoporus volvatus</u>	white
<u>Fomitopsis officinalis</u>	brown
<u>Fomitopsis pinicola</u>	brown
<u>Ganoderma applanatum</u>	white
<u>Ganoderma oregonense</u>	white
<u>Heterobasidion annosum</u>	white
<u>Hirschioporus abietinus</u>	white
<u>Laetiporus sulphureus</u>	white
<u>Perenniporia subacida</u>	white
<u>Phellinus weirii</u>	white
<u>Stereum</u> spp.	white

---

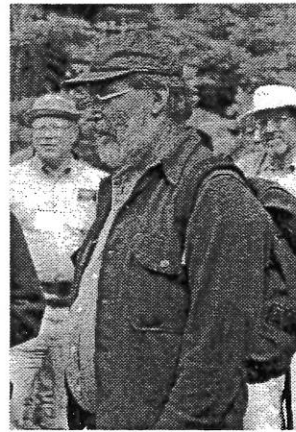
#### References

- Allen, E., D. Morrison, and G. Wallis. 1996. Common Tree Diseases of British Columbia. Canadian Forestry Service, Pacific Forestry Centre, Victoria, BC, Canada.
- Bull, E. L., C. G. Parks, and T. R. Torgesen. 1997. Trees and wildlife important to wildlife in the interior Columbia River basin. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. Gen. Tech. Rep. PNW-GTR-391.
- Edmonds, R. L. and A. Eglitis. 1989. The role of the Douglas-fir beetle and wood borers in the decomposition of and nutrient release from Douglas-fir logs. Can. J. For. Res. 19: 853-859.

- Edmonds, R. L. and D. S. Lebo. 1998. Diversity, production, and nutrient dynamics of fungal sporocarps on logs in an old-growth temperate rain forest, Olympic National Park, Washington. *Can. J. For. Res.* 665-673.
- Edmonds, R. L. and J. L. Marra. Decomposition of woody material: nutrient dynamics, invertebrate/fungi relationships and management in northwest forests. In *Proceedings of Soil Organism Symposium*. USDA Forest Service, Pacific Northwest Experiment Station, Portland, OR. Gen. Tech. Rep. (in press).
- Franklin, J.F., D. A. Perry, T. D. Schowalter, M. E. Harmon, A. McKee and T. A. Spies. 1989. Importance of ecological diversity in maintaining long-term site productivity. p 82-97. In D. A. Perry, R. Meurisse, B. Thomas, R. Miller, J. Boyle, J. Means, C. R. Perry, and R. F. Powers (editors). *Maintaining the Long-term Productivity of Pacific Northwest Forest Ecosystems*. Timber Press, Portland, OR.
- Harmon, M. E., J. J. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack, Jr. and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. *Adv. Ecol Res.* 15: 1333-302.
- Hennon, P. E. 1995. Are heart rot fungi major factors of disturbance in gap-dynamic forests? *Northwest Science* 69:284-293.
- Kaarik, A. A. 1974. Decomposition of wood. p 129-174 In C. H. Dickinson and G. J. F. Pugh (editors). *Biology of Plant Litter Decomposition*. Vol 1. Academic Press, New York, NY.
- Kohm, K. A. and J. F. Franklin (editors). 1997. *Creating a Forestry for the 21st Century*. Island Press, Washington, D.C.



John Guyon



Mike McWilliams

**PANEL: FOREST DISEASE MODELS: WHO IS USING THEM  
AND WHO IS NOT?**

**Ellen Michaels Goheen - Moderator**

**Summary of Panel Papers**

**Panel:**

**Introduction and Results of WIFDWC Survey.** *Ellen Michaels Goheen*, USDA Forest Service, Southwest Oregon Forest Insect and Disease Technical Center, Medford, Oregon.

**Models for Whom and for What: Overview of the State of the Art.** *Judy Adams*, USDA Forest Service, Forest Health Technology Enterprise Team, and *Robert Havis*, Autometric Service Corporation, Ft Collins, Colorado.

**Douglas-fir Dwarf Mistletoe and Northern Spotted Owl Nesting, Resting, and Foraging Habitat: Using the Dwarf Mistletoe Model to Compare Treatment Alternatives.** *Helen Maffei*, USDA Forest Service, Central Oregon Insect and Disease Area Office, and *Jim Stone*, USDA Forest Service, Deschutes National Forest, Bend, Oregon.

**Looking at the Landscape: Using the Western Root Disease Model in Forest Health Analyses.** *Blakey Lockman*, USDA Forest Service, Missoula Field Office, Missoula, Montana.

**Modeling Ecosystems: How Disease models Link with Other Models and Tools.** *Rich Teck*, USDA Forest Service, Forest Management Service Center, Ft. Collins, Colorado.

The panel was kicked off with a report on the results of the modeling survey conducted during the first few days of the 1998 WIFDWC meeting. Of those attendees responding, 54 percent have been involved in some aspect of disease model development, 83 percent have attended some disease model training, and 14 percent provide training to others on using these models. Forty-two percent of the respondents describe themselves as model users; 58 percent describe themselves as non-users.

Model users are most likely to describe their use as occasional or rare. Frequent users are in the minority. In the last two years, approximately 30 percent of users were actively punching computer keys for less than one week, 14 percent for one to three weeks, 26 percent for three to six weeks, 20 percent for six to eight weeks, and ten percent for more than eight weeks. Users spent approximately one-half of their time working on resource-based modeling questions. In most cases they worked with resource specialists, less frequently they worked with other pathologists, and, in some cases, the user was the sole modeler on the project. Other model use time was devoted to (in order of time spent) preparing for and conducting model-related training sessions, testing the models, "fiddling around with software" to make the models work, and other activities such as reviewing model-related publications. Model users express a mixture of feelings related to their comfort level with the Forest Vegetation Simulator (FVS), the base model for most of the disease models and also with the disease models themselves. Most users feel that the disease models adequately predict disease behavior. They suggest that the reason models are not being used is that the resource specialists do not have the time and that use requires the assistance of a "model-savvy" pathologist. Model users suggest that the situation could be improved by having and using assistance to set up the models, by being given example

exercises to use in training, by continued emphasis on sensitivity analyses, and by production of readable user guides. They also suggest that assistance would be beneficial related to linking the models to other software and in using the internet connections related to modeling. They encourage those who have done analyses that incorporate the disease models to share their techniques and results.

Non-users do not use the disease models essentially because modeling is not considered a part of their job, OR they have not taken the time to learn how to use them and have not installed the models on their computers. Non-users have limited information on accessing the models and on the information required to run the models. Some respondents do not have disease models available for their geographic areas. Only a few of those responding expressed concerns regarding the models' ability to accurately predict disease behavior. Non-users are interested in opportunities to learn how to use the models. Demonstrations at or close to their home units by local pathologists who understand the models is the preferred method for transferring model technology. Demonstrations and workshops within the WIFDWC framework would also be of interest. Some non-users suggest that they just need to set aside some time and "just do it!"

*Judy Adams* and *Bob Havis* with the Forest Health Technology Enterprise Team (FHTET) in Ft. Collins, Colorado provided an overview of the USDA Forest Service's disease modeling efforts. FHTET oversees disease model development and revision and provides assistance with training and technology transfer. FHTET also cooperates with the staff of the Forest Management Service Center, who are charged with development, revision, and training related to FVS.

Recent improvements to the disease/vegetation modeling system include moving models from the internal USDA Forest Service computer system, the Data General, to the PC platform. This has not only made disease modeling available to a much wider user group than USDA Forest Service personnel, it has also streamlined the modeling process considerably. Models and documentation are now readily available from FHTET's internet web site:

<http://www.fs.fed.us/foresthealth/technology/products.html>. Developing a "user-friendly" interface to FVS and the disease models called SUPPOSE has dramatically improved ease of use.

Pathogen models available include the Western Root Disease Model vers. 3.0 which simulates the effects of Armillaria root disease, laminated root rot, or both P-type and S-type Annosus root diseases. A new User's Guide was recently released for this model entitled User's Guide to the Western Root Disease Model, Version 3.0, PSW-GTR-165.

The Dwarf Mistletoe Model exists as a part of FVS. It simulates dwarf mistletoe effects on tree growth and mortality. It also includes a module for dwarf mistletoe spread and intensification that is currently best suited to modeling single-storied stands. Helen Maffei is currently working with FHTET to develop spread and intensification functions that will work well in multi-storied stands.

The White Pine Blister Rust Model has recently been updated based on the recommendations from a workshop facilitated by FHTET in 1991. It is currently in beta test mode in northern Idaho. The model and its User's Guide are expected to be released in 1999.

A demonstration of the Western Root Disease Model concluded Judy and Bob's portion of the panel.

*Jim Stone* presented work that he and *Helen Maffei* have been doing that demonstrates the power of using FVS with the Dwarf Mistletoe Model at the stand level to compare the outcomes from various silvicultural treatments. Their example stand type is composed of predominantly young Douglas-fir with dwarf mistletoe remaining after a recent overstory removal. Certain structural elements are necessary for this stand type to meet Northern Spotted Owl Nesting, Resting, and Foraging habitat in the future. These include specific minimum numbers of trees per acre in larger size classes, stand-level and large tree basal areas, and at least 50 percent canopy cover. The modeling was done to help answer the question "Can we manage lightly to moderately infected trees for brooms along with other desired structural elements?"

Treatment scenarios modeled included 1) no treatment, 2) thinning the stand but ignoring the dwarf mistletoe, and 3) thinning the stand with priority removal of dwarf mistletoe-infected trees. The outcome of this effort was that no treatment might be the best alternative of those tested because habitat requirements were met for two decades eighty years in the future. What was demonstrated was that modeling, including dwarf mistletoe effects was a quick and inexpensive method for making general relative comparisons among management options, including the no treatment alternative. Combined with visual tools available, it helped to communicate treatment effects to those unfamiliar with treatments and terminology.

*Blakey Lockman* described the modeling approaches that the Northern Region of the USDA Forest Service has been using related to several types of landscape-level analyses. Information from root disease permanent plots has been used to build Western Root Disease Model keyword sets specific to habitat type/stand structure classes. These keyword sets have been applied to individual stands across planning areas based on aerial photo interpretation and ground-truthing. Entire watersheds have been modeled using this approach.

FVS and the dwarf mistletoe and western root disease models are being used to examine pathogen and insect successional functions in forest ecosystems. A range of vegetative conditions for a given Forest are stratified and a sample selected. Successional functions associated with insects and pathogens are identified and characterized for those conditions and probability indices are assigned. Historical information is used to classify polygons; past vegetative conditions are then compared to present conditions. FVS with the pathogen extensions is calibrated to reflect the actual changes that have taken place over time. Information obtained from these simulations using the pathogen models is being used to calibrate landscape-level models used in Regionwide analyses.

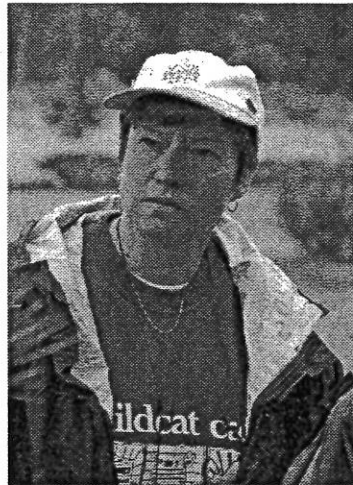
*Rich Teck* concluded the panel presentations with some thoughts on models and modeling in general, and an overview of how the disease models interface with other models and modeling efforts.

Scientists express a wide variety of comfort levels related to modeling. Some individuals will never be comfortable with predictions on vegetation or disease behavior coming from any kind of models. Others who are skeptical of models may be so because they have witnessed inappropriate use of models. It is critical to match the question being asked with the right model. Some models may be so complex that they can never be used to answer simple resource-based questions. However, these complex models may be extremely valuable for identifying research questions. Some simpler models cannot be relied upon for predicting exact outcomes but are extremely powerful for making relative comparisons of different treatment alternatives. Once the assumptions behind the model are known and the appropriate use identified, skeptics may become more comfortable with modeling. It is important that the community of pathologists remain active and involved in pathogen model development.

Model development is currently a very active field. Beside the insect and pathogen models discussed, much emphasis is being placed on developing other disturbance models such as fire models. Tools are being developed to make predictions across landscapes or for entire watersheds. Ties to Geographic Information System data are being incorporated. User-friendly interfaces and portable systems are emphasized.

*Exciting things are happening in the field of pathogen modeling!*

Panel Summary prepared by Ellen Michaels Goheen



Ellen Michaels Goheen



Blakey Lockman and Jim Stone



Judy Adams

## POSTERS

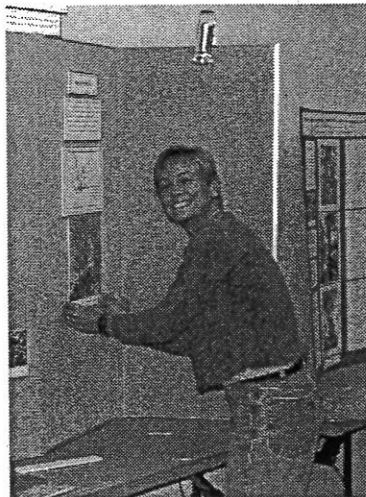
### Dothistroma Needle Blight Of Limber Pine In Montana

Jane E. Taylor  
USDA Forest Service  
Missoula, MT

John W. Schwandt  
USDA Forest Service  
Coeur d' Alene, ID

### ABSTRACT

*Dothistroma septospora* appears to be associated with mortality of *Pinus flexilis* in Montana. Nine monitoring plots have been established at several Montana locations. Mortality has been monitored on four plots on the Lewis and Clark National Forest since 1996 and ranged from 12-45%, with 85% of the mortality attributed to *D. septospora*. The remaining five plots were established in 1998, and mortality data are not yet available. However, on the newly established plots, trees were rated for percent of crown affected by *D. septospora*; 72% of the trees were rated as having 75% or greater of their crown affected. Monitoring of existing plots for defoliation and mortality associated with *D. septospora* will continue into the future, and additional surveying and monitoring may be undertaken if the current outbreak continues or if new areas of infection are discovered.



Jane Taylor

## Screening For Blister Rust Resistance In British Columbia Yields Western White Pine Seed-Orchards

R.S. Hunt and G.D. Jensen  
Pacific Forestry Centre, Victoria, BC

### Introduction

To date, there are only two western white pine seed orchards in British Columbia (BC) - coast and interior. About 90 half-sibs (seedlings) from each of 291 and 216 carefully chosen candidate trees were inoculated from 1987 through 1995 for the coast and interior zones respectively. These candidates were chosen for good growth and putative mature tree resistance. Each annual inoculation takes 6 years before final assessment for resistant traits is determined, thus observations will continue until 2001. Each parent is well-marked in the forest and detailed records of each are located at BC Forest Service District offices.

