United States
Department of
Agriculture

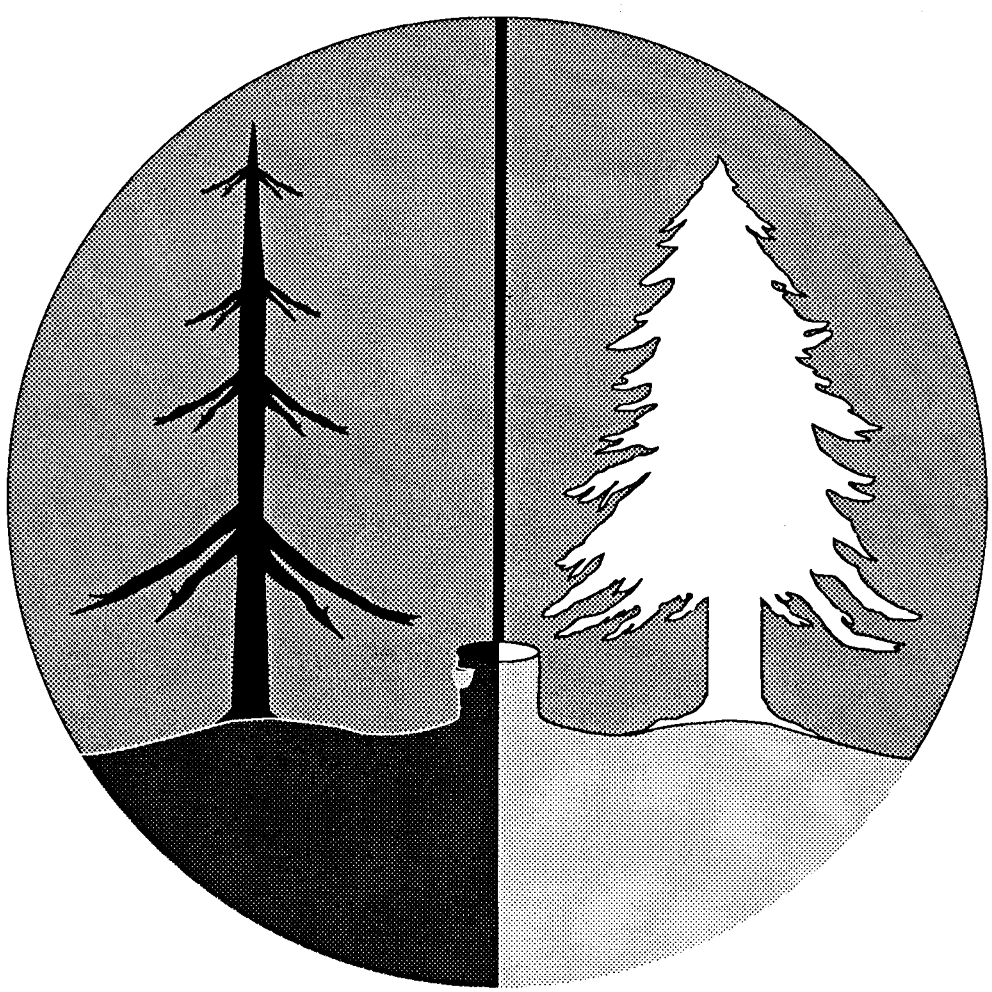
Forest Service

**Pacific Southwest
Forest and Range
Experiment Station**

General Technical
Report PSW-116

Proceedings of the Symposium on Research and Management of Annosus Root Disease (*Heterobasidion annosum*) in Western North America

April 18-21, 1989, Monterey, California



Otrosina, William J. ; Scharpf, Robert F., technical coordinators. 1989. Proceedings of the symposium on research and management of annosus root disease (*Heterobasidion annosum*) in western North. America; April 18-21, 1989; Monterey, CA. Gen. Tech. Rep. PSW 116. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 177 p.

The proceedings is a collection of papers presented at the Symposium on Research and Management of Annosus Root Disease (*Heterobasidion annosum*) in Western North America held in Monterey, California, April 18-21, 1989. As the first symposium dealing with this subject in the western United States, the papers presented address current research and management issues relating to the topics of biology, ecology, epidemiology, and genetics of *Heterobasidion annosum;* symptomatology, diagnosis, disease loss, and impacts; factors affecting loss and impact; and management strategies relating to survey, detection, and control, including case studies.

Retrieval Terms: Heterobasidion annosum, annosus root disease, root disease biology, root disease management, symptomatology, root disease impact, root disease losses.

Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

September 1989

Proceedings of the Symposium on

Research and Management of Annosus Root Disease (*Heterobasidion annosum*) in Western North America

April 18-21, 1989, Monterey, California

William J. Otrosina and Robert F. Scharpf, Technical Coordinators

CONTENTS

FOREWORD

Root diseases caused by fungi are considered by the Forest Service to be among the most damaging diseases of conifers in western North America. Research and development on control of these diseases is considered to be high priority.

Annosus root disease caused by the fungus *Heterobasidion annosum (Fomes annosus)* has been recognized as a worldwide problem in conifer forests for decades, and a substantial body of information and literature has accumulated on its biology, impact, and control. For example, at least 4 conferences on *H. annosum* have taken place under the auspices of the United Nations, Section 24, International Union of Forest Research Organizations. These were held in Germany (1954), Scotland (1960), Denmark (1968), and in the United States (in Georgia) (1973). To my knowledge, no other conferences have been held on *H. annosum* since 1973, and none has ever been hosted in western North America.

Does this mean that we have solved the annosus root disease problem elsewhere in the world and that western North America merely needs to apply their management practices? Unfortunately, neither situation is correct. Unlike Europe or eastern North America, the West has an entirely different collection of host species, different fungal strains, and a highly diverse range of climatic and edaphic conditions that affect the behavior of the pathogen and expression of disease.

We have by no means ignored the annosus problem in the West, however. There is an increasing awareness and concern among managers about the importance of this disease in our western forests, and scientists and pest managers have accumulated a substantial body of knowledge over the last decade or two on the management of annosus root disease. For example, we know that this disease does not operate alone to cause damage. Insects, other diseases, and weather (particularly drought) interact to influence the prevalence and severity of annosus root disease. In addition, we know that certain management practices can either increase or reduce disease losses.

It is for these and other reasons that a symposium on research and management of annosus root disease in western North America is particularly timely. The purpose of this symposium is to bring together scientists and managers from both east and west with the latest research information and case histories of management, along with other users and other managers to freely share and exchange the latest knowledge and information on research and management of this serious disease. This symposium should also indicate what further research and development are needed to improve the manager's ability to reduce losses from these and other serious root diseases of Western forests.

I hope this symposium will provide the forum for the free and open exchange of information among all symposium participants.

Robert F. Scharpf
General Chairman and Technical Coordinator

ACKNOWLEDGMENTS

Sponsors for this symposium were USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA; USDA Forest Service, Forest Pest Management, Region 5, San Francisco, CA; and University of California, Department of Plant Pathology, Berkeley, CA. We thank the many people involved in various phases of this symposium: John Kliejunas, Greg DeNitto, Fields W. Cobb, Jr., Thomas E. Chase, John Pronos, Melissa Marosy, and John R. Parmeter, Jr., for their help as members of the program committee; Arthur H. McCain and Garey Slaughter for local arrangements; Jeannie Buckingham and Alice Ratcliff for their assistance in registration, accounting, installing exhibits and setting up visual aids. Finally, we thank the panel moderators for their time and effort in preparation and presentation of symposium papers, the speakers for their informative presentations, and the many participants whose questions, comments, and discussions made this symposium a truly stimulating and valuable meeting.

William J. Otrosina, Forest Service, U.S. Department of Agriculture
Program Chairman and Technical Coordinator

Robert F. Scharpf, Forest Service, U.S. Department of Agriculture
General Chairman and Technical Coordinator

Arthur H. McCain, University of California, Berkeley
Local Arrangements Chairman

Top row -Earl Nelson, James Truman, Duncan Morrison, John Nesbitt, Martin MacKenzie, Sam Alexander, Bob Edmonds, Paul Hennon, John Pronos. **2nd row** - Melissa Marosy, Mike Williams, Ellen Goheen, David Shaw, Alan Kanaskie, Jerry Beatty, Mark Schultz, Susan Frankel, Greg Filip, Mark Fenn. **3rd row** - Jim Allison, Allea Haley, Art McCain, Leslie Markham, John Kliejunas, Ralph Williams, Nolan Hess, Bov Eav, Gary Petersen, Lome West. Bottom row - Jon Arnold, Bob Scharpf, Gregg DeNitto, Terry Shaw, Fields Cobb, Carroll Williams, Garey Slaughter, Frank Tainter.

Top row - Charlie Castro, Mike Rutty, Greg Filip. **2nd row** - Dick Parmeter, Lee Boeckstiegel, John Schwandt, Ellie Young, William McArthur, Bob Mathieson, Tom Corse, Pete Angwin. **3rd row** - Dave Adams, Mike Srago, Don Owen, Lew Roth, Don Goheen, Ken Russell, Catherine Parks, Dick Smith, Jim Byler. Bottom row - Craig Schmitt, Will Littke, Fred Baker, Jerry Beatty, Tom Warner, ?

History

Annosus Root Disease in Europe and the Southeastern United States: Occurrence, Research, and Historical Perspective'

William J. Stambaugh[2]

Abstract.--The history of annosus root disease in Europe and the southeastern United States is reviewed in prefacing the focus of this symposium on the disease as it occurs in the western United States. The topic is developed mostly from world literature on the disease published since mid-1970. The occurrence of annosus root disease in both plantations and natural stands of conifers is discussed, with particular emphasis on disease range, host-pathogen variability, and environmental influences. Concluding attention is given to re-examination of the U.S.D.A. Forest Service guidelines for management of annosus root disease in the southeastern United States in the light of current understanding and the continuing need for improved technology transfer.

The "death circle" in Hartig's (1894) textbook description of annosus root disease nearly a century ago has become an all too familiar sight in conifer stands throughout the north temperate region. Even then, he recognized tree-to-tree spread of Trametes radiciperda Hartig (equals Heterobasidion annosum (Fr.] Bref.) via root contacts, but it was not until more than 50 years later when Rishbeth (1951) made the connection by showing the potential for disease initiation through plantation thinning and basidiospore colonization of fresh-cut stumps, thereby reaching adjacent trees. This mode of spread has accounted for a long history of damage in Europe where losses occur as: (1) mortality of residual stems in young conifer plantations, following and related to the extent and number of thinnings (Greig 1984) and (2) wood loss from butt and heart rot of old-growth timber, particularly Norway spruce (Picea abies Karst.), on previously cut-over lands (Dimitri 1973). The total loss from such impacts has been estimated for the countries of the European Economic Community alone at $35 million annually (Dimitri 1973).

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2]Professor of Forest Pathology, Duke University, Durham, NC

In the eastern United States and Canada, where H. annosum has been known mycologically since the 1980's (Ross 1975), disease occurrence was not recognized until the late 1940's as plantations reached thinning age at an increasing number of locations (Kuhlman and others 1976). A major research effort, spearheaded by the USDA Forest Service, soon followed, especially in the southeastern United States, where vast mono-cultures of fast-growing, densely planted southern pines required frequent thinning and thus were considered vulnerable. As studies evolved, it became evident that the mode of spread in the principal southern hard pines conformed to that of Pinus spp. in Europe (Kuhlman and others 1976), whereas butt rot and windthrow of live stems are more common in eastern white pine (P. strobus L.), western hemlock (Tsuga heterophylla [Raf.] Sarg.) (Edmonds and others 1984), and perhaps other less resinous species, much like that of spruce in Europe. Additional data on disease impact showed significant reduction in height and trunk diameter growth in loblolly pine (P. taeda L.) (Alexander and others 1975, Bradford and others 1978) and slash pine (P. elliottii Engelm. var. elliottii) (Froelich and others 1977) during the few years preceding tree death.