### Methods

Needle infection spots are counted on each inoculated seedling to produce a family spotting profile. High spotting families usually produce a high incidence of cankering 18 months post-inoculation, followed by mortality. Low spotting families are more difficult to infect and suffer less cankering at 18 months post-inoculation, and have greater survival.

Throughout both zones 21 very low spotting families have been identified. In general interior selections are more spotted than selected low spotting families for the coast. When canker-free seedlings are re-inoculated under severe conditions, by placing them in a diseased currant garden, a few individuals are confirmed to be extremely difficult to infect; these are propagated for seed orchards.

Cankers on some seedlings grow slowly and are not likely to grow down the branch to the stem, or if in the stem, to girdle it. These cankers are subjectively classified into four types: no swelling, constricted, fusiform and gall, with the no swelling type being the most common. To date, these have been identified in 66 interior families, with the incidence equal to or greater than 9% in six families, and identified in 131 coastal families with the incidence in all families less than 9%.

### Results

Forwards selections, i.e., low-spotting seedlings, confirmed by re-inoculation, and slow-canker-growth seedlings and have been cloned for two coastal seed orchards and one interior seed orchard. The interior orchard additionally has selections from Idaho. Backwards selections, i.e., parents producing low spotting, or slow-canker-growth offspring have been cloned for one additional coastal orchard. Since selection is still ongoing, additional good parents and seedlings will be incorporated into the orchards and some existing selections may be culled and replaced by superior ones. Crosses have been made of superior parents and the resulting seed will be used in test plantations.

Seed, from the parents identified as superior, can be collected and used. However, test plantations based on some of these parents confirms that such plantations should be pruned. Seed Production Areas can be produced by culling cankered trees, particularly in areas where low spotting and/or slow-canker-growth parents have been identified.

**Detection of a Chitinase-like Protein in the Roots of Douglas-fir Trees  
Infected with *Armillaria ostoyae* and *Phellinus weirii***

Richard Robinson, Rona Sturrock, Joanne Davidson,  
Abul Ekramoddoullah, and Duncan Morrison  
Canadian Forest Service, Pacific Forestry Centre  
Victoria, B.C.

Current address of R. Robinson:  
Conservation and Land Management, CALMScience Division,  
Manjimup, Western Australia

Root bark extracts of 11- and 25-year-old interior Douglas-fir (*Pseudotsuga menziesii*), naturally infected with *Armillaria ostoyae*, were analyzed for total protein content and separated by SDS-PAGE into individual proteins. The total protein content of root bark tissue adjacent to infected areas was significantly higher than that of healthy tissue, while total protein levels in infected tissues were consistently lower than those of healthy tissue. SDS-PAGE profiles of healthy, infected, and adjacent-to-infected root bark tissues revealed significant differences in their content of a 29.3 kDa protein. When the N-terminal amino acid sequence of the protein was determined it was found to display significant homology to a basic endochitinase. Using a polyclonal antibody raised against the 29.3 kDa putative endochitinase-like protein (ECP), differences in the quantities of the protein in healthy vs *A. ostoyae*-infected roots of 11-year-old and 25-year-old Interior Douglas-fir, were demonstrated. The antibody was then used to screen roots of 24-year-old coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*), artificially inoculated with and colonized by *Phellinus weirii*, for presence of the 29.3kDa protein. The ECP was elicited in root bark of coastal Douglas-fir in response to *P. weirii* infection, although in lower quantities relative to the *A. ostoyae*-interior Douglas-fir pathosystem. The sequence homology of the ECP to a basic chitinase, together with its estimated molecular mass of 29.3 kDa and its increased synthesis in response to two different fungal pathogens, support a possible role for the protein in the general defense strategy of Douglas-fir.



Rich Hunt

**Screening Coastal Douglas-Fir for Resistance to the Laminated Root Rot Pathogen,  
*Phellinus Weirii*: Interim Results**

Rona Sturrock  
Canadian Forest Service,  
Pacific Forestry Centre  
Victoria, B.C.

Alvin Yanchuk and Jack Woods  
Research Branch  
B.C. Ministry of Forests  
Victoria, B.C.

Research was begun in 1995 on variations in response of selected coastal Douglas-fir (Fdc) families to infection by *Phellinus weirii*, a serious root disease pathogen. Using a novel technique developed at the Pacific Forestry Centre (PFC), about 3500 seedlings representing 97 full-sib families in British Columbia's Coastal Douglas-fir Tree Improvement Program were inoculated with two isolates of the fungus (PFC-Pw581 and PFC-Pw583). By August 1997, 27 months after inoculation, approximately 21% of seedlings had been killed by *P. weirii* while another 62% were still alive, although considered successfully inoculated with the fungus. These latter trees were destructively sampled and assessed for evidence of *P. weirii*, root collar swelling and annual height growth. The remaining 17% of living trees were considered not successfully inoculated with the fungus and were reinoculated for assessment at a later date.

Analyses of mortality and genetic data from the 97 families indicate that there are significant differences among families of coastal Douglas-fir in their response to *P. weirii* infection. This is the first reported evidence for genetically-based resistance of coastal Douglas-fir to *P. weirii*. The data also revealed that the two *P. weirii* isolates tested vary in their virulence (a quantitative measure of the amount of disease caused by a pathogen) and aggressiveness (a measure of the rate at which virulence is expressed). Isolate 581 killed more Fdc's and at a faster rate than isolate 583. Swelling at the root collar was a common occurrence among the Fdc's infected and killed by *P. weirii*. Unfortunately, our knowledge of the infection processes of *P. weirii* and associated host responses is limited so at this time we cannot say what swelling signifies. It could be a disease-tolerant or disease-susceptible host response or it could be a generalized host response to injury, with tree survival ultimately determined by other factors.

Future research will include field and laboratory studies with healthy and *P. weirii*-infected juvenile and mature trees of selected Fdc families and inoculation of clonal Fdc with a range of *P. weirii* isolates.



Jerry Beatty and Walt Thies

## Computer Demonstration of Preliminary Work on a Mathematical Description of Root Disease Spread through Root Contact and Fungus Transfer

F. G. Peet, R.S. Hunt, R.N. Sturrock, D.M. Morrison, and M. Cruickshank  
Pacific Forestry Centre, Canadian Forest Service  
Victoria, British Columbia

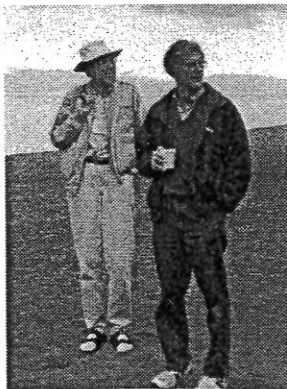
A mathematical description of the spread of *Tomentosus* root disease by root contact is under development. Instead of representing the spread of the disease by a set of expanding circles around a diseased stump, the approach here is to explicitly describe the spreading of the fungus from diseased roots to healthy roots at points of root contact. The resulting tree-to-tree disease spread gives rise to irregularly-shaped patches of disease infestation. These patches more closely resemble irregular disease-caused openings seen in the forest than circles do.

This description of root disease spread assumes that one is dealing with a site which has been clear cut and is to be planted, and that a survey of stump tops has been carried out to determine the density of infested stumps. The computer program which represents the mathematical description of the spread distributes infested stumps either randomly or in precise locations in the site if their coordinates have been measured. It then plants the seedlings at a user-selected density. The model grows the seedling roots and eventually some contact the roots of the infested stumps. Some of these seedling roots become infected from the stump roots. The program simulates the growth of the fungus along the seedling roots, onto the root collar, and distally out onto other roots. Subsequently, some of the uninfected roots from nearby seedlings become infected by contacting the infected roots of their seedling neighbors. This root contact and root infection process continues for the user-selected number of iterations or years of growth. Thus, in this model the disease spread is described explicitly via root contact and fungus transfer, initially as a consequence of the roots of new seedlings contacting the infested roots of stumps and, subsequently during the growth of the new forest, as a consequence of roots of new trees contacting the roots of other new trees which have already become infected.

The mathematical description relies heavily on probabilistic distributions. Some of the randomly distributed variables are: the root lengths of the stumps, the orientations of stump and seedling roots, the number of infested stumps in a clump, the number of stump and seedling roots, the growth rate of seedling roots, and the growth rate of the fungus along a root.

An overall constraint on the mathematical description, or its connection with reality, is the rate of spread of the disease. This can be computed using model parameters and then compared with the observed value which is assumed to be known *a priori* for the disease being modeled.

Parts of the mathematics have been programmed and a demonstration was given. It is expected that this approach will also have applicability to other root diseases such as those caused by *Armillaria ostoyae* and *Phellinus weirii*.



Fred Peet and Stan Barras

## Causes of Decline in Pacific Madrone (*Arbutus menziesii* Pursh)

Marianne Elliott and Robert L. Edmonds  
College of Forest Resources  
University of Washington, Seattle, WA

### Introduction

A decline in Pacific madrone has been reported during the past 20 years in the Pacific Northwest. The problem was first seen in urban areas, but declining trees are also found in natural forests. The problem is not restricted to madrones in the Pacific Northwest, and can be seen in forests throughout the entire range of madrone. There are many fungi that are pathogenic to madrone, and of these, the canker fungus *Nattrassia mangiferae* Nattrass (Deuteromycetes) is most often associated with dying trees. It infects the woody parts of the tree through wounds made by sunscald and mechanical damage. Other canker and decay fungi act as contributing factors in the decline (Table 1).

Table 1. Elements of Pacific madrone decline

Predisposing factors	Inciting factors	Contributing factors
Large size (diameter)	defoliation	<i>Fusicoccum aesculi</i>
Climate change	sunscald	decay fungi
Fire suppression	soil compaction	<i>Armillaria</i> root rot
Increased UV radiation	<i>Nattrassia mangiferae</i>	
Low resistance to pathogens	<i>Phytophthora cactorum</i>	
Genetics	waterlogged soil	
Shallow roots	drought	
	urban development	

The objectives of this study were to identify fungi and environmental factors important in madrone decline, and to make suggestions for reducing environmental stresses and control measures for diseases.

### Materials and Methods

Madrone trees in the Seattle area surveyed in this study were classified into three groups based on their growing environment; mature conifer forest, open urban environment, and the exposed bluff environment at Magnolia Bluffs Park, Seattle. The following were determined for each tree: DBH (cm), live crown ratio (%), branch dieback (%), number of *N. mangiferae* cankers on the main stem and large branches (1 = 0 to 5 cankers, 2 = 5 to 15, 3 = more than 15). Both healthy and declining trees were examined (N=283).

A subset of the trees (n=65) were used in a smaller, more detailed study. They were classified according to their crown architecture and physiological age using a 7 stage system (ABC, or Architecture Based Classification) (Mayer 1997). Stage 1 represents juvenile trees, 3 the period of maximum vigor, 5 and 6 senescence, and 7 decline. Samples for starch analysis from each madrone tree were taken with an increment borer at four locations around the root burl. Stored starch was determined in the laboratory using methods modified from several sources (Haissig and Dickson 1979, Kolb and McCormick 1991), and expressed as mg glucose/g sample.

## Results and Discussion

### *Disease Characteristics*

The results of the tree surveys indicate that trees with large diameters are more susceptible to cankers than smaller diameter trees. Trees with the most stem cankers also had the most branch dieback in the crown. Stem cankers put water stress on the branches and increase the activity of opportunistic fungi like *Fusicoccum*. In the forest environment, trees with the fewest cankers had more dieback. This is probably due to stress from insufficient light. There is a stronger relationship between dieback in the crown and number of cankers on the main stem in the urban environment and Magnolia Bluffs, both of which are open.

There was little difference between urban and forest environments in disease characteristics. At Magnolia Bluffs, there was a higher amount of disease than in the other two groups. The difference between Magnolia Bluffs and other open environments is that the trees are more exposed to wind and sun. Trees exposed to wind have less starch reserves than those growing in more protected environments, presumably because they lose some of their canopy to breakage (Waring 1987). Also, drought stress is more of a problem because of runoff, since the trees are growing on a steep slope.

Saplings from the three groups were compared for disease characteristics to determine if mature trees were affected more by disease than young trees. The Magnolia group had significantly higher levels of cankering than the other two groups. This may be due to the higher inoculum level of *N. mangiferae* from heavily infected mature trees. The harsh environmental conditions at Magnolia also contribute to the higher levels of disease on the madrones there.

### *Environment*

Table 2 shows the effect of the environment on growth of Pacific madrone. The trees growing in open conditions of Magnolia Bluffs and other urban environments are larger in diameter than madrones growing in a forest environment. Diameter indicates the level of maintenance respiration for the tree. Live crown ratio, which indicates photosynthetic capability, was lowest for trees at Magnolia Bluffs, but not much different than that for trees growing in the forest environment. At Magnolia Bluffs, the trees have a photosynthetic ability similar to madrones growing in a forest environment, but they have a larger respiratory burden similar to trees growing in an open urban environment. The low ratio of photosynthesis to respiration is a predisposing factor to disease, and may be one reason for the higher amount of disease on the madrones at Magnolia Bluffs.

Table 2. Characteristics of madrones at Magnolia Bluffs compared with madrones in the other two types of environment: forest and open urban habitat. The mean values for each characteristic are given, and compared using one-way ANOVA.

Environment (n)	DBH, cm	Live crown ratio	Avg. # cankers	% dieback
Magnolia Bluffs (98)	46.4	64%	11	56.64
Forest (42)	33.8	65%	3	30.11
Urban (143)	42.1	74%	3	26.65
p-value	0.008	0.007	$1.7 \times 10^{-14}$	$3.7 \times 10^{-25}$

### *Stored Starch and Tree Health*

Stored starch increases in ABC crown classes 1-3, then begins to decline as the trees age. Average diameter of the trees in each group increases. The result is lower levels of stored starch for the largest trees, reflecting the low P:R ratio. This suggests that large trees have fewer resources for defense, and thus are more susceptible to environmental stress and attack by pathogens than younger, smaller trees. The amounts of stored starch in young trees with a full crown were similar to older trees

with a lower live crown ratio. The older trees were larger in diameter, and so had more maintenance respiration than younger, smaller trees.

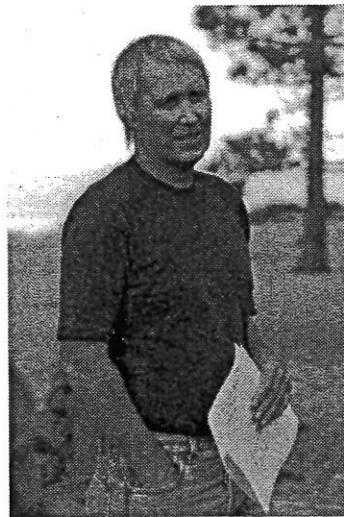
Percent dieback in the crown was significantly correlated with starch content ( $p = 0.003$ ). Trees with more than 50% dieback had about 33% less stored starch than healthy trees, making it difficult for these trees to escape the decline spiral.