In the last two decades in the United States, the emphasis in research on H. annosum has shifted almost exclusively to the western states where the pathogen attacks a broad array of tree species in a variety of environments and where its potential in second-growth forest management is a mounting concern because of the historical record of the disease elsewhere. Now, after the passage of nearly 100 years, more than cursory attention, and two bibliographies (Koenigs 1960, Hodges and others 1971), the literature base on the disease is conservatively estimated at 1800 research papers and reports.

The focus of this paper is drawn primarily from the literature published since the mid-1970's, as identified by the last IUFRO (International Union of Forest Research Organizations) conference solely devoted to annosus root rot (Kuhlman 1974), the eastern states status report by Ross (1975), and the disease management recommendations of Kuhlman and others (1976). These accounts basically closed the ledger on USDA Forest Service research on the disease in the eastern United States. With research continuing so actively in the west ever since, there is ample justification for naming this symposium "... in Western North America." Citations to western work herein, however, will be selectively limited in deference to this being the historical review topic of Smith (1989) that immediately follows in this symposium.

OCCURRENCE

Host-Pathogen Range

The incidence of *H. annosum* is greatest where plantation culture and thinning of conifers are practiced and less so in natural stands, due in part to a diminished root-contact potential and the likelihood of intervening non-host species in mixed stands. Judging from the comprehensive host list of Sinclair (1964) and subsequent updatings (Greig 1976, Webb and Alexander 1985), there seem to be few coniferous species that have not been reported as hosts. A number of hardwoods and woody shrubs are also listed, but damage of any consequence is reported only from continental Europe on *Alnus* and *Quercus* spp. (Dimitri 1973) and from Great Britain on *Q. borealis* Michx. and *Nothofagus obliqua* (Mirb.) Blume underplanted to *Pinus* spp. (Greig 1974). It remains to be seen whether the findings of *H. annosum* in several Central American countries (Greig and Foster 1982) and in eastern Australia (Shain and Bolland, in Kuhlman 1974) pose any threat for ultimate spread to extensive exotic plantings of known hosts at various locations in the southern hemisphere, particularly Australia and New Zealand.

Given its broad host range and its long history of disease occurrence (Dimitri 1973, Ross 1975), *H. annosum* must be considered present throughout the north temperate region wherever local concentrations of host species exist. A facultative parasite, the fungus utilizes many substrates for its survival and reproduction. Basidiospores of *H. annosum* colonize freshly exposed wood of conifers in newly cut stumps, which are the primary mode of stand access (Rishbeth 1951); in logging slash; in stem wounds, as limited to western hemlock and true firs, *Abies* spp. (Aho and others 1983); and in roots (Siepmann 1976). While root-contact infection is the common pattern of spread (Rishbeth 1951, Hodges 1969), both the circumstantial evidence of significant levels of root infection in unthinned loblolly pine (Webb and others 1981) and the successful inoculation of roots with conidia in undisturbed natural soil (Kuhlman 1969) supports the view that basidiospore percolation downward in soil accounts for at least some direct root infection, perhaps more than is currently recognized. Fortunately, *H. annosum* behaves only as a stump saprophyte in the majority of thinnings, and root-contact progression to stand infection does not occur on many sites. Only in the southeastern United States has a high hazard relationship with deep sands (Alexander and others 1975, Kuhlman and others 1976) been used to achieve, albeit limited, advantage in disease management.

H. annosum fruits most consistently in applanate form at duff level on infected trees and 1- to 2-year-old stumps and, in resupinate form, dorsally on slash and root sprung/thrown roots. Basidiocarps, which initially appear as rubbery white pustules, are mostly annual in the south and tend to be perennial further north. Basidiospore inoculum is generally available throughout the year in the south (Ross 1973), in the northeast (Stambaugh and others 1962, Sinclair 1964), and in the northwest (Edmonds and others 1984), but it declines relative to rising summer temperatures, and dwindles to only trace amounts in southernmost latitudes (Ross 1973). Just how uniform this inoculum is over the time and space of disease occurrence has been the subject of much speculation and, until recently, little understanding.

Host-Pathogen Variability

World source isolates of *H. annosum* have shown some remarkable similarities in culture (Rishbeth 1987) but also notable differences in other physiological characteristics, including virulence, as reported by Worrall and others (1983). The potential for linking virulence (that is, relative disease capacity) of the fungus with host origin became tenable with the discovery in Finland (Korhonen 1978) of two intersterility groups: group S causes butt-rot in Norway spruce and kills young pines in the near vicinity; group P kills pines of all ages as well as young spruce, junipers, and even some hardwoods. Both groups have been identified in the western United States but only P has been detected to date in the east (Harrington and others 1989). The host specificity implications of these findings were applied by Worrall and others (1983) in evaluating observed elevational differences in the incidence of *H. annosum* in pine (*P. ponderosa* Dougl. ex Laws)-fir (*A. concolor* [Cord. & Glend.] Lindl. ex Hildebr.) mixtures in California. Seedling inoculations of both species with isolates from their range showed significant differential interaction between isolate groups and host species; pine isolates were most lethal on pine and least so on fir, while the lethal effect of the isolates from fir was intermediate between the pine extremes on both. Alternative interpretations were explored and the need for further evaluation was indicated.