### Bibliography

1. Haissig, B.E. and D.E. Dickson. 1979. Starch measurement in plant materials using enzymatic hydrolysis. *Physiol. Plant.* 47:151-157.
2. Kolb, T.E. and L.H. McCormick. 1991. Relationship between total nonstructural carbohydrate concentration and root diameter in sugar maple. *Forest Science* 37:343-346.
3. Mayer, S. 1998. Architecture Based Classification (ABC): Evaluation of an architectural method designed to assess vigor of Pacific Madrone. Report to Save Magnolia's Madrones, 4751 West Ruffner St. Seattle, WA 98199.
4. Waring, R. H. 1987. Characteristics of trees predisposed to die. *Bioscience* 37:569-574.



Eugene Van Ardell



Det Vogler

## COMMITTEE REPORTS

### Dwarf Mistletoe Committee Report

Submitted by Jerome S. Beatty

#### I. TAXONOMY, HOSTS, AND DISTRIBUTION.

- a. Our work on the taxonomic status of the shore pine dwarf mistletoe is continuing. Additional work was completed on the susceptibility of the hosts of shore pine dwarf mistletoe and on the phenology of populations near Horne Lake on Vancouver Island, B.C. More specimens of both shore pine dwarf mistletoe and western hemlock dwarf mistletoe will be collected from several populations throughout their geographic ranges in October for additional morphological measurements. We also plan to start data analysis this winter and are considering the examination of molecular characters. (R. Mathiasen, Northern Arizona University, Flagstaff, AZ; E. Wass, Canadian Forest Service, PFC, Victoria, B.C.; S. Shamoun, Canadian Forest Service, PFC, Victoria, B.C., and D. Smith, Grand Forks, B.C.)
- b. Taxonomic studies of the dwarf mistletoe severely parasitizing true firs (*Abies* spp.) in central Oregon are continuing. Additional collections of plants and observations of phenology will be completed in October. (R. Mathiasen, Northern Arizona University, Flagstaff, AZ)
- c. Additional taxonomic and host range data were collected for the knobcone pine dwarf mistletoe (*A. siskiyouense*) from southwestern Oregon and northwestern California in June. Jeffrey pine is a principal host of knobcone pine dwarf mistletoe at many locations in the Klamath-Siskiyou Mountain Region and shore pine is an occasional host. (R. Mathiasen, Northern Arizona University, Flagstaff, AZ)
- d. Host range data was collected at three locations where dwarf mistletoes are severely parasitizing Brewer spruce (*Picea breweriana*) in the Siskiyou Mountains (Oregon and California). Additional taxonomic and host range data will be collected in 1999 from other sites where dwarf mistletoes have been reported on Brewer spruce. (R. Mathiasen, Northern Arizona University, Flagstaff, AZ)
- e. The distribution, morphology and phenology of Hawksworth's dwarf mistletoe (*A. hawksworthii*) were investigated in Belize and Guatemala during March and in Belize in early June. Additional measurements of plants (height, basal diameter and third internode length and width) were completed for over 100 plants of each sex. Hawksworth's dwarf mistletoe was not found in the pine populations near Poptun, Guatemala and we do not believe it occurs in Guatemala. Therefore, the mistletoe only occurs in the Mountain Pine Ridge region of Belize in an area representing approximately 250 sq. km. Its principal host is *Pinus caribaea* var. *hondurensis* and *P. oocarpa* var. *ochoterenai* appears to be a secondary host. (R. Mathiasen, Northern Arizona University, Flagstaff, AZ; C. Parks, PNW Research Station, LaGrande, OR; B. Geils, RMRS, Flagstaff, AZ, and J. Beatty, WTCFID, Region 6, Sandy, OR)
- f. Shoots of Honduran dwarf mistletoe (*A. hondurensis*) were collected in March from near San Pedro Sula and in August from southeast of Tegucigalpa, Honduras. The shoots will be used for analysis of ITS sequences so this taxon can be compared with those of other dwarf mistletoes. (D. Nickrent, Southern Illinois University, Carbondale, IL; R. Mathiasen, Northern Arizona

University, Flagstaff, AZ; C. Parks, PNW Research Station, LaGrande, OR, and J. Beatty, WTCFID, Region 6, Sandy, OR)

- g. Sugar pine dwarf mistletoe (*A. californicum*) was collected on sugar pine (*Pinus lambertiana*) approximately 6 miles northwest of Callahan, CA in the Klamath Mountains (T. 41 N, R. 9 W., Sec. 31, 1330 m) in June. This extends the distribution of sugar pine dwarf mistletoe 30 miles west and five miles north of its previously known most western and northern location southwest of Mt. Shasta City, CA. (R. Mathiasen, Northern Arizona University, Flagstaff, AZ)
- h. Western dwarf mistletoe was found parasitizing planted Colorado blue spruce and Norway spruce in Upper Cuddy Valley, CA (Kern County). This is the first report of western dwarf mistletoe on blue spruce and the second report of this dwarf mistletoe on Norway spruce (albeit the first report of this host-parasite combination from California). (J. Allison, San Bernadino NF, CA; B. Geils, RMRS, Flagstaff, AZ, and R. Mathiasen, Northern Arizona University, Flagstaff, AZ)

## II. PHYSIOLOGY AND ANATOMY

- a. Association of aerial shoot production and light environment. We have begun some initial investigations into the light and the production of aerial shoots. Stu Weiss has been up to the WRCCRF and we have taken fisheye photos at over 100 infections. These were chosen by starting at the bottom of a tree and working our way up one side of the crown and going back down the next, stopping every 5 meters and choosing the closest infection. Using the fisheye photo, a model can be run that estimates the relative amount of sunlight reaching that location throughout the year. We are comparing infections with aerial shoots vs. those that do not have aerial shoots. Although complicated by infection age, this is an interesting way to investigate the influence of light on aerial shoot production. (D. Shaw and S. Weiss, Wind River Canopy Crane Research Facility, Carson, WA)

## III. LIFE CYCLES

## IV. HOST-PARASITE RELATIONS

- a. Field data were collected in 1998 from 16 permanent plots on the Targhee National Forest in eastern Idaho. The 100-tree plots are four replicates of four spacing regimes established in a 25-year old stand in 1983. This will be the last re-reading of the plots. Objectives are to determine: 1) the effects of pre-commercial thinning on growth of dwarf mistletoe infected lodgepole pine; 2) the changes in dwarf mistletoe incidence and intensity over time; and 3) the effects of dwarf mistletoe parasitism on growth and mortality of lodgepole pine trees. (J. Hoffman, USFS, FHP R-4, Boise)

## V. EFFECTS ON HOSTS

## VI. ECOLOGY

- a. We have initiated a study to determine wildlife use of witches' brooms induced by Douglas-fir dwarf mistletoe (*A. douglasii*) in northern Arizona. We hope to examine at least 100 infected and 100 uninfected trees and determine which wildlife species are utilizing brooms for nesting, resting, foraging and hiding sites and compare the use of infected trees with similar, but uninfected Douglas-fir. (S. Hedwall, C. Chambers, R. Mathiasen, Northern Arizona University,

Flagstaff, AZ; ML. Fairweather, FHP, R3, Arizona; and C. Parks, PNW Research Station, LaGrande, OR)

- b. Spatial patterns of western hemlock dwarf mistletoe infections in an old-growth Douglas-fir/western hemlock forest. This is a two-part study, in the Thorton T. Munger Research Natural Area, where we are attempting to get a handle on the factors involved in spatial patterns of mistletoe infection centers, and thereby infer controlling factors for disease etiology. Spatial patterns on a mapped 12 hectare forest. We have mapped a 12 ha segment associated with the Wind River Canopy Crane, all trees 5cm dbh and greater have been mapped. All western hemlocks, and true firs were rated using the six class dwarf mistletoe rating system. Mapping is continuing and analysis will begin this fall. Spatial patterns on the T.T. Munger RNA. A series of 9 mortality strips, totaling 104 square acres, were established in 1947 to determining the rates and processes associated with mortality in an old growth forest. These strips represent a 10% sample of the 1,100 acre RNA. In 1991, we tagged all the trees >18 inches dbh, in these strips. This year, we remeasured the strips for mortality, and growth and yield. In association with this 50 year remeasurement, we are rating every tagged hemlock and true fir using the 6 class system. This approach provides two views into the etiology of western hemlock dwarf mistletoe; a detailed stem map, and a macro view of pattern across the forest. Interestingly, I initially thought western hemlock dwarf mistletoe was limited to fairly discrete infection centers, but the northern end of the RNA has a HUGE infection center, covering over 100 hectares. A first blush implies that stand structure and disturbance (wind disturbance and effective area burned 500 years ago) appear to be two extremely important factors in controlling mistletoe spread (SURPRISE!). (D. Shaw, J. Chen, D. Braun, Wind River Canopy Crane Research Facility, Carson, WA)

## VII. GENETICS

- a. In the fall of 1997, 103 selected ponderosa pine were visited to collect scion-wood, which was pot-grafted and. The following spring, planted into a clone bank. These trees represented both dwarf mistletoe resistant candidates (93) and susceptible controls (10). A similar collection is being made this fall for Jeffrey pine candidates (71) and controls (10). These are being grafted for future outplanting into the same clone bank as the ponderosa pine. A pilot study to compare resistance levels of progeny from a sample of the above candidate and control populations of ponderosa pine was planted in 1997. Progeny from a third group, comprised of controlled pollinations between resistant candidates, was also established in the same outplanting. Survival remains at close to 99% for all outplanted material after the second growing season. Artificial inoculation of all three groups will begin in about 3-4 years. (P. Stover, FS, PSW, Camino, CA and R.F. Scharpf, FS, PSW ret., Placerville, CA)

## VIII. MANAGEMENT

- a. Evaluating the accuracy of ground based dwarf mistletoe rating: A case study using the wind river canopy crane. We originally used only one individual to compare ground rating to those taken from the canopy crane, and this was seen as too limited. So we had an additional 4 people rate the trees under the crane from the ground: one forest pathologist, 2 timber stand inventory cruisers, and 2 biological technicians. The manuscript is currently in review. (D.Shaw, E. Freeman, R. Mathiasen, Wind River Canopy Crane Research Facility, Carson, WA)
- b. We have been monitoring the effects of prescribed fire on dwarf mistletoe infection levels in ponderosa pine on the Santa Fe National Forest in northern New Mexico. Rectangular plots with 100-150 trees each have been installed prior to burning and are being followed for several years

after burning. Relations between crown scorch, DMR, and tree mortality are being followed, as are the "sanitizing" effects of partial crown scorch in the surviving trees. To date we have documented significant effects from three separate fires. (D. Conklin, FHP, Region 3, Albuquerque, NM)

## IX. SURVEYS

- a. Under the Survey & Manage guidelines of the Northwest Forest Plan, as revised in July 1995, this Region is required to "conduct general regional surveys" for mountain hemlock dwarf mistletoe (MHDM), *Arceuthobium tsugense* subsp. *mertensiana*, in the State of Washington. In 1998, we surveyed in the vicinity of plots from the new Continuous Vegetation Survey (CVS) on the Gifford Pinchot National Forest. MHDM was growing on mountain hemlock and sub-alpine fir, and rarely on lodgepole pine, in the lava field in the vicinity of CVS plot 2165168, one half mile east off of Forest Road 60, southeast of Indian Heaven Wilderness, Mt. Adams Ranger District, T. 5N, R. 8E, S. 14. We also searched the stand around CVS plot 1168164, T. 6N, R. 8E, S.20, Wind River Ranger District, and did not find dwarf mistletoe on the mountain hemlock. The survey will continue in 1999. (D. Hildebrand, FID, Region 6, Portland, OR; J. Beatty, WTCFID, Region 6, Sandy, OR)

## X. MODELING

## XI. MISCELLANEOUS

- a. Douglas-fir Dwarf Mistletoe Permanent Plots. In 1997, Katy Marshall and Greg Filip remeasured eleven Douglas-fir dwarf mistletoe plots that were established in 1992. They are located in the Southern Oregon Cascades on the Rogue River and Umpqua National Forests. Information gained from these plots will increase our understanding of spread and intensification of Douglas-fir dwarf mistletoe. The data will also be used to calibrate the Dwarf Mistletoe Impact Extension for the West Cascades and Interior California-Southern Cascades variants of the Forest Vegetation Simulator Model (FVS). When the plots were established, all live trees greater than two inches in diameter were tagged and data were collected on species, diameter breast height (dbh), dwarf mistletoe rating (DMR, Hawksworth's six-class rating system modified for Douglas-fir by Tinnin, 1998), crown class and damage. Total height, height to the base of the live crown, breast height age, and ten-year radial growth were measured in a subsample of the live trees. Five plots were stem mapped. Data were also collected on slope, aspect, site index, plant association and stand origin and history. In 1997, the condition (live or dead) and dbh were remeasured on all tagged trees. Total heights and DMRs were remeasured on all live Douglas-fir.



Jerry Beatty

The following table summarizes changes in Douglas-fir on the plots during the five-year period:

Plot	#live DF	% DF infected		Plot DMR		Mortality		Diameter Growth (inches)	
	1992	1992	1997	1992	1997	%	DMR	Infected	Uninfected
1	44	55	74	2.0	2.5	14	3.3	0.38	0.47
2	108	39	39	1.1	1.2	9	1.9	0.60	0.57
3	40	55	74	1.4	1.9	5	3.0	0.67	0.17
4	114	60	75	2.2	2.5	9	4.3	0.28	0.50
5	55	33	46	0.7	0.8	9	0.0	0.42	0.68
7	78	22	23	0.4	0.4	0	-	1.35	1.52
8	15	60	73	2.9	2.2	0	-	0.69	0.73
9	100	22	21	0.6	0.5	8	0.8	0.49	0.45
13	101	46	55	1.5	1.7	6	2.5	0.69	0.91
14	22	73	75	3.6	2.3	9	6.0	0.24	0.52
16	55	78	75	3.2	2.1	5	5.3	0.45	0.67
over all	732	45	51	1.5	1.5	7	2.6	0.52	0.75

Sixty-one percent of the Douglas-fir had the same DMR in 1992 and 1997 (including DMR 0). Twenty-four percent changed by one rating class and eight percent by two rating classes. Seven percent changed by three or more rating classes (these trees were probably rated incorrectly and will be revisited at the first opportunity).