The sexual cycle of *H. annosum* also was resolved by Korhonen (1978) and later substantiated by Chase and Ullrich (1983): they showed it to be heterothallic, multiallelic, and unifactorial. Armed with this genetic information, Chase and Ullrich (1983), working with monobasidiospore isolates from basidiocarps on red pine (*P. resinosa* Ait.) in four separate plantations in Vermont, and Stenlid (1985), with direct isolations from the butt of infected trees in a 120-year-old Norway spruce stand in Sweden, were able to detect multiple incompatibility alleles and thus analyzed population structure as patterns of spread. The results from spruce were more definitive for clonal patterns of spread; the largest area was 30 m in diameter and involved 13 trees, whereas the Vermont study suggested that infection centers commonly develop from multiple inoculations, rather than by progressive vegetative extension of the fungus; the disparity is probably explained by the use of markedly different isolate derivations between the two studies. In further broad screening of isolates, Chase and Ullrich (1985) found and reported mutagenesis in H. annosum for the first time; this further confirms the potential for genetic variation in the fungus as suggested by their observations, and those of many others, of the multinucleate condition of hyphal cells. This work also described the most reliable methods yet reported (45 percent success) for promoting the fruiting of H. annosum heterokaryons in culture and their application in routine analysis of genetic criteria.

These recent advances which have resulted in better understanding of, and have stimulated further investigation of, the genetic diversity of H. annosum, may well dampen the search for host resistance. Screening for resistance continues to receive emphasis in Europe, in spite of problems resulting from the methodology and from the long-term nature of the work. Norway spruce has received the most attention in this regard and, without going into detail, Johansson and Unestam (1982) furnish a good review of both old and new approaches for evaluation of and selection for resistance.

Environmental Influence

Whether a given host tree species is inherently susceptible or resistant, the incidence and severity of attack by H. annosum in that host population are mediated by the site characteristics or growth environment. Since soil is the growth medium for root diseases, it is most influential in governing disease development, to the extent with annosus root rot, that some, if not the majority, of stump-colonization sites do not result in disease (Kuhlman and others 1976), nor does the rate of stump colonization always correlate with subsequent disease severity (Ross 1973). Thus, development of reliable predictors for segregating high hazard sites before stand thinning would be operationally advantageous. It would permit focusing disease management efforts only on areas with high potential for spread of the pathogen. Most correlations, to date, have been broadly qualitative and too inaccurate for regionwide application (Kuhlman, in Dimitri 1980).

Soil characterization of annosus root rot has been featured in investigations, first in England and later in the southeastern United States. In England, disease severity is greatest on naturally alkaline (pH > 6) soils or on former agricultural soils, whereas on acid-heathland soils, the disease is less severe and mortality rarely exceeds 5 percent of the planted crop (Greig 1984). In a survey across the entire southeastern United States, high-hazard sites that averaged losses > 5 percent of the residual stand were identified by deep (> 10 inches) sandy or silty soils (Kuhlman and others 1976). Alexander and others (1975), in Virginia, compared high-hazard and low-hazard plots in thinned loblolly pine and found root infection rates of 32.6 and 7.8 percent, respectively; of the 14 soil parameters measured on all plots, only sand, noncapillary pores, and bulk density correlated positively with high disease incidence. The high order of root contacts (2.5X) and resultant root infection (5X) detected in high-hazard versus low-hazard soils by Kuhlman and others (1976) was not detected in this study. Instead, several pockets of infection, with each bounded by uninfected tissue, were found on individual roots. These observations and the results of spore percolation tests and previous mechanical excavation studies that showed 5.7 percent infection of 648 loblolly pines in unthinned stands (Webb and others 1981) suggest that direct root infection by spores may be as important as root infection by way of root contacts. If this is so, high-hazard sands would seem to directly influence root infection more than the relatively protected avenue of vegetative spread within roots. Litter accumulation was not definitive in hazard classification studies (Kuhlman and others 1976); however, the fact that prescribed burning reduced cumulative infection 7 years after stump inoculation with H. annosum in thinned plots by an average of 45 percent of that in unburned plots (Froelich and others 1978), indicates that some factor associated with the litter may play a role in the epidemiology of annosus root disease.

Site hazard also has been used to rate the possible interaction between annosus root disease and predisposition of a host tree to bark beetle attack. Alexander and others (1981) selected plots in Virginia, Texas, and Georgia in which loblolly pine had been recently attacked by the southern pine beetle (Dendroctonus frontalis Zimm.) along with uninfested control plots on high-hazard sites in thinned plantations and on low-hazard sites in unthinned natural stands. They found mean H. annosum colonization of excavated root systems in beetle-infested and uninfested control plots to be 23.1 and 10.9 percent, respectively, and that beetle-infested trees had produced 28 percent less radial growth for the last 1-5 years than otherwise similar trees. They concluded that trees preferred by the beetle were being stressed by H. annosum prior to attack and that this stress resulted in reduced radial growth.

Other environmental factors whose interactions with infection of conifers by H. annosum have been reported are air pollutants, as included in Horn's (1985) review. The most comprehensive studies are those of James and others (1980a, 1980b, 1982) and James and Cobb (1982) on the effects of ozone (0_3) on the H. annosum-ponderosa pine/Jeffrey pine (P. jeffreyi Grev. and Balf.) pathosystem in California. They found: a very substantial effect of 0_3 on the rate of increase of H. annosum in the hosts (seedlings) subjected to chronic injury; that surface area and vertical colonization by H. annosum were significantly greater in stumps from severely oxidant-injured host trees; that *in vitro* effects of 0_3 at field dosages on sporulation, spore germination, and growth of H. annosum showed little potential for altering disease epidemiology; and that 0_3 had not influenced the virulence of H. annosum in comparative testing of isolates taken from chronically exposed and pollutant-free sites.

Air pollution aspects in the complex and unresolved etiology of widespread forest decline or "waldsterben" in Europe have focused some attention on the predisposition of trees to forest pests, but primarily bark beetles and defoliators (Baltensweiler 1985). From a disease standpoint, Grzywacz and Wazny (1973), in Poland, sampled the incidence of six forest pathogens along an $S0_2$ gradient that extended 4.3 km from an industrial center and found that all responses followed a sigmoid curve, with H. annosum peaking at 0.5 percent infection 2 km from the source, and for comparison, Armillaria mellea (Vahl.) Quel. peaking beyond at 3.5 km with 1.2 percent infection.

DISEASE MANAGEMENT

Minimizing Losses to *Heterobasidion annosum*

Termination of USDA Forest Service research on annosus root disease in the southeastern United States was summarized by publication (Ross 1975, Kuhlman and others 1976) of recommended practices to control the disease in southern pine plantations, abbreviated as follows:

1. Plant to wider spacings and delay or reduce thinnings
2. Identify site hazard units and focus control procedures on high-hazard sites
3. Thin from April through August south of 34°N latitude (approximately Atlanta, GA); at all other times southward, and at all times northward, use stump protectants when thinning stands on high-hazard sites
4. Treat fresh stumps immediately with dry granular borax, or if biological control is preferred, use Phlebia (equals Peniophora) gigantea (Fr.) Massee
5. No special precautions are needed in replanting sites heavily damaged by H. annosum
6. Plant wisely, using longleaf pine (P. palustris Mill.), for example, because it does well on the deep sands of high-hazard sites and is more resistant to H. annosum than either loblolly pine or slash pine

Wider spacing is still advantageous because it lengthens the time to first thinning and reduces the number of thinnings and the potential for root contact (Kuhlman and others 1976) but as Ross (1975) cautions, plant at as wide a spacing as optimum productivity permits without increasing the hazard from fusiform rust (Cronartium quercuum [Berk.] Miyabe ex. Shirai f. sp. fusiforme). The closer spacing rule (plant sufficiently close to inhibit tree growth and thus rust infection) is no longer considered compatible with the economics of plantation establishment which calls for underutilization of the site, approximately 450 stems/A. at age 5, until trees reach minimum merchantability (Belcher and others 1977, Powers and others 1981). At this rust survival density, spacing would have adjusted at about 10 x 10 ft. (about 3 m^2) which is considered near optimum for productivity in loblolly pine (Shepard 1974).

Site hazard prediction to delineate the need for preventive control of annosus root disease is clearly desirable. However, neither qualitative nor quantitative guidelines have proven adequate to date on a regionwide scale (Kuhlman, in Dimitri 1980). Highly correlative soil parameters in one area, such as Virginia (Alexander and others 1975), do not necessarily apply elsewhere. For example, 25 years of surveillance of H. annosum in approximately 2000 acres of planted loblolly pine on the Duke Forest has seen stump colonization rates, usually in excess of 50 percent, in thinnings on a range of soils, including deep sands, but only two stands have suffered damage, one with 17 percent residual tree infection on a clay loam and the other with 26 percent infection on sand over a clay pan at 1 foot (0.304 m) depth. Both areas were rated intermediate to low hazard for H. annosum according to guidelines then available (Morris and Frazier 1966).

The success of summer thinning south of 34°N latitude is predicated on high temperatures reducing spore availability and elevating daytime stump surface temperatures (• 35C) that result in no stump colonization (Ross 1973). Careful monitoring of the weather when opting for summer thinning is recommended by Witcher and Lane (1980) who reported sufficient H. annosum spread to slash pine adjacent to inoculated and control stumps exposed monthly through the year near Aiken, South Carolina, to seriously question the existence of a summer "safe" period. However, the study site is only 30 miles south of 34°N latitude and some inconsistency from year to year might be expected that close to the line.

Chemical stump treatments to prevent stand invasion by H. annosum in first and subsequent thinnings have been widely investigated, but in the southeastern United States, powdered borax is considered the most effective, cheapest, and safest chemical to date (Kuhlman and others 1967). Borax leaches into the top few inches of freshly cut stumps where it remains toxic to _H_. _annosum_ for up to 2 years, thus allowing sufficient time for competitive soil saprophytes to gain entrance and colonize the declining roots of treated stumps. At demonstrated treatment costs of less than $7.50 per hectare (Hodges 1974), borax use on high-hazard sites is estimated to yield cost: benefit ratios of 1:3 to 1:14 (Kuhlman, in Dimitri 1980).

Use of _P_. _gigantea_ as an alternative for borax treatment is recommended, especially where a limited amount of _H_. _annosum_ is already present in the stand, where use of chemicals is undesirable, or with mechanical harvesters (Ross 1973). Discovery of the biocontrol potential of _P_. _gigantea_ is attributed to Rishbeth in England, where studies on applied biology have led to its operational use in pine thinning (Rishbeth 1979, Greig 1984). Like _H_. _annosum_, _P_. _gigantea_ is a common natural colonizer of pine stumps, but it is an obligate saprophyte with a higher growth rate and range than that of _H_. _annosum_ (Blakeslee and Stambaugh 1974), which permits it to gain initial dominance over and ultimately to exclude the pathogen in dual colonization of stumps. The mere presence of _P_. _gigantea_ fruiting on colonized stumps, however, is no assurance of complete root colonization, as shown by Blakeslee (1970) who found at least one root per stump colonized distally by _H_. _annosum_ in 33 percent of 80 excavated stumps bearing _P_. _gigantea_ fruiting. This is yet another example of direct root infection by _H_. _annosum_, but the potential for spread from one partially occupied root compared to the total stump and root mass would seem to be rather limited. _P_. _gigantea_, as oidial suspensions, has been applied successfully in water and chain-saw oil carriers, and most recently, into stumps left from mechanical tree harvesting (Ross and Hodges 1981).

The recommendation that no special precautions are needed in replanting sites heavily damaged by _H_. _annosum_ has been further substantiated by Kuhlman (1986), who found minimal impact of 6 percent or less at age ten years among trees of seven coniferous tree species planted on two annosus root disease sites 22 years previously. Webb and others (1982) recorded high levels (54-83 percent) of stump colonization by _H_. _annosum_ on two low-hazard Florida sites after clearcutting and site preparation, but did not find _H_. _annosum_ in slash pine seedlings 18 months after planting them in those areas. Stump breakdown is quite rapid under the temperature regimes of the southeastern United States, whereas in the northern climates and especially in Europe, _H_. _annosum_ can persist in stumps for decades and associated stand regeneration seedling losses are not uncommon. For this reason, the feasibility of stump extraction in high-hazard stands is under investigation in England (Greig 1984).