The ten-year remeasurement of the plots will be due in 2002. At that time, all the variables that were measured when the plots were established will be remeasured. Ingrowth will be tagged and measured. (K. Marshall, SWOTC, Region 6, Central Point, OR; G. Filip, Oregon State University, Corvallis, OR)

- b. Project title: Biological Control of Dwarf Mistletoes, Project Leader: Dr. Simon Francis Shamoun- CFS Victoria, BC, Canada

Research Associates/Cooperators: Drs. Alan Thomson (CFS-Victoria); Harry Kope (Contact Biologicals- Victoria); Zamir Punja (S.F.U.- Burnaby); Richard B. Smith (Ex-CFS- Research Scientist- Grand Forks); Mr. Ed Wass (CFS-Victoria); Bart van der Kamp (UBC- Vancouver); Ms. Carmen Oleskevich (CFS-Victoria); Ms. Shannon Deeks (M.Sc. candidate, SFU- Burnaby); and Mr. Tod Ramsfield (Ph.D. candidate- UBC, Vancouver); Stephan Zeglen (BC Min. of Forests- Nanaimo, BC); Fred Pattenden (BC Min. of Forests- Duncan Forest District- BC); Ed Senger (BC Min. of Forests-Lillooet- BC); George White (Riverside Forest Products- Williams Lake, BC); Kim Peel (Lignum Ltd., BC); Claire Tretheway - UBC Alex Fraser- Willams Lake, BC).

Research Objectives: The overall objective of the project is to survey and collect fungal hyperparasites and to investigate their potential use as biological control agents for dwarf mistletoes. Currently the focus of this research project is on biocontrol of western hemlock and lodgepole pine dwarf mistletoes.

Research Progress : Western Hemlock Dwarf Mistletoe- collection of hyperparasitic fungi were made from 18 sites of Vancouver Island and coastal British Columbia (BC) as well as one site from Mary's Peak, near Corvallis, Oregon. From the diseased shoots, berries and swellings of western hemlock dwarf mistletoe, twenty species of fungi were isolated, purified and identified,

with a subsequent database of 223 isolates created (computerized database is available from Dr. Simon Shamoun). All isolates are preserved under liquid nitrogen/or -80C for further research.

Detailed information about the hyperparasitic fungi has been reported and published at the 45<sup>th</sup> Annual WIFDWC in Prince George, BC, 1997, pages 36-42. Fungi of special interest that have been isolated includes *Colletotrichum gloeosporioides* (new record on western hemlock dwarf mistletoe), *Nectria neomacrospora*, and *Cylindrocarpon gillii*.

Field trial- a field trial was initiated to evaluate the effect of fungal application on hemlock dwarf mistletoe *in situ*. Two selected hyperparasitic fungi namely *C. gloeosporioides* and *N. neomacrospora* (Anamorph *Cylindrocarpon cylindroides*) were used as candidate biocontrol agents. An inert carrier formulation was developed for the delivery of these two fungi. On September 04, 1997, the application of these two fungi on hemlock mistletoe were completed on a site near Duncan, BC. Observation at two months post-treatment showed high mistletoe shoot mortality for both fungal treatments. At 7.5 months post-treatment, there was shoot mortality up to 90%. Monitoring and data collection will continue for the next 3-5 years post-treatment.

Tissue Culture of western hemlock dwarf mistletoe- A novel protocol for *in vitro* tissue culture of western hemlock dwarf mistletoe was successfully produced callus for the first time with this species. Research efforts underway are to develop an *in vitro* rapid method for screening the potential candidate hyperparasitic fungi and their use as biocontrol agents.

Publications/Conferences- The following publications and conference attendance were achieved: 1) First report of *Colletotrichum gloeosporioides* on *Arceuthobium tsugense* sub sp. *tsugense*. 1997 (81): 1095. PLANT DISEASE JOURNAL.; 2) Managing Dwarf Mistletoe- A biological and genetic control approach, Dec. 1997- CFS- Victoria publication; 3) Tissue culture of western hemlock dwarf mistletoe . In Proceedings of the Canadian Society of Plant Physiologists 41:9-10; 4) Tissue culture of parasitic plants- methods and application in agriculture and forestry- In Vitro Cell Dev. Biol. Plant (In preparation); 5) A joint publication Shamoun and DeWald- control of dwarf mistletoes by biological. Chemical and genetic control methods which is in preparation for publication in: Mistletoes of North American Conifers (Edited by B. Giels et al); 6) A survey of mycoflora associates of western hemlock dwarf mistletoe plants and swellings in British Columbia, Canada- for publication in Mycological Research journal- In preparation.; 7) A new report of *Nectria* species on Shore pine (*Pinus contorta* var. *contorta*) swelling affected by *Arceuthobium tsugense* subsp. *tsugense* ), for submission to PLANT DISEASE JOURNAL- In preparation.

Dr. Shamoun and his students attended many conferences and presented their research findings:

1) 45<sup>th</sup> annual WIFDWC meeting, 1997- Prince George September 15-19, BC; 2) Joint Meeting of the Canadian Plant Physiologists- western Region and Uvic- Forest Tree Research Colloquium, April 7-8, 1998; and 3) CFS- Forest Pest Management Forum Meeting in Ottawa November 17-20, 1997.

In 1997 another new project was initiated on biological control of Lodgepole Pine Dwarf Mistletoe. Mr. Tod Ramsfield - Ph.D. Candidate at the Dept. of Forest Science - UBC is working under the directions of Drs. Bart van der Kamp (UBC) and Simon Shamoun (CFS- Victoria). To date, there has been more than 30 sites selected throughout BC. Diseased samples from shoots, berries and swellings of Lodgepole Pine Dwarf Mistletoe have been collected and currently hyperparasitic fungi have been isolated and preserved for further research.

## Hazard Tree Committee Report

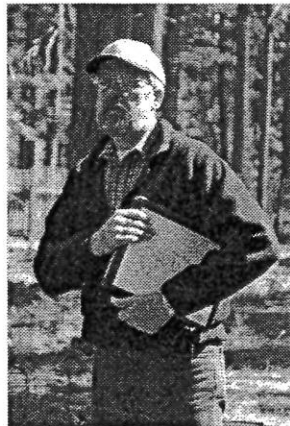
Submitted by John Pronos

The Hazard Tree Committee sponsored a workshop held at the Hood River Hotel in Hood River, Oregon from May 19-21, 1998. There were 61 paid attendees plus and an additional 11 speakers. About half the participants were WIFDWC members and many of the remaining were from the private arborist munity.

Worshop activities were split between indoor presentations and two field trips. Panel and presentation topics included the evaluation of decay, wildlife/danger tree assessment in British Columbia, site factors influencing tree root failures, preventing hazard trees through vegetation management, legal issues and tree species failure profiles. The field trip featured evaluating several standing trees with defects and then viewing these trees two days later after they were felled and dissected. Decay evaluation included demonstations of the Arborsonic Decay Detector and the Resistograph by Scott Baker from Seattle, WA. Keith Sprengel, with Forest Health Protection in Sandy, OR, arranged to have several logs, colonized with different decay fungi, on display at a nearby county park. Also, the group traveled to Lost Lake Campground to see and hear about hazard tree management challenges.

At the HT committee luncheon meeting in Reno, we discussed the work of a company called Riparian Environmental Management, located in British Columbia. They have developed a methodology to treat forest stands and individual trees to increase wind firmness. Our group had numerous questions and reservations about these procedures and decided not to pursue having a demonstration of the techniques.

A discussion of future HT committee activities yielded little results with the group uncertain about what, if anything, the committee should do.



John Pronos

## Rust Committee Report

Submitted by Rich Hunt

Thirty-seven persons attended the rust breakfast meeting. Kim Hummer in-charge of the USDA-ARS ribes collection outlined that there was an opportunity for North Americans to grow currants, because there was a virus disease reducing production in Europe. As a result of a meeting last January in Albany NY there is a web site established to facilitate communication among those interested in white pines and/or ribes cultivation. The growing of currants is in conflict with several state laws that favour the growing of white pines. There was additional concern expressed that currant growing may: 1) spread *Cronartium ribicola* genotypes around by movement of ribes infested stock; 2) currants grown in certain areas may act as bridges to connect western and eastern North American gene pools of *Cronartium ribicola*; 3) reduce the resistance in currant varieties known to be resistant (immune) to *Cronartium ribicola*; 4) once resistance failed in commercial currants how soon would they be removed and replaced with new resistant varieties? These problems were deemed as opportunities for the white pine workers and the ribes horticulturists to work together in solving these problems for the benefit of both industries.

As an initial first step, Kim Hummer will recommend a panel of ribes varieties that have a range of susceptibilities, from immune to 100% infected. Funding will be sought, and once obtained, the varieties will be propagated and outplanted by co-operators in a uniform fashion and the data will be collected using a uniform protocol. This should help determine if *Cronartium ribicola* varies in virulence on ribes located in different geographic areas. Perhaps known genotypes (clones) of white pines will be planted at some of these locations. Interested co-operators should contact R. Hunt or B. Geils. Kim is attempting to have a joint meeting of white pine workers and ribes horticulturists next fall, in Corvallis. Contact Kim if you have interesting source of ribes, for she may want to add them to the USDA-ARS ribes-germplasm collection. Ellen Goheen noted that the USFS is planting ribes for habitat restoration. To her knowledge these were wild-type *Cronartium ribicola* susceptible plants. Fred Baker noted that horticultural growers propagate many ribes varieties for horticultural uses not associated with currant or gooseberry production. It was suggested that white pine workers may want to interact with the APS Smallfruits committee.

Geral McDonald gave a report on the IUFRO rust meeting recently held in Finland. The next such meeting will be in Beijing or western North America.

The above is based on notes taken by R. Hunt; he has been known to make errors and omit pertinent information.



Rich Hunt, wearing a hat, behind the speaker

## Root Disease Committee Meeting Report

Submitted by Ellen Michaels Goheen

The Root Disease Committee met for breakfast on Thursday, October 1, 1998. Thirty-four members attended. Susan Frankel presented the results of recently completed work to validate the Western Root Disease Model P-type annosus functions (report follows). Members with or aware of other longterm datasets that could be used to validate Armillaria root disease or laminated root rot within the model should contact Susan or Ellen for more information. Also of note: the User's Guide to the Western Root Disease Model Version 3.0, Technical Coordinator Susan Frankel, is now available. Contact Susan for a copy. Other modeling news includes that Fred Baker has begun to test a tomentosus root disease model using the Western Root Disease Model as a framework.

Rich Hunt shared a video during the Thursday afternoon session on a new piece of stump-extracting equipment recently tested in British Columbia.

**Upcoming Meetings:** Walt Thies reported that the Phellinus coop meeting that was supposed to be held in October 1998 is postponed until sometime in the spring. Ellen Goheen reminded members that the first IUFRO working party meeting on Phytophthora Diseases of Forest Trees will be held in Grants Pass, Oregon, in late August 1999.

### Submitted Reports:

A comparison of Western Root Disease Model predictions and permanent plot data tracking the impacts of Annosus Root Disease in CA: submitted by Susan J. Frankel, Larry J. Wilson and Garey Slaughter

I am assuming that most of you are familiar with the Forest Vegetation Simulator and the Western Root Disease Model, version 3.0 (WRDM3). If you aren't I recommend you attend Friday's panel on forest disease models. Today, I want to update you on some of our validation work for the Annosus root disease functions of the WRDM3.

Many of you were involved in model development and are intimately familiar with how the model was designed, it is conceptually based, so comparisons to actual data of stand dynamics in root disease areas over time are needed to fully demonstrate that the model is functioning in a reasonable manner. For those of you that aren't familiar with the model and its design you can learn all about it in the recently published User's Guide. Chapter 5 of the User's guide is a short validation chapter by Frankel, Wilson and Slaughter, we used permanent plot data from true fir stands in the central Sierra Nevadas and demonstrated that in areas with S-type Annosus root disease, the WESSIN (Westside Sierra Nevada variant) underpredicted mortality by 76% and overpredicted growth by 41% (Frankel and others, 1998) over a short prediction period of 13 years. The Western Root Disease Model improved FVS performance predicting 99% of the mortality and 80% of the growth. This year we completed a similar test of the model, for pine-type (P-type) Annosus root disease functions, comparing them to data from plots tracking Annosus root disease impacts in Eastside pine stands in California.

### Methods

Permanent plots established in 1972 in pine stands centered around large (30"+) pine stumps with Annosus root disease and adjacent mortality were remeasured in 1997. Tree and site data to conform with the Pacific Southwest Region, Forest Inventory and Analysis system (USDA Forest Service, 1996)

including species, dbh, and site information were recorded for .1 acre (37.2 feet) surrounding the forty-eight plot centers. Trees and stumps were also inspected for evidence of root disease: conks, associated decay, chlorosis, poor growth and needle loss. Trees that were recorded in 1997 as ingrowth or seedlings were excluded from the analysis, in order to make tree per acre comparisons more meaningful.

The plots are located on the Inyo, Plumas, Lassen, and Modoc National Forests in Eastside pine stands. Typically these approximately 100 year-old stands are predominately ponderosa pine (*Pinus ponderosa*) or Jeffrey pine (*Pinus jefferyi*), with some western juniper (*Juniperus occidentalis*) and white fir (*Abies concolor*). They range in elevation from approximately 4000 to 6000 feet in elevation. The stands are mostly flat with slopes from 0 to 20%. The plots were set-up in 1972 and monitored periodically through 1997 by the USDA-Forest Service, Forest Pest Management group, and Dick Parmeter and Garey Slaughter at the University of California at Berkeley.

Data from 1972 was entered into the Forest Vegetation Simulator, Southern Oregon Northeastern California (SORNEC) variant, with and without the Western Root Disease Model running. The model was run with defaults for all parameters except area of root disease center which was entered to represent specific condition. Regeneration routines available in FVS were not used.

Several methods of entering root disease information into the Western Root Disease Model were compared. The following methods were used (see Table 1).

- 1) The model was instructed to read the Annosus root disease damage codes directly from the inventory data. These inventory damage codes identify every tree that is infected with Annosus root disease and all trees within 30 feet of infected trees. The model then assigns inoculum to each identified tree.
- 2) Estimates of the area infected with Annosus root disease were made from the data and then entered for each plot. The area of infection is used by the model to assign root disease inoculum to a percentage of the trees in the plot.

Each of the above methods were used with and without default bark beetle functions. Bark beetle functions instruct the model to kill a percentage of the trees each time the stand grows above a specified basal area. The thresholds and percent kill mimic the mortality patterns of common bark beetles, such as western pine beetle and mountain pine beetle.

## Results

Based on actual plot measurements, over 24 years, an average of 128 trees/acre died in root diseased areas, with a basal area of 21 sq ft/ac. Dividing the basal area by the number of trees we can calculate the average dbh of the dead trees to be about 5.5 inches. On an annual basis 5.3 trees per acre were killed in areas with root disease.