The options for substituting more resistant species in planting high-hazard sites seems rather limited. While longleaf pine is a wise choice based on resistance, its growth rate is not comparable to that of loblolly and slash pine, and this alone may nullify its use.

Finally, in the context of the objectives of this symposium (that is, knowledge and technology transfer), use of the preceding recommendations in southern forestry should pose a challenge to all. A 1974 questionnaire revealed that foresters were not well informed about the procedures for managing annosus root disease (Kuhlman, in Dimitri 1980); then and now, this information was/is available and there is no excuse for not using it.

REFERENCES

Aho, P.E.; Fiddler, G.; Srago, M. 1983. Logging damage in thinned second-growth true fir stands in California and recommendations for control. Research Paper PNW-304. Corvallis, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 8 p.

Alexander, S.A.; Skelly, J.M.; Morris, C.L. 1975. Edaphic factors associated with the incidence and severity of disease caused by _Fomes_ _annosus_ in loblolly pine plantations in Virginia. Phytopathology 65: 585-591.

Alexander, S.A.; Skelly, J.M.; Webb, R.S. 1981. Effects of _Heterobasidion_ _annosum_ on radial growth in southern pine beetle-infested loblolly pine. Phytopathology 71: 479-481.

Baltensweiler, W. 1985. "Waldsterben": Forest pests and air pollution. Zeitschrift für Angewandte Entomologie 99: 77-85.

Belcher, H.J.; Craft, W.J., Jr.; Ericksen, W.D.; Ward, R.H. 1977. Fusiform rust management strategies in practice: Plantation management. _In_: Dinus, R.J.; Schmidt, R.A., eds. Proceedings of the symposium on management of fusiform rust in southern pines; 1976, December 7-8; Gainesville, FL; 158-163.

Blakeslee, G.M. 1970. Investigations of _Peniophora_ _gigantea_ (Fr.) Massee for biological control of _Fomes_ _annosus_, (Fr.) Cke. in operational first thinnings of planted southern pines. Durham, NC: Duke University, MF thesis; 119 p.

Blakeslee, G.M.; Stambaugh, W.J. 1974. The influence of environment upon the physiology of _Peniophora_ _gigantea_ on _Pinus_ taeda. In: Kuhlman, E.G., ed. Proceedings of the fourth international conference on _Fomes_ _annosus_. 1973, September 17-22, Athens, GA; 266-274.

Bradford, B.; Alexander, S.A.; Skelly, J.M. 1978. Determination of growth loss of _Pinus_ _taeda_

L. caused by Heterobasidion annosus (Fr.) Bref. European Journal of Forest Pathology 8: 129-134.

Chase, T.E.; Ullrich, R.C. 1983. Sexuality, distribution, and dispersal of Heterobasidion annosum in pine plantations of Vermont. Mycologia 75: 825-831.

Chase, T.E.; Ullrich, R.C. 1985. Fruiting and genetic analysis of Heterobasidion annosum. Mycologia 77: 464-471.

Dimitri, L. 1973. Root-rot caused by Fomes annosus in the forests of western Europe: Frequency, damage and current research. European Journal of Forest Pathology 3: 245-248.

Dimitri, L., ed. 1980. Proceedings of the fifth international conference on problems of root and butt rot in conifers. 1978, August 7-12.; Kassel, Federal Republic of Germany.

Edmonds, R.L.; Leslie, K.B.; Driver, C.H. 1984. Spore deposition of Heterobasidion annosum in thinned coastal western hemlock stands in Oregon and Washington. Plant Disease 68: 713-715.

Froelich, R.C.; Cowling, E.B.; Collicut, L.V.; Dell, T.R. 1977. Fomes annosus reduces height and diameter growth of planted slash pine. Forest Science 23: 299-306.

Froelich, R.C.; Hodges, C.S., Jr.; Sackett, S.S. 1978. Prescribed burning reduces severity of annosus root rot in the South. Forest Science 24: 93-100.

Greig, B.J.W. 1974. Fomes annosus: Mortality rates in young trees underplanted among pine. In: Kuhlman, E.G., ed. Proceedings of the fourth international conference on Fomes annosus. 1973, September 17-22; Athens, GA; 53-63.

Greig, B.J.W. 1976. Host plants of Fomes annosus in Great Britain. Transactions of the British Mycological Society 66: 517-519.

Greig, B.J.W. 1984. Management of east England pine plantations affected by Heterobasidion annosum root rot. European Journal of Forest Pathology 14: 393-397.

Greig, B.J.W.; Foster, L.E.P. 1982. Fomes annosus in the pine plantations of Jamaica. Commonwealth Forestry Review 61: 269-275.

Grzywacz, A.; Wazny, J. 1973. The impact of industrial air pollutants on the occurrence of several important pathogenic fungi of forest trees in Poland. European Journal of Forest Pathology 3: 129-141.

Harrington, T.C.; Worrall, J.J.; Rizzo, D.M. 1989. Compatibility among host-specialized isolates of Heterobasidon annosum from western North America. Phytopathology 79: 290-296.

Hartig, R. 1894. Text-book of the diseases of trees. Translated from German by W. Somerville and H.M. Ward; New York: MacMillan; 331 p.

Hodges, C.S. 1969. Modes of infection and spread of Fomes annosus. Annual Review of Phytopathology 7: 247-266.

Hodges, C.S., Jr. 1974. Cost of treating stumps to prevent infection by Fomes annosus. Journal of Forestry 72: 402-404.

Hodges, C.S., Jr., Koenigs, J.W.; Kuhlman, E.G.; Ross, E.W. 1971. Fomes annosus, a bibliography with subject index-1960-70. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 75 p.

Horn, N.M. 1985. Effects of air pollution and acid rain on fungal and bacterial diseases of trees. Rijksinstuut voor Onderzoek in de bos-en Landschapsbovw de Dorschkamp 20 (1): 1-69.

James, R.L.; Cobb, F.W., Jr.; Miller, P.R; Parmeter, J.R., Jr. 1980a. Effects of oxidant air pollution on susceptibility of pine roots to Fomes annosus. Phytopathology 70: 560-563.

James, R.L.; Cobb, F.W., Jr.; Wilcox, W.W.; Rowny, D.L. 1980b. Effects of photochemical oxidant injury of ponderosa and Jeffrey pines on susceptibility of sapwood and freshly cut stumps to Fomes annosus. Phytopathology 70: 704-708.

James, R.L.; Cobb, F.W., Jr. 1982. Variability in virulence of Heterobasidion annosum isolates from ponderosa and Jeffrey pine in areas of high and low photochemical air pollution. Plant Disease 66: 835-837.

James, R.L.; Cobb, F.W., Jr.; Parmeter, J.R., Jr. 1982. Effects of ozone on sporulation, spore germination, and growth of Fomes annosus. Phytopathology 72: 1205-1208.

Johansson, M.; Unestam, T. 1982. The search for resistance to Heterobasidion root rot in Norway spruce - old and new approaches in studies of infection biology. European Journal of Forest Pathology 12: 346-357.

Koenigs, J.W. 1960. Fomes annosus: a bibliography with subject index. Occasional Paper 181. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 35 p.

Korhonen, K. 1978. Intersterility groups of Heterobasidion annosum. Communications Instituti Forestalia Fenniae 94: 1-25.

Kuhlman, E.G. 1969. Number of conidia necessary for stump root infection by Fomes annosus. Phytopathology 59: 1168-1169.

Kuhlman, E.G., ed. 1974. Proceedings of the fourth international conference on Fomes annosus. 1973, September 17-22; Athens, GA; 289 p.

Kuhlman, E.G. 1986. Impact of annosus root rot minimal 22 years after planting pines on root rot infested sites. Southern Journal of Applied Forestry 10: 96-98.

Kuhlman, E.G.; Hodges, C.S., Jr.; Froelich, R.C. 1976. Minimizing losses to Fomes annosus in the southern United States. Research Paper SE-151. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 16 p.

Morris, C.L.; Frazier, D.H. 1966. Development of a hazard rating for Fomes annosus in Virginia. Plant Disease Reporter 50: 510-511.

Powers, H.R., Jr.; Schmidt, R.A.; Snow, G.A. 1981. Current status and management of fusiform rust on southern pines. Annual Review of Phytopathology 19: 353-371.

Rishbeth, J. 1951. Observations on the biology of Fomes annosus, with particular reference to East Anglian pine plantations. II. Spore production, stump infection, and saprophytic activity in stumps. Annals of Botany (New Series) 15: 1-21.

Rishbeth, J. 1979,. Modern aspects of biological control of Fomes and Armillaria. European Journal of Forest Pathology 9: 331-340.

Rishbeth, J. 1987. Forest pathology - present and future. Canadian Journal of Plant Pathology 9: 321-333.

Ross, E.W. 1973. Fomes annosus in the south-eastern United States: Relation of environmental and biotic factors to stump colonization and losses in the residual stand. Technical Bulletin 1459. Washington, DC: U.S. Department of Agriculture, Forest Service; 26 p.

Ross, E.W. 1975. Fomes annosus in eastern North America. In: Bruehl, G.W., ed. Biology and control of soil-borne plant pathogens (a symposium). St. Paul, MN: American Phytopathological Society; 107-110

Ross, E.W.; Hodges, C.S., Jr. 1981. Control of Heterobasidion annosum colonization in mechanically sheared slash pine stumps treated with Peniophora gigantea. Research Paper SE-229. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 3 p.

Shepard, R.K., Jr. 1974. An initial spacing study. In: Williston, H.L.; Balmer, W.E., eds. Proceedings of the symposium on young pines: Winter session. 1974, October 22-24, 1974; Alexandria, LA. 121-128.

Siepmann, R. 1976. Uber die infektion von fichtenwurzeln (Picea abies Karst.) durch Fomes annosus (Fr.) Cke. European Journal of Forest Pathology 6: 342-347.

Sinclair, W.A. 1954. Root and butt rot of conifers caused by Fomes annosus with special reference to inoculum dispersal and control of the disease in New York. Memoir 391. Ithaca, NY: Cornell University Agricultural Experiment Station; 54 p.

Smith, R.S. History of Heterobasidion annosum in the west. 1989. (these Proceedings).

Stambaugh, W.J.; Cobb, F.W., Jr.; Schmidt, R.A.; Kreiger, F.C. 1962. Seasonal inoculum dispersal and white pine stump invasion by Fomes annosus. Plant Disease Reporter 46: 194-198.

Stenlid, J. 1985. Population structure of Heterobasidion annosum as determined by somatic incompatibility, sexual incompatibility, and isoenzyme patterns. Canadian Journal of Botany 63: 2268-2273.

Webb, R.S.; Alexander, S.A. 1985. An updated host index for Heterobasidion annosum. Information Series 85-2. Blacksburg, VA: Virginia Polytechnical Institute and State University; 27p.

Webb, R.S.; Alexander, S.A.; Skelly, J.M. 1981. Incidence, severity, and growth effects of Heterobasidion annosum in unthinned loblolly pine plantations. Phytopathology 71: 661-662.

Webb, R.S.; Hollis, C.A.; Swindel, B.F. 1982. Incidence of Heterobasidion annosum basidiocarps on two low-hazard Florida soils after clearcutting and site preparation. Southern Journal of Applied Forestry 6: 39-41.

Witcher, W.; Lane, C.L. 1980. Annosus root rot in slash pine plantations in the sand hill section of South Carolina. Plant Disease 64: 398-399.