Without the Western Root Disease Model running the base SORNEC model predicted an average mortality rate for the 24 year period of 17 trees/acre, with a basal area of 2 sq ft/acre. Dividing the basal area by the number of trees we calculate that it predicts that an average of 0.7, 4.8 inch trees per acre are dying each year.

Using the Western Root Disease Model the closest estimate of mortality was 145 trees per acre and 25 sq/ft basal area or an average of 6, 5.6 inch trees per acre each year. This prediction was generated by

estimating the area of root disease from the data and turning-off the default bark beetle functions. Using the tree-by-tree inventory information the model predicted mortality of 89 trees per acre and 28 sq ft basal area or 3.7, 7.6 inch dbh trees per ac/yr.

## Discussion

This comparison of permanent plot data to model predictions demonstrates that in eastside pine stands including the Annosus root disease and bark beetle effects in growth and yield projections performed on stands with root disease can greatly improve the accuracy of projection results. Not including pathogen and insect effects resulted in the 24 year projection having nearly double the number of trees and over twice the basal area as was observed in the field. Without the Western Root Disease Model the base SORNEC model under predicted mortality expressed as trees per acre by 87%, and basal area loss per acre due to mortality by 91%. The actual number of trees dying each year was 5 times greater than the SORNEC base model predicted.

Mortality and growth predictions were simulated for each plot, and the results were averaged. The model did not accurately predict the mortality on a plot-by-plot basis. The plots are very small, which makes the model simulations more variable: one tree killed or not killed on a plot is a high percentage of a small plot.

The study also demonstrates that the model is very sensitive to the way root disease information is entered into the model. Results varied depending on whether the model was instructed to enter the tree-by-tree and stump -by-stump root disease inventory data, or started from an estimate of the amount of root disease area based on a map of root disease in the plot. Close attention needs to be paid to how the model is initialized if projection results are to be reliable. In this study, initializing the model using the default values and an estimate of root disease area gave a better result than using the more detailed and more difficult to collect tree-by-tree inventory data. But all methods of root disease initialization yielded much better mortality and growth estimation than the base SORNEC model running alone.

The permanent plot data demonstrate that on average in eastside pine stands, 5.5, 5.3 inch dbh ponderosa pine trees will die per acre/yr. The tree density in these areas will be lower than uninfected areas. The mortality rate will be five times greater than background mortality, generally estimated as approximately 1 tree per acre per year. This impact may be viewed as beneficial or detrimental depending on the local land use pattern and goals and objectives of stand management. In a high-use recreation area or along the forest/urban interface a mortality 5 times background levels may be unacceptable. However, if the land is forest land in a roadless area, the higher mortality rate and lower basal area growth may be beneficial, serving to open the stand, provide habitat for shade-intolerant plants, thin out weaker trees, etc.

## References

Frankel, Susan J., L. J. Wilson, G. Slaughter. 1998. A comparison between Western Root Disease Model Predictions and Real Data. In Frankel, Susan J. Comp. 1998. User's Guide to the Western Root Disease Model. PSW-GTR-165. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. p. 131-135.

USDA Forest Service. 1996. Forest Inventory and Analysis user's guide. San Francisco, CA: Pacific Southwest Region. 431 p.

Colorado State University: submitted by Bill Jacobi

Continued to analyze the spatial relationships of Armillaria root disease and site features in the Back Hills of South Dakota.

In cooperation with Forest Health Management, Rocky Mountain Research Station, and the Bureau of Indian Affairs, a study was initiated to see a) if aerial infrared photos would pick up black stain root disease and Ips beetle damage in pinyon pine, b) to determine if there are any site or stand conditions related to incidence of these damages, and c) to see if potential insect vectors of black stain root disease can be trapped in southern Colorado.

In 1999 our plans are to:

1. In cooperation with Forest Health Management, USDA Forest Service, we will finish analysis of the influence of meteorological, site, and soil factors on the spatial small (1/2 mile) and landscape scale distribution of Armillaria root disease on ponderosa pine in the Black Hills.

2. Continue a research project on black stain root disease of pinyon pines in southwest Colorado. We will be looking at spatial relationships with site, soil, and management activities. Funding is not secure yet.

In cooperation with John Lundquist, Rocky Mountain Station, try to obtain funding to look at root diseases on spruce-fir blown over in the fall of 1997.

British Columbia Forest Service: submitted by John Muir

We have released version 1.0 of "PROGNOSIS BC", our metricized version of the Forest Vegetation Simulator for southern Interior BC. Several projects are underway to calibrate the base model and the root disease module for our conditions. A very active committee is directing the projects, developing training courses, and providing help for users. With increased interest in partial cutting strategies to offset anticipated timber supplies there is considerable interest in using the model. Our first (pilot) training session (2 days) was held at Nelson in June 1998.

Don Norris, Regional forest pathologist at Nelson is continuing work on developing a pop-up treatment to extract whole trees in young stands infested by Armillaria root disease. The objective is to reduce inoculum and prevent flare-ups of disease that usually result when these young stands are thinned or spaced using conventional tree-cutting methods.

Spectacular growth rates of western larch have been observed on several sites in the Nelson Forest Region that were stumped (push-over logged) for Armillaria root disease. Five-year-old trees have been growing approximately one meter in height per year.

Work is also ongoing to refine survey methods for root disease and to improve our methods for evaluating root disease risks and hazards on a landscape and site-specific basis. These improved techniques will be used to upgrade our recommended management practices for our new Forest Practices Code of BC guidebook. Current recommended practices are posted on the Ministry web page.

Bill Chapman, research scientist at Williams Lake, Cariboo Forest Region is pursuing work on inoculating stumps with *Hypoholoma* spp. to reduce Armillaria root disease inoculum.

## Disease Control Committee Report

Submitted by Diane M. Hildebrand

The Disease Control Committee met at breakfast on Wednesday, September 30, 1998. Approximately 15 people attended and most of them participated.

Major discussion topics included 1) the EPA reregistration (or threatened non-reregistration) of many pesticides important to forestry, especially to forest nurseries, and 2) the next meeting of the Forest Nursery Pathology Workshop.

The Committee decided that we need more information on the status of EPA reregistration of carbamates, organophosphates, and certain pesticides on the list of B1 and B2 carcinogens. Forest Service nursery specialists provided statements of potential impact if these pesticides were lost to use, to the Washington Office in June 1998. The Forest Service was to submit the information to USDA for deliberation with EPA. Pesticides in question, of importance to Federal, State, and private forestry, include:

**Carbamates:** Benomyl, Thiophanate-methyl, Carbaryl

**Organophosphates:** Chlorpyrifos, Acephate, Malathion, Diazinon

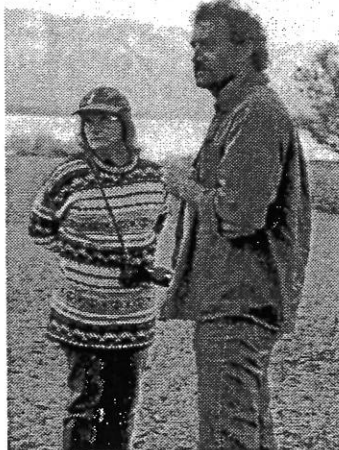
**B1 and B2 Carcinogens:** Captan, Chlorothalonil, Iprodione

The Committee encourages Bob James to seek a speaker on this topic for the Nursery and Seed Orchard session at the Joint WIFIWC/WIFDWC Meeting in Breckenridge (see below).

The Forest Nursery Pathologists plan to meet for our annual workshop from noon to 5 pm on Monday during the Joint WIFIWC/WIFDWC Meeting. This will be our usual informal and very informative exchange among all participants. The meeting may continue on into the evening.

For the Joint Meeting, the Disease Control Committee proposes a half day session, "Insects & Diseases of Forest Nurseries and Seed Orchards." Bob James has agreed to organize this session. The Disease Control Committee encourages Bob to seek speakers on alternatives to methyl bromide fumigation, genetics of Fusarium, and status of reregistration of important pesticides (see above).

Diane Hildebrand communicated the plan for the Forest Nursery Pathology Workshop and the proposal for the half-day session on Insects and Diseases of Forest Nurseries and Seed Orchards, to Fred Baker, WIFDWC Program Chair.



Diane Hildebrand and Keith Sprengel

## REGIONAL REPORTS

### Rocky Mountain Region Report

Submitted by Dave Johnson

#### 1. New and Continuing Projects

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

95-D-2 Ski area vegetation management: biology and impacts of the Armillaria root disease/western balsam bark beetle complex (P. Angwin, T. Eager, J. Negron).

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

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

##### F. 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).

##### K. Miscellaneous Studies

98-K-1 GIS-based landscape-scale prediction system for pinyon pine decline (W. Jacobi, S. Harrison, P. Angwin, T. Eager, R. Mask).

97-K-1 Stand characterization and manipulation associated with western balsam bark beetle and decline of subalpine fir in the central Rocky Mountains (T. Eager, P. Angwin).

92-K-1 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, T. Eager).

#### 2. Terminated Projects

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

95-D-1 GIS-based landscape-scale root disease hazard rating system (W. Jacobi, M. Kallas, R. Reich, J.L. Harris).

RECENT PUBLICATIONS (as of September 1998)

- Allen, K.K. and J.L. Harris. 1997. Evaluation of forest overstory and regeneration conditions at the Bessey and McKelvie units of the Nebraska National Forest. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-98-1. 12 p.
- Allen, K.K. 1998. Evaluation of mountain pine beetle activity in the Kine Analysis Area of the Black Hills National Forest. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-98-05. 11 p.
- Eager, T.J. and P.A. Angwin. 1997. Forest Health Assessment- Piney Analysis Area, Holy Cross Ranger District, White River National Forest, p. 116-120. IN: R. Teck, M. Moeur, J. Adams (comps). Proceedings: Forest Vegetation Simulator Conf., Ft. Collins, CO., February 3-7, 1997. USDA For. Serv., Intermountain Res. Sta. Gen. Tech. Rep. INT-GTR-373. 222 p.
- Harris, J.L.; K.K. Allen, and T. Juntti. 1997. Ramshorn Analysis Area, Wind River Ranger District, Shoshone National Forest, insect and disease survey. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-98-04. 31 p.
- Jacobi, W.R., E.F. Kelly, C.A. Troendle, P.A. Angwin, and C.A. Wettstein. 1998. Environmental conditions and aspen regeneration failure. USDA For. Serv., Renewable Resources, Rocky Mountain Region Tech. Rep. R2-60. 25 p.
- Johnson, D.W. 1998. Evaluation of Hidden Lakes dwarf mistletoe pruning study, Routt National Forest, Colorado. USDA For. Serv., Renewable Resources, Rocky Mountain Region Tech. Rep. R2-61. 8 p.
- Johnson, D.W. 1998. Evaluation of vegetation health in Big Creek Lakes Campground, Parks Ranger District, Routt National Forest, Colorado. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-98-03. 23 p.
- Johnson, D.W. 1998. Evaluation of Porcupine and Snyder Creeks dwarf mistletoe thinning studies, Routt National Forest, Colorado. USDA For. Serv., Renewable Resources, Rocky Mountain Region Tech. Rep. R2- . (Draft).
- Johnson, D.W. *Picea engelmannii* Parry ex Engelm. IN: Schutt, Schuck, Aas, Lang [eds.]. Enzykopedie der Holzgewachse (Encyclopedia of Woody Plants). Ecomed Verlag, Landsberg, Germany. (In press).
- Johnson, D.W., W.C. Schaupp, Jr., M. Hood and E. Smith. 1997. Cold Springs Analysis Area, Douglas Ranger District, Medicine Bow National Forest - Forest Health Assessment. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-98-02. 51 p. plus appendices.
- Johnson, E., S.J. Johnson and D.W. Johnson. 1997. Interpretation of aerial photography of Colorado's forest health monitoring plots 1992-1995. USDA For. Serv., Renewable Resources, Rocky Mountain Region Tech. Rep. R2-59. 11 p. plus appendix.
- Johnson, S.J. (Editor). 1997. Forest Insect and Disease Conditions in the Rocky Mountain Region 1996. USDA For. Serv., Renewable Resources, Rocky Mountain Region. 45 p.

Mask, R.A. and T.J. Eager. 1997. Mountain pine beetle assessment for the Vail Valley area of Colorado. USDA For. Serv., Renewable Resources, Rocky Mountain Region Biol. Eval. R2-97-04. 27 p.

Pasek, J.E. and T.M. Juntti. 1997. Comparison of risk/hazard rating systems for mountain pine beetle in Black Hills ponderosa pine forests. USDA For. Serv., Renewable Resources, Rocky Mountain Region Tech. Rep. R2-58. 36 p.

---

DWARF MISTLETOE COMMITTEE REPORT - 1998  
ROCKY MOUNTAIN REGION

9. Control - Silvicultural

Plans are to treat 3,162 acres of dwarf mistletoe infested stands on the Medicine Bow/Routt; Pike and San Isabel and White River National Forests. (P. Angwin, D. Johnson, USFS, R-2).

10. Dwarf Mistletoe Surveys

Presuppression surveys for dwarf mistletoe are planned for 19,550 acres on the Arapaho and Roosevelt and Medicine Bow/Routt; San Isabel, White River and San Juan National Forests. (P. Angwin, D. Johnson, USFS, R-2).

---

DISEASE CONTROL COMMITTEE REPORT - 1998  
ROCKY MOUNTAIN REGION

The Bessey Nursery, located in Halsey, Nebraska, is participating in the nationwide project for developing alternatives to methyl bromide. Basamid (Dazomet), solarization and fallowing with tilling will be compared to methyl bromide as alternative treatments. Soil samples were tested at Oregon State University for pathogenic nematodes and soil-borne fungi. Eastern redcedar was sown in the treated beds and will be evaluated for emergence and growth vigor for the next two years along with soil samples to compare the best yield results of the various treatments.

---

ROOT DISEASE COMMITTEE REPORT - 1998  
ROCKY MOUNTAIN REGION

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

INVESTIGATORS: Pete Angwin, Tom Eager, Jeri Lyn Harris, Dave Johnson and Bernard Benton, Forest Health Management, Rocky Mountain Region.

COOPERATORS: Bov Eav, Renee Platz, Julie Williams-Cipriani, Judy Adams, Forest Health Technology Enterprise Team; 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; Jon Morrissey, Grand Mesa, Uncompahgre and Gunnison National Forests; Phil Kemp and Bob Vermillion, San Juan NF.

YEARS: Begun- 1990; End- indeterminate

PROJECT DESCRIPTION: From 1991 to 1997, a network of permanent plots were installed to track the spread and intensification of root diseases, dwarf mistletoes, stem rusts and western spruce budworm in a variety of cover types throughout the Rocky Mountain Region. The objective of the project is to establish a series of permanent plots to provide data for the validation and calibration of various insect and disease computer simulation models. In 1998, all 426 root disease plots were remeasured and the installation of plots to track white pine blister rust in limber and whitebark pine was completed. Additional plots were also installed to monitor subalpine fir decline in Utah and Wyoming. Placement of the data into the PTIPS database and data analysis are currently underway.

---

PROJECT TITLE: GIS-Based Landscape-Scale Root Prediction System For Pinyon Pine Decline.

INVESTIGATORS: William Jacobi and Sam Harrison, Dept. of Plant Pathology and Weed Science, Colorado State University (CSU); Pete Angwin, Tom Eager, Roy Mask and Michelle Frank, Forest Health Management, Rocky Mountain Region

COOPERATORS: Eric Smith, Forest Health Technology Enterprise Team; Jose Negron and John Lundquist, Rocky Mountain Forest and Range Experiment Station; Robin Reich and Gene Kelly, CSU; John Guyon, R4 FHP; Terry Rogers, R3 FHP; Phil Kemp, Eric Lindroth and Dan Greene, Dolores Ranger District, San Juan NF; Jim Friedley, BIA Southern Ute Agency; John Waconda, BIA Albuquerque Area Office; Dan Ochocki, Colorado State Forest Service, Durango District.

YEARS: Begun- 1998; End- 2000

PROJECT OBJECTIVE: To produce a GIS-based landscape scale prediction system for incidence of pinyon pine decline in Southwest Colorado. The general principles of this model will be applicable, with local modifications, to pinyon/juniper forests throughout the Intermountain West.

PROJECT DESCRIPTION: Although a variety of causes are responsible for decline of pinyon pine in various areas, in many locales the key agents are black stain root disease (*Leptographium wageneri*) and pinyon ips (*Ips confusus*). Using aerial photography and site visits by field personnel, mortality centers in pinyon pine on the San Juan National Forest and Southern Ute Indian Reservation will be located and entered into a GIS database along with soil and site characteristics and locations of disturbed areas. By analyzing the data using spatial statistics, a hazard rating system will be developed for pinyon pine decline in Southwest Colorado.

During the 1998 field season, conventional and digital color infrared aerial photographs were acquired in the study areas on the San Juan NF and Southern Ute Indian Reservation. Ground transects were run over a sample of mortality sites, where insect, disease and site characteristics were recorded.

## Forest and Shade Tree Disease Studies in 1998

Dr. Bill Jacobi,  
Lab Tech. Ronda Koski,  
Graduate Students Sam Harrison, Jeff Kepley, Holly Kearns  
Undergraduate students, L. Polis, S. J. Wang, B. Swan, and A. Strueh  
Department of Bioagricultural Sciences and Pest Management  
Colorado State University, Fort Collins CO

### In 1998 we conducted:

1. a third season of determining better IPM procedures for Colorado nurseries
2. completed our study on *Cytospora* fungi pathogenicity.
3. initiated a study to determine if wood chip mulch is a potential pathogen inoculum source.
4. initiated a canker study on trees under three irrigation treatments at our tree and turf research facility.
5. continued the writing of a shrub and tree disease guide for Colorado.
6. continued water potential study of old growth cottonwoods in Denver CO.

### Results:

#### 1. Nursery IPM:

Since the year started out dry there was limited damage from *Marssonina* leaf spot of poplars but considerable damage late in the season from *Septoria* leaf spot.

We collected spores during the growing season from *Marssonina*, *Septoria*, and poplar rust leaf spot fungi to find when spores are produced in relation to meteorological variables so preventative measures can be taken.

#### 2. *Cytospora* Canker:

Pathogenicity tests of two fungal isolates from 6 host species are done and analysis indicates there are host specific *Cytospora* species on hardwoods. Ash isolates seem host specific, cottonwood, aspen isolates seem to have the same host range but we are not sure about elm, willow and alder. We have collected some of the isolates needed for a companion genetics study of *Cytospora* that will be conducted in the future if we can find funding.

#### 3. Mulch Study:

We have started a study at our Tree and Turf facility to determine if uncomposted wood chips can harbor inoculum of canker pathogens and how long does the fungus remains viable. Low and high irrigation treatments will be used to determine if mulch moisture content affects viability.

#### 4. Tree and Turf Research Facility:

The facility was completed this summer and treatments and data collection on tree physiology and pest resistance started this year. We are inoculating green ash with *Cytospora* and Honeylocusts with *Thyronectria* isolates to see if different irrigation treatments affect resistance to these canker pathogens.

5. Shrub and Tree Guide:

We are slowly working on a combined insect and disease guide that is under development on shrubs and trees in Colorado. Both electronic and paper forms are planned with color pictures for diagnosis.

6. Old Growth Cottonwoods:

We are studying the water status of old cottonwoods along a 100 yr-old irrigation canal that runs through metropolitan Denver. The water may be shut off from the canal and we trying to find how long the trees can handle reduced water etc. We hope to use the study to also look at cottonwood's susceptibility to Cytospora under various drought stress scenarios.

**Plans for 1999:**

1. Continue mulch/inoculum and canker resistance studies at the tree and turf research site.
2. Publish Cytospora pathogenicity study.
3. Complete nursery IPM studies and write up monitoring guides
4. Continue cottonwood drought stress study.
5. Complete a tree and shrub disease identification and management guide for use by arborists, nurseries, and homeowners.

**Forest Tree Disease Studies in 1998**

1. continued to analyze the spatial relationships of Armillaria root disease and site features in the Black Hills of SD.
2. in cooperation with Forest Health Management, Rocky Mt Research Station, US Forest Service, BIA, initiated a study to see if aerial IR photos would pick up black stain root disease and Ips beetle damage in pinyon, and determine if there are any site or stand conditions related to the incidence of these damage and if we can trap potential insect vectors of black stain root disease in southern CO.

**In 1999 our plans are to:**

1. In cooperation with Forest Health Management, US Forest Service, finish analysis of the influence of meteorological, site and soil factors on the spatial small (1/2 mile) and landscape scale distribution of Armillaria root disease on ponderosa pine in the Black Hills.
2. Continue a research project on black stain root disease of pinyon pines in southwest CO. We will be looking at spatial relationships with site, soil and management activities. Funding is not secure yet.
3. In cooperation with John Lundquist, Rocky Mt Research Station, try to obtain funding to look at root diseases on spruce-fir blown over in the fall of 1997.

**Publications:**

Jacobi, W.R., Kelly, E.J., Troendle, C.A., Angwin, P.A., Wettstein, C.A. 1998. Environmental conditions and aspen regeneration failure. USDA, For. Serv. Rocky Mt. Region, Tech Rep R2-60. 25pp.

## BUSINESS MEETING MINUTES

prepared by Lori Trummer, 1998 WIFDWC Secretary

Chairperson Bob Edmonds called the meeting to order at 10:30 am on Friday, October 2, 1998 in Reno, Nevada. The minutes from the 1997 WIFDWC meeting in Prince George, British Columbia, were approved as written. A moment of silence was observed in remembrance of those who have recently died: Toby Childs, Charles Gardner Shaw, John Woo, Virgil Moss, Art E. Parker, Reed Miller, and Pat Gilbertson (wife of Bob Gilbertson). Art Parker was proposed and recognized as an Honorary Member.

John Schwandt, WIFDWC Treasurer, could not attend the business meeting but prepared a written report. The report stated a balance of over \$5,000 as a result of John Muir, B.C. Ministry of Forests, kindly covering the costs of printing the 1997 proceedings, a modest surplus balance from the 1998 Hazard Tree Conference in Hood River, and thanks to several successive years when the proceedings were printed at no cost to WIFDWC. A copy of the full Treasurer's Report is included in the 1998 Proceedings.

### Committee Reports

Ellen Michaels Goheen, Chair of the Root Disease Committee, reported 34 participants at the breakfast meeting. Susan Frankel presented the results of recent work to validate the Western Root Disease Model P-type annosus functions (full paper in the Root Disease Committee Meeting Report). The User's Guide to the Western Root Disease Model Version 3.0 is now available.

Bob Mathiason, Chair of the Dwarf Mistletoe Committee, reported 500 participants (Wow!) at the lunch meeting. The group discussed the format of the Committee Report, deciding it would not be changed, and the production of new and or updated FIDL's for various dwarf mistletoes.

Diane Hildebrand, acting for Bob James as Chair of the Disease Control Committee, reported 15 participants at the breakfast meeting. The primary discussions centered on 1) the EPA re-registration of many pesticides important to forest nurseries, and 2) the next meeting of the Forest Nursery Pathology Workshop in 1999 at WIFDWC/WIFIWC in Breckenridge.

Rich Hunt, Chair of the Rust Committee, noted 37 participants at the morning meeting. Discussions centered around increased horticulture and habitat restoration planting of *Ribes* spp. plants which could exacerbate the spread of *Cronartium ribicola*.

John Pronos, Chair of the Hazard Tree Committee, reported that the group met and discussed the work of a company called Riparian Environmental Management (REM) in British Columbia. The group had many questions and reservations about the company's methods for treating forest stands and individual trees to increase windfirmness and decided not to pursue a demonstration by the company.

Written committee reports are included in the 1998 Proceedings.

### Future Meetings

The 1999 WIFDWC meeting will be held jointly with WIFIWC in Breckenridge, CO, September 13-17, 1999. The railroad committee selected the following officers for the 1999 meeting: Chair - Fred Baker; and Secretary - Ellen Goheen. The selections were approved, seconded, and passed with a lone

dissenting vote by Don Goheen. Other officers for the meeting include Jane Taylor as Interim Program Chair, John Schwandt as Treasurer, and Dave Johnson taking care of the Local Arrangements. A Program Chair will be selected by the Chair at a later date.

The 2000 WIFDWC meeting will take place in Hilo, Hawaii. Susan Frankel (Region 5) initially investigated meeting plans, however Region 5 has bowed out of the planning and Jerry Beatty and Sally Campbell (Region 6) will undertake final meeting coordination. The timing of the meeting and price structure (group rates) will still need to be worked out. Concern was raised that Canadian participants may not be able to receive permission to attend the meeting unless the program clearly demonstrated benefits to the provinces. The program is still under discussion but panel topics will likely include exotic pests and log imports.

An invitation was extended by Lori Trummer (Region 10) to hold the 49th WIFDWC in 2001 in Anchorage, Alaska. Dates and other meeting arrangements will be investigated by Lori Trummer.

An invitation was extended by John Muir to hold the 50th WIFDWC in 2002 in Victoria/Vancouver Island. Since the 1st and 25th WIFDWC meetings were also held in Victoria, the Canadian participants are excited about possibly holding the 50th meeting there as well.

### **Old Business**

WIFDWC Outstanding Achievement Award - An Awards Committee composed of Ken Russell, Susan Frankel, Greg Filip, and Simon Shamoun developed a "new award" proposal. Susan Frankel presented the proposal for a new award to take the place of the former Social Achievement Award (retired in 1997). A lively discussion followed which centered primarily on whether the award should only honor lifetime/career-long achievement or honor any outstanding achievement, and whether there should be two awards - one for "younger" members and one for "more senior" members. An amendment was proposed to only recognize lifetime achievement in Forest Pathology, however it failed. A second amendment was proposed to eliminate the stipulation that the individual's achievement record is limited to the past 5 years. This amendment passed. A motion was made and carried to accept the amended Outstanding Achievement Award proposal. The Assembly decided to try the award criteria for a several years to see how it worked. The final Outstanding Achievement Award description can be found in the 1998 Proceedings.

WIFDWC Bylaws - Susan Frankel presented the Draft Bylaws to the Assembly. The Bylaws Committee composed of Walt Thies, Jerry Beatty, Rona Sturrock and Susan Frankel developed revised WIFDWC Bylaws that were a "fine-tuning" of Bylaws proposed by John Laut at the 1997 WIFDWC Business Meeting. An amendment was proposed and passed for Article 2: Membership to add in Manitoba, Dakotas, Nebraska, and Kansas as states or provinces defined as Western North America. An second amendment was proposed and passed for Article 6: Bylaws to read that the Bylaws may be amended by a 2/3 majority vote of the membership queried at the business meeting, striking that Bylaw amendments could be made through vote by mail. A motion was made and carried to accept the Bylaws as amended. The final Bylaws can be found in the 1998 Proceedings.

### **New Business**

Rich Hunt raised the subject that participants at the 1998 WIFDWC reviewed and revised the proposed list of common names for diseases of Douglas-fir, as printed in the American Phytopathology Society (APS) newsletter, Phytopathology News, in May 1998. The common names agreed to at the 1998 WIFDWC meeting now agree with the WIFDWC list of common names for tree diseases:

Hawksworth, F.G., Gilbertson, R.L., and Wallis, G.W. 1985. Common names for tree diseases in the western United States and western Canada. Supplement to the Proceedings of the 32nd Annual Western International Forest Disease Work Conference. Taos, NM, Sept. 25-28, 1984.

Rich Hunt proposed a motion that the Secretary send the WIFDWC revised list to APS under the signature of the WIFDWC group. The motion was seconded and carried. Rich Hunt also raised the subject that the WIFDWC list should be reviewed and possibly revised in the future. The Assembly agreed to discuss revision of the WIFDWC list at the 1999 Business Meeting.

There was a brief discussion on a web site for WIFDWC. Brian Geils suggested that, with some money for software costs, his Webmaster Dan Huebner could assist in site development. However, the question remains as to where the site would be housed. Discussions would continue with Treasurer John Schwandt who was not present at the meeting. The Assembly generally agreed that a web site would be useful but no vote was taken on the subject.

Bob Mathiason raised the subject of the time allotted for committee meetings, indicating that 1.5 hours is really necessary to cover all the business in the meetings. No vote was taken on the subject.

Hal Burdsall raised the subject of the timing for the business meeting, suggesting that holding the business meeting at the end of the conference is the worst time to encourage participation. Many people have already left or are preparing to leave the conference site. Walt Thies suggested that the business meeting be split into two parts; one part earlier in the meeting and a second part later in the meeting. The Assembly agreed that the subject of the Business Meeting comes up nearly every year but no changes are made. The Assembly agreed to talk about it at the 1999 Business Meeting.

Ellen Goheen, author/editor of the WIFDWC Forest Pathology Family Tree, raised the question of whether only WIFDWC members are to be included in the Family Tree. After receiving questions and some complaints regarding names on the tree, she brought the question to the Assembly. The consensus of the Assembly was to include only WIFDWC Members.

The meeting was adjourned at approximately 12:25 p.m.

Respectfully submitted by Lori Trummer, WIFDWC 1998 Secretary



Lori Trummer



Greg DeNitto

**Bylaws of the  
WESTERN INTERNATIONAL FOREST DISEASE WORK CONFERENCE**

Passed by Vote of the Assembly at the Business Meeting  
October 2, 1998

Article 1  
**OBJECTIVES**

The Western International Forest Disease Work Conference (WIFDWC) was formed in 1953 to provide a forum for information exchange among forest pathologists in western North America. The primary objectives of the organization are:

To exchange information on forest pests and related matters through periodic meetings and other appropriate means,

To promote education, research and extension activities in forest pathology,

To sustain and improve the health of western North America's forests.

Article 2  
**MEMBERSHIP**

Membership is open to individuals who are engaged in forest pathology related endeavors in western North America. These include but are not limited to: research, survey, management, teaching or extension activities pertaining to tree diseases, forest health, or deterioration of forest products.

Western North America is defined as:

**Canada: British Columbia, Yukon, Alberta, Manitoba, Saskatchewan;**

**United States: Washington, Oregon, California, Idaho, Nevada, Utah, Arizona, Montana, Wyoming, Colorado, New Mexico, North Dakota, South Dakota, Nebraska, Kansas, Alaska, Hawaii, Guam, the Commonwealth of the Northern Mariana Islands and other Pacific Islands in Micronesia;**

**and all of Mexico.**

Membership is established after attending one Western International Forest Disease Work Conference. Members must attend another Western International Forest Disease Work Conference within 5 years or their membership is no longer valid.

Honorary members are WIFDWC members who have retired from continuous employment in the field of forest pathology. A list of honorary members will be published in the Proceedings of each meeting.

Article 3  
**OFFICERS**

WIFDWC officers will include a chairperson, secretary, treasurer, and historian. The chairperson and secretary will be elected by majority vote of the membership at the annual business meeting. If there is no majority, an acting chairperson will be appointed by the current chairperson. The tenure of the chairperson and secretary begins at the conclusion of the WIFDWC meeting where they were elected and ends when all business from their year's WIFDWC is completed. The treasurer and historian will be elected every five years, to serve for the following 5 years.

**Duties of the Chairperson.** At each WIFDWC, the chairperson will run the general and business meetings. The chairperson will appoint an interim program chairperson at the start of each WIFDWC to gather suggestions and opinions to guide the conference in the planning of next year's conference. The chairperson will also appoint three members to serve as the "railroad committee" to nominate candidates for next year's chairperson and secretary (and every fifth year, treasurer and historian). The chairperson may appoint members to assist in conducting the affairs of the Conference including but not limited to: local arrangements chairperson and program chairperson. The chairperson, secretary, treasurer and other appointees together form the executive committee. The chairperson may also appoint ad hoc committees and their chairpersons as deemed necessary to assist in carrying out the mission of WIFDWC.

In the event that the chairperson cannot carry out their duties, the previous chairperson will carry them out. If other members of the executive committee cannot or will not carry out their duties the chairperson may appoint a replacement.

**Duties of the Secretary.** The secretary shall maintain the membership and mailing lists. The secretary shall send out meeting notices to the membership, take minutes at the business meeting, and compile and distribute the Conference proceedings.

**Duties of the Treasurer.** The treasurer shall receive all payments, be custodian of WIFDWC funds, keep an account of all moneys received and expended, and make commitments and disbursements authorized by the chairperson. At the annual business meeting the treasurer shall make a full report covering the financial affairs of WIFDWC. All funds, records and vouchers in the treasurer's control should be subject to inspection by the executive committee.

**Duties of the historian.** The historian will keep a complete set of WIFDWC proceedings and answer any inquires as needed. The historian will contact the WIFDWC secretary and provide the address for mailing the archival copy of the proceedings.

**Compensation.** Officers will not be compensated for their services.

**Non-liability of officers.** The officers shall not be personally liable for the debts, liabilities or other obligations of WIFDWC.

Article 4  
**DECISION MAKING PROCESS**

The business meeting will be run by Roberts Rules of order. Meetings are open to the public and non-members may participate in meetings. Only members may vote.

Decisions will be made by majority, with each member granted one vote. Votes may be called for at the annual business meeting. A quorum is reached when more than 25 members are present.

Article 5  
**FINANCES**

**Expenditures.** The chairperson may authorize expenditures of WIFDWC funds. Checks, orders for payment, etc. may be signed by the treasurer, or other person designated by the chairperson. The executive committee may determine which and how many, outside speakers they want to invite, and travel costs for such speakers can be paid from registration fees.

**Contracts.** The chairperson may authorize any officer or agent of WIFDWC to enter into a contract on behalf of WIFDWC. Unless so authorized, no person shall have any authority to bind WIFDWC to any contract.

**Gifts.** The chairperson or the treasurer may accept on behalf of the WIFDWC any contribution, gift, or bequest. Commercial sponsorship of conference special events is not allowed.

**Fiscal year.** The WIFDWC fiscal year shall begin on the first of January and end on the last day of December.

Article 6  
**BYLAWS**

**Amendments.** Changes to bylaws shall be presented to all WIFDWC members for review. The bylaws may be amended by a 2/3 majority vote, queried at a business meeting.

Article 7  
**MEETINGS**

**Frequency.** The WIFDWC endorses holding annual meetings but will, on vote of the membership, change the time of any particular meeting when circumstances dictate that such action be taken.

**Date.** WIFDWC endorses holding meetings in late Summer but will, change the interval between any two meetings when circumstances dictate that such an action be taken.

Article 8  
**COMMITTEES**

The following are standing committees of WIFDWC:

Hazard trees committee,  
Dwarf mistletoe committee,  
Root disease committee,  
Rust committee,  
Disease Control committee.

Article 9  
**PROCEEDINGS**

Papers for each year's proceedings must be submitted to the secretary by November 1 of the year of the meeting.

Distribution of proceedings is made to all paid registrants and honorary members who have indicated a desire to receive them and will be made available to others at cost. The secretary will query all honorary life members to determine if they want to receive a free copy of the proceedings and only those responding in the affirmative will receive a copy.

---

**Items omitted that were in previous bylaws:**

Use of tape and other transcribing equipment to record presentations is not permitted.

Students are defined as "any individual enrolled in Forest pathology in a university and who is not more than 50% employed". They should not be charged a registration fee but they can be charged for field trip and banquet.

5 year membership requirement does not apply to members from Mexico.

Award competition be divorced from the banquet and that the event be moved to an earlier night so the award could be presented at the Banquet. The award committee make their choice before midnight, the night before the banquet.

Select meeting site 3 years in advance.

Affiliation with other groups - WIFDWC should not have direct affiliation with any group.

Meeting location shall be in Victoria, Portland, OR or Spokane, WA.

Transcripts of meetings follow the format of the proceedings of the 3rd WIFDWC.

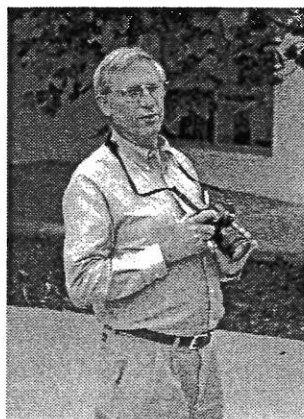
## TREASURER'S REPORT, 46th WIFDWC

prepared by John Schwandt, WIFDWC Treasurer

Meeting Participants: There was a total of 83 participants at the 1998 meeting; 61 regular members, 8 students, 8 retirees, and six guest speakers.

The following is a summary of transactions for the 1998 WIFDWC meeting in Reno, Nevada.

TRANSACTION	AMOUNT	BALANCE
Balance reported at close of 45th meeting in Prince George, BC (11/1/97)		5,138.28
1998 Hazard Tree Conference - Hood River, OR		
Total Registration Receipts	8,355.00	13,493.28
Expenditures since 11/97: (total = \$7688.50; \$500 deposit paid in last proceedings)	-7,188.50	6,304.78
Hazard Tree Balance: (\$1,874.83 from '96 + new balance \$666.50 = \$2,541.33)	-2,541.33	3,763.45
1997 WIFDWC (Prince George, BC) adjustments		
Mailing costs for proceedings (printing/binding thanks to John Muir)	-320.96	3,442.49
Additional residual (in addition to the \$832.48 previously reported)	249.37	3,691.86
1998 WIFDWC Transactions		
Total registration	7,110.69	10,802.55
Field trip transportation	-932.00	9,870.55
Speaker expenses	-1,387.19	8,483.36
Meeting rooms, banquet, etc.	-3,331.23	5,152.13
Mailing costs for announcements (2)	-366.86	4,785.27
Breaks, Hospitality, misc. expenses	-1,097.00	3,688.27
Interest paid to account from 11/1/97 through 11/23/98	145.94	3,834.21
Sales of proceedings	20.00	3,854.21
<b>CURRENT BALANCE (as of 11/23/98):</b> <u>excluding Hazard Tree balance of \$2,541.33</u>		<b>3,854.21</b>
Printing and mailing costs for 1998 proceedings will be subtracted from this balance and reported in next years proceedings.	???	



John Schwandt, Treasurer  
and photographer.

## MEMORIAL STATEMENTS

### In Memory of Charles Gardner Shaw (1917-1998)

The following memorial statement is an excerpt from an article written by Jack Rogers and Lori Carras in the Department of Plant Pathology at Washington State University. The full text of the article can be found in the September-October 1998 issue of *Mycologia*, pages 927-929.

“Charles Gardner Shaw, a former long-time member of the faculty of Washington State University, died February 12, 1998, in Pullman. Professor Shaw was born August 12, 1917, to Dr. Walter A. and Hattie M. Hendricks Shaw in Springfield, Massachusetts. He was reared and educated in Springfield. Following graduation from high school, he attended Ohio Wesleyan College where he received a baccalaureate degree. He continued his education at Pennsylvania State University, earning a master’s degree, and the University of Wisconsin, earning a doctorate in botany in 1947 under the late M.P. Backus. His dissertation dealt with the Peronosporaceae of Wisconsin. While at UW he married Esther Anne Tennant on August 17, 1940. During WWII he served in the U.S. Marine Corps in the South Pacific Theatre including Okinawa and Guadalcanal. He was honorably discharged with the rank of major. He later served in the Marine Corps Reserves and while in Pullman was the liaison officer for the Marine Corps at the State College of Washington, now University, for several years. Shaw joined the faculty of the State College of Washington in 1947 and became chairman of the Department of Plant Pathology in 1961, serving through 1972. He retired from Washington State University in 1983.

“Professor Shaw, at various times, taught mycology and forest pathology. He was known as an enthusiastic and demanding teacher. He often was colorfully garbed in combinations of plaids and stripes with the inevitable handlens hanging from his neck. He was highly educated and interested in all things with a mycological connection. Examinations might, for example, ask the student to make a connection between a Greek myth and a mycological phenomenon. He was an excellent field botanist and made careful identifications of host plants. He was likewise attuned to wildlife and geological phenomena. He loved collecting and field trips connected with the Field Mycology course were particularly memorable. Professor Shaw planned the trips with special regard to unusual scenery and opportunities to observe or discover particular host-parasite phenomena. He would divide students among available vehicles and, being the lead driver, take off at the highest legal speed. It was up to the following drivers to keep up with him. Short cuts over poorly maintained roads were the rule. When a collecting area was reached, everyone would pile out and begin to collect everything in sight. Shaw would be close to the literature used to identify host plants, and along with his hand lens, help students determine host plants on the spot. Plants were then put in a plant press. Nights were always spent camping. Camps were usually made at some spot that coincided with sunset. Supper was hastily prepared, water boiled for morning use, and lanterns lit. In at least one tent, Professor Shaw would initiate a bridge game that would continue into the wee hours. Breakfast was at daybreak and usually featured Shaw’s pancakes. Then, it was clean up, pack up, and tear off to the next site. All told, these field trips were interesting, educational, and exhausting.

“Professor Shaw was involved in a number of research areas in forest pathology, usually with his graduate students. Among his research areas were: white pine blister rust; dwarf mistletoes; insect dissemination of basidiospores from sporophores of wood decay fungi; decay of forest residues. He and his students had, and continue to have, an enormous influence on forest pathology nationwide. In combined contributions to mycology and forest pathology, Professor Shaw published over 130 papers.”

WIFDWC 1998

To Fellow Forest and Plant Pathologists:

I learned Saturday that Dr. C. Gardner Shaw, Professor Emeritus, died Friday, February 13 of heart failure in Pullman, Washington. Many of us knew Gardner well and learned much from him throughout our careers. I remember him most through his attendance at the Western International Forest Disease Work Conferences over the last 32 years. He was one of the charter members of that organization and was instrumental in seeing that it got off to a lively and educational start.

When I first came to Washington in 1965, Gardner was most helpful in welcoming a new and very green forest pathologist into a forest where only a few had been. I would call him on many occasions to ask his opinion on the various pathogens that we then knew mostly about in name only. His advice was well taken and helped to shape a course of research and diagnosis for numerous mysterious diseases of forest trees.

In the late 60's and early 70's Gardner made sure that the State's many Plant Pathologists and the lone Forest Pathologist (me) got acquainted through annual get-togethers where I learned about things like "simple dimple" and "dapple apple;" and the agriculturally oriented Plant Pathologists learned about my struggles on what to tell landowners about "Poria."

Gardner's late night poker games at these meetings were legendary - one of the things I did not learn; I could not stay up that late! I only heard about the games from the losing players!

Gardner left an educational legacy in Plant Pathology at Washington State and around the world. He left it for us in the science of Plant Pathology to carry forward. A memorial service on February 16 in Pullman will celebrate his life.

Kenelm Russell  
Forest Pathologist  
Olympia, Washington  
USA

WIFDWC 1998

**In Memory of Thomas W. "Toby" Childs (1908 - 1998)**

30 June 1998  
14120 SW Stallion Dr.  
Beaverton, OR 97008

WIFDWC Secretary  
British Columbia ministry of Forests  
Silviculture Branch  
3rd Floor - 31 Bastion Square  
Victoria, BC Canada V8W 3E7

Dear Sir-

My dad is Thomas W. "Toby" Childs. I don't know if you have heard about it, but he passed away on May 7. I'm sure that he would have wanted you to know, because you folks were important to him and he always thoroughly enjoyed the times that he could spend with you at your meetings. While he was physically able, he always looked forward with much anticipation to your meetings and conferences. I know that all of you occupied a very special place in his heart.

He was having some difficulty getting around from the beginning of 1998. He should have been using a cane all of the time, but you obviously know how stubborn he was. So, he fell in early April and broke his hip. After the surgery he was in a rehabilitation center, but he had difficulty breathing and his blood count became very low. My wife, our children, and I went to see him every day, and we took Mom (Edith) to see him the day before he passed away. In case you want to write her, her address is:

Mrs. Edith Childs  
Park Place Assisted Living  
8445 SW Hemlock, #219  
Portland, OR 97223

Among Dad's belongings were some writings of his. I've scanned some of them and find them heartwarming because of his humor and insight. I was purposely looking for some writings that referred to his work as a forester, as I knew that his professional work was very important to him. The enclosed, Some Nostalgic Trivia, is the first thing that I came across, and I hope that you find it valuable in some manner. If I come across anything else that I think will be of interest to you, I will send you a copy.

Thank you for being such an important and happy part of my father's life.

Sincerely,

Greg Childs

SOME NOSTALGIC TRIVIA

The important part of the history of forest pathology is mostly embodied in published reports together with a few unpublished ones. Equipment and methods in the past were somewhat less efficient, but technical difficulties, administrative conflicts, and financial stringencies did not differ essentially from those in research today.

Our lives, however, differed in many respects, and not always for the worse. Many years ago I knew an old lady who had crossed the plains in a covered wagon. I myself crossed the plains in a Model T Ford, on dirt or occasionally on gravel roads, at a maximum rate of 125 miles per day. A few months ago I crossed from Atlantic tidewater to Pacific tidewater between mid-morning and mid-afternoon, and enjoyed it far less than the Model T crossing. So a few personal memories may perhaps be of interest to WIFDWC antiquarians a century hence.

\* \* \* \*

My first job in pathology was in 1927, when lack of funds forced me to quit school and spend 6 months computing data for Jack Boyce. At first I ran a hand-crank calculator. Then we got an electric machine; you turned the motor on, and multiplied by holding the X button for the desired number of revolutions, just like firing a specified burst from a Tommy-gun. A good operator could get results almost as fast as from the machines now used, but the job that took me 6 months in 1927 would now be done in a few minutes by computer. I disliked being confined to an office, and was only moderately interested in pathology. I simply wanted to be a forester, and had no strong preference for any one speciality.

In 1928 I chased smoke in California. One period of 6 days on the fire-line with a total of 8 hours sleep convinced me there were easier ways to earn a living. Nevertheless, when I was graduated from Oregon Agricultural College in 1929 I'd have taken a job with the Forest Service except that I was 60 days too young. So I went to work for Portland Branch of the Office of Investigations in Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering, U.S. Department of Agriculture. This redundant title had grown as each new Bureau Chief added the name of his old Division. What finally stopped its growth was no doubt the increasing use of official automobiles; there wasn't room on the door for a longer Bureau name.

At the same time that I joined Portland Branch we acquired our first official car, a rather primitive pickup that served long and faithfully, with fewer defects than any of its numerous successors. (I hope its shade is cruising contentedly along forest roads in the Happy Hunting Grounds reserved for old Chevrolets.) Before then, field travel had been by train or boat as far as possible, and then by rented car, horse and buggy, or saddle horse.

During the early 'thirties my work was principally on slash decay, a useless and boring study. Examining pines for blister rust cankers was also monotonous, but we could envision worthwhile results, and there were occasional bright moments such as finding a Tuberculina infection or manoeuvring a friend into a yellow-jacket nest.

Our development as researchers was unquestionably hurt by an overdose of routine work, but at least we were in close contact with the things we were researching. The modern ideal seems to be to take a young Ph.D. and have him do nothing but sit at a desk and cerebrate over the data accumulated by technicians. This may be OK for nuclear physics, where entities must be inferred from their effects at several removes, but a biological researcher needs a first-hand acquaintance with his subject.

Monotony or no monotony, we were usually glad when April brought the field season.\* One exception was the spring when I was courting the girl I later married. By then I was fairly good at managing the boss (Harry Lachmund), so I kept suggesting that I ought to start field work. Harry kept replying that he made the decisions and would tell me when to go. In late May my girl went home to San Francisco. I pointed out the importance of some office jobs and was soon in the field.

Harry was a brilliant personnel problem, who finally misbehaved so seriously that he was lucky to be allowed to resign. The close administrative supervision that we now have (and which I have often cursed) would probably have saved the career of a high-quality researcher. Moral: The small and relatively independent research organization is the most efficient one if it has no major personnel problem. But, unfortunately, the more brilliant the man the more likely he is to be a problem.

Faster transportation and 'adjusted work weeks' have greatly improved working conditions. Now you can go anywhere in the region, work for 10 days, and have at least 3 days at home before starting another trip. We used to work a 6-day week, and travel was so slow that, for example, when we examined plots in Idaho we'd be gone for 5 or 6 weeks. If we weren't too far back in the brush we'd go to town on Saturday night and have a hot bath.

Although we usually got home every month or so, work on blister rust in British Columbia (under agreement with the Canadian Government) often meant leaving in early spring and not coming back until late fall. When Hansbrough was transferred here, his trip from the East to Portland was his honeymoon. As soon as he arrived he was sent to B.C. 'for 3 weeks' and was there for 6 months. The rest of us were not much more enthusiastic than Hansbrough about such long trips, but in those days of the Great Depression you had a free choice between hanging onto your job or starving. You couldn't even go on relief, because there wasn't any. What with long field trips and 3½ years of military service, I didn't have much chance to get acquainted with my sons until they were grown men.

We did a lot of camping, and as a young man I enjoyed <sup>most of</sup> it. Our cooking wasn't always good but it was better than that in most restaurants, and a couple of blankets on the ground were preferable to bedbugs in a cruddy hotel.

Outside the largest towns, restaurants ranged from poor to horrible. I still think that Captain Gray, when he discovered the Columbia River, must have penetrated as far inland as Crescent, Oregon, because the grease in that beanery couldn't have gotten so rancid in the time since Lewis and Clark's journey. But I often worked out of logging camps, where food was almost always good, and each spring I made up for a winter of boarding-house grub.

Food in Civilian Conservation Corps camps was rarely good. Most of the kitchens were run by Regular Army mess sergeants and camps were administered by Reserve Officers who didn't have enough experience to keep the sergeants from grafting. However, several of the men in my battery during World War II had been in the CCC, and they all said that it had been a fine thing for them.

Two of our men had to take jobs temporarily with the CCC when Portland funds were cut. Fortunately, Buchanan and I were working out of a nearby ranger station, and packed huge lunches each morning to keep our exiles from starving. Speaking of Buck and food reminds me -- he was responsible for the commissary on a back-pack job. I helped the crew pack in, and from the weight of the packs I was sure they had ample grub. But they had to work the last two days on a total of one box of crackers and one package of prunes. Buck had planned to spend his evenings picking huckleberries, and had bought a lot of pickles in order to have the jars for containers.

Since I have mentioned British Columbia, I should add that food there was almost always better than in the States. I never could figure why rustic cooking should be good north of the boundary and so God-awful south of it. Daisy Lake (now Garibaldi) was an exception; we'd get nothing but beans and salt pork there for 3 or 4 weeks.

At Daisy Lake we stayed at Shorty Knight's place. Shorty was a 'character', but since the idiosyncrasies of characters rarely seem funny at second-hand I'll refrain from examples. It seems as if there aren't any characters like there used to be. Lew Roth says that we in our turn will be considered characters by the next generation. Who, me? Impossible.

I was talking about food when I got off the line. Perhaps I have given it undue emphasis, but tobacco and an occasional good meal were our only field season luxuries. I still prefer cork-flavored coffee because it used to taste so good from the thermos at noon. The plastic plugs we get in thermos bottles now don't do a thing for the coffee, and I wish I had a good old-fashioned cork.

I don't want to convey the impression that our life was one of hardship. Life wasn't as easy then as now, but we were used to it and enjoyed most of it. In fact, we had 'hired out to be tough' and, within reasonable limits, we took pride in being tough.

We were always ready to go back to a warm office in November, for 5 months of data analysis and report writing. I enjoyed the analysis, although I used to long for a Hollerith Tabulator such as the Census Bureau used. Writing was, as it has remained, a hard task for me. With a salary that was never princely I have probably been one of the world's highest paid writers on a cost-per-word basis.

Just as the low quality of my golf game doesn't keep me from giving advice to my partners, the difficulties I have in writing will not keep me from offering a few words of wisdom on the subject. Just say what you mean as accurately, clearly, and concisely as you possibly can, without worrying about formulas for technical writing. If your result conforms to Washington Office guidelines, so much the better. But I have read a lot of damned bad papers that were perfect by these guidelines, while some of the very best technical writing -- Darwin's "Origin", for example -- would grade near zero. And if you can't make even tentative generalizations from your data, don't publish. Put the data in your files until they will support conclusions.

We did good work, on the whole, but I hate to think of the efforts we wasted. For example, the slash decay study was worthless. We spent 100 man-months on the Revelstoke plot when, with proper sampling, 20 man-months would have done the job. And, mea culpa, when I was the Portland boss we continued the windthrown timber decay study for several years after our road network had made immediate salvage possible almost everywhere.

\* \* \* \*

In 1929 I had promised Harry Lachmund to stay for the entire field season, so had to decline the offer of a fellowship at the University of Minnesota. Dr. Metcalf, our 'big boss' in Washington, did not approve of Harry's holding me to my promise, and in 1933 he got me a generous fellowship at the University of Pennsylvania. I quit my job (I was still on a 'temporary' appointment), got married, and took a Greyhound bus back to Philadelphia. When I got there my assets consisted of my wife and about \$100.

All of us, I am sure, enjoyed our work much more after Jess took charge, even though we were annually troubled by 'Fiscal Year blues'. (A little insecurity adds zest to life, but a man's work suffers when he lies awake at night worrying about how his dependents will fare if appropriations are cut any further. I did not enjoy World War II but preferred it to the Depression.) Jess was always fair and open to argument. Occasional differences of opinion never hurt our personal relations. Perhaps it's because I've been lucky in most of my superiors, but my experience has been that Civil Servants are freer to differ with their bosses than are men in private employ. At least, I have rarely seen the servility in public service that I have seen more than once in private business.

We gradually shifted a lot of our effort from routine blister rust studies to more interesting projects, and started to get acquainted with previously neglected Oregon and Washington forests. Then the war disrupted our activities, and I went into the Army to fight (Anopheles mosquitos, mostly) and bleed (a few samples to the medics) for my country.

Immediately after the war, several forest supervisors expressed concern about an outbreak of Elytroderma. I told them not to worry, that foliage diseases occasionally looked bad for a year or so but soon died down. Besides, I had seen immature Douglas fir commonly infected with Fomes pini or F. subroseus in several localities, and I wanted to look into the matter. But the Elytroderma did not die down, and it soon became apparent that heart rot was far less important than Poria weirii in young Douglas fir. If we had started work on Elytroderma in 1946 instead of 1950 we'd have done a better job because our records would have covered an earlier stage of the outbreak.

We should also have started dwarfmistletoe studies long before we did. We simply did not have the men or money to do this and other jobs that we knew were necessary. Consequently, as management became more intensive, forest managers were badly in need of research results long before we could supply them.

The Elytroderma and Poria studies, in my opinion, were my best research jobs. I enjoyed them even more because of the pleasure of working in ponderosa pine and immature Douglas fir types.

These studies were essentially long-term, and I had to resist a little pressure from Washington to give priority to jobs that could be wrapped up in a year or so. I could sympathize with the W.O. attitude, because Congressional committees are interested in current rather than potential results, but these important problems couldn't be solved on a crash basis even if we'd had unlimited financing. (Short-term studies are good for the morale of young researchers, who often feel that they aren't accomplishing anything; old researchers know that, even though progress seems slow, when they look back a few years they can always see that they have learned a lot.)

Like whiskey, a study plan is a good servant but a poor master. The Elytroderma study plan was all right as far as it went, but the thousands of observations it called for took so much time that I was at least 10 years slower than I should have been in noticing some of the clues to the parasite's peculiar behavior. Although the Poria study plan was also too limited in scope, we did a better job of picking up useful byproducts as we went along.

The high cost of our small additions to knowledge has always troubled me, and it is little consolation that nuggets are also few to the pan in other fields of research. However, I had the good fortune to do two jobs each of which more than repaid society for the total cost of my education, salary, and expenses. In the first instance, a week of reconnaissance showed that a proposed blister rust control project on high-altitude recreation areas would be futile because spread was from ribes more than 3 miles away. (Blister Rust Control refused at first to believe this conclusion, but soon found that a lot of lower-elevation control projects were leaking at every seam. This shows the great importance of keeping research free from vetoes by management agencies.) In the other instance, an examination showed that current heavy losses on a company forest were caused primarily by root rot and would continue indefinitely. The consequent change in logging plans saved the company nearly 100 MM feet of high quality stumpage. (These instances are not presented as examples of transcendent genius but simply of the economic value of trained, experienced men.) I have felt better ever since.

Like most superannuated researchers, I suppose, I regret especially the waning of my vigor as my experience waxed. It was only after about 15 years on the job that I began to believe I could do quality work, and those 15 years plus a considerable period of military service didn't leave me time to do much, even if I hadn't rapidly run out of gas. (I am no longer amused by bar-room signs asking "Why do we get so soon old and so late smart?") I regret that I used my legs more than my brains. And I regret that I was more interested in trees than in people -- not that I was too much interested in forestry, but that I was not interested enough in the many fine people with whom I had the privilege of working.

As I look over these reminiscences, I am disappointed. I always thought I'd had an interesting life, until I tried to write about it. I have read with interest the lives of lawyers, locomotive engineers, farmers, and a lot of other kinds of workers; I don't know why a forester's life shouldn't be equally interesting. But even though I am in my anecdotage I doubt that I could interest my public in such things as McCready and the woodpecker, the attractive Dumont sisters with whom we never took any liberties (their father was big as a horse and strong as two horses), or Lollie the Revelstoke bear. And my readers, both of them, are so familiar with cold April rain in vine maple understories, and crisp, golden October days in pine forests, that there is no need for me to be poetic on these subjects.

So this, Gordie, is the story of my life. You asked for it.

T.W. Childs  
Portland, Oregon  
30 January 1972

**In Memory of Douglas Reed Miller (1905 - 1998)**

Douglas Reed Miller, dedicated WIFDWC member died August 16, 1998. Reed and his wife Edna attended many WIFDWC's even after retirement and will be remembered for his rousing "Hail Beavers", his kindness and contributions to forest pathology over his 44 years of Federal service.

Reed was born in Maynardsville, TN and received his BS degree in Forest Management from Oregon State University in 1928 and an MS in Forest Pathology from Univ. of Idaho in 1932. In 1924 he was on one of the first crews eradicating Ribes in attempt to control blister rust in Idaho. He also worked in Oregon, and California, starting the Disease Survey Staff in California (now Forest Health Protection). He retired from the US Forest Service in 1970. Reed won the WIFDWC Social Achievement Award in 1964 and Edna won it in 1986. In addition to WIFDWC, he was active in the Society of American Foresters and the Boy Scouts of America.