Worrall, J.J.; Parmeter, J.R., Jr.; Cobb, F.W., Jr. 1983. Host specialization of Heterobasidion annosum. Phytopathology 73: 304-307.

History of *Heterobasidion annosum* in Western United States[1]

Richard S. Smith, Jr.[2]

Abstract: H. annosum was first discovered as a root pathogen of pine in western United States by E. P. Meinecke in 1909. Other early researchers reported it as a root and butt decay of nonresinous conifers in the west. Olson demonstrated its pathogenicity to western conifers and Wagener and Cave described its occurrence and role in the eastside pine forests. In the last 20 years pathologists have become more aware of H. annosum's role as a root pathogen of true fir. The adverse effects of annosus root disease in the Institute of Forest Genetics and Yosemite National Park have helped to call attention to this disease.

A history of Heterobasidion annosum is a history of Fomes annosus until 1968, when the fungal root pathogen's name was changed (Pegler and Waterston 1968). The reader must keep in mind that F. annosus (which is used in this paper as in the original literature) currently is H. annosum. One of the first finds of F. annosus in western United States was made in Monterey, California by E. P. Meinecke in 1909, about 80 years ago. In an unpublished office report, Meinecke described the disease as he observed it on Monterey pine. In his field notes he first described the pathogen as a Trametes sp. but later concluded that it was F. annosus, which was very well known in Europe where he (Meinecke) had studied. In light of the great impact this root disease has on our forest recreation areas today, it is interesting that he found this disease in a grove of Monterey pine which had been converted into a park and in which considerable tree mortality had occurred. In his manual, Forest Tree Diseases Common to California and Nevada, (Meinecke 1914), he states "This fungus (Fomes annosus--pronounced fomeez) is one of the most dangerous forest fungi in Europe and is also destructive in the eastern United States. Although at the present, apparently somewhat rare in California it may prove to be more prevalent." His prediction has proven to be correct.

The history of F. annosus in the western United States is closely related to the evolution of forestry during its developmental stages in the west, and how forestry influenced the interest and research in forest pathology. During the early stages when old-growth forests were being harvested, foresters and lumbermen were not concerned about scattered and occasional tree mortality, but rather were concerned about decays in old growth trees and how much decay was likely to be present in various species and stand types. This information was the basis for estimation of the volumes and values of old-growth timber stands and which stands should be entered first. This was an interesting period of research in the western United States. It was largely a period of descriptive research; large old-growth trees were dissected and their external and internal features were examined to determine the amount and position of decay in the tree and the resulting amount of cull, the causes of the decay (the species of wood rotting fungi), the infection courts or methods of fungal entrance into the tree, and the external indicators of decay in the standing tree. This information was used to develop statistical tables to indicate the probable amount of cull based on the tree species, its age, location, and external features. Forest pathologists spent whole summers out in the forest conducting these old-growth dissections. Willis Wagener, a young researcher in this period, described this research several decades later to the next generation of forest pathologists (personal communication).

> "We would leave San Francisco by train in May for Quincy, a small logging town at the juncture of the northern Sierra Nevada and the southern Cascade Mountains. From here we would travel by horseback to the study area and set up a long term summer camp. We worked a six-day week, dissecting and describing old-growth trees and the decay and cull they contained. Sundays were set aside as a rest day, when we went over our field notes and corrected any errors they contained. In September, some 5 to 6 months later, we returned to San Francisco via horseback and train. The winters were spent analyzing our data, writing office reports and preparing for the next field season."

It was these kinds of research efforts from 1900 to 1940 by notable forest pathologists, such as Boyce(1932), Weir and Hubert(1919), and Englerth(1942), that first described F. annosus as a fungus causing a root and butt rot in conifers in the western United States. Even in these reports, except for western hemlock, the incidence

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, Calif.

[2]Principal Plant Pathologist, Forest Insect and Disease Research, Forest Service, USDA, Washington, DC.

of _F_. _annosus_ in nonresinous conifers was reported to be rather low. This is somewhat surprising in light of the high incidence of _F_. _annosus_ found in both old-growth and second-growth true fir today. Years later, toward the end of his career, Wagener wrote an office memo to another western pathologist, "My first work was in 1917 as a member of Meinecke's field crew working on the dissection studies in virgin white fir on the Sierra N.F. Working with Meinecke and Boyce, I had an unusual opportunity to become acquainted with some of the misconceptions and difficulties which helped to shape the conclusions of that period. In those days no one thought of confirming the identity of decays through culturing. --no guides, such as Miss Nobles were available. Practically all the decay in true fir found originating from fire wounds was put down in the field notes as 'atypical E.t.', although I was to learn in later years that probably none of it was E.t." (E.t. is an abbreviation for _Echinodontium_ _tinctorium_, a wood rooting fungus.) I imagine that most present day forest pathologists would suspect that a good deal of the atypical butt decay behind those fire scars was in fact caused by _F_. _annosus_.

After World War II we were still concerned about decay and cull in old-growth stands, and these research efforts continued and were reported by Wright and Isaac(1956), Kimmey(1964), and Kimmey and Bynum(1961) in the United States and Buckland and others(1944) in British Columbia. During this period there were more reports of _F_. _annosus_ causing a frequent root and butt rot of fir and hemlock and of its role as an invader of fire scars and logging wounds.

It is interesting, but not surprising, that during this period _F_. _annosus_ was not recognized to be an important cause of tree mortality in these nonresinous old-growth conifers. Wagener and Cave(1946) refer to the saprophytic life style of _F_. _annosus_ in fir and hemlock.

In 1934, some 2 decades after Meinecke found _F_. _annosus_ in Monterey, K.A. Salman, a forest entomologist, reported some unusual mortality of Jeffrey pine in Lassen County to E. Wright, forest pathologist with the Bureau of Plant Industry in San Francisco. Salman, who was studying bark beetle-caused tree mortality in the eastside pine type, had found some tree mortality which was not caused by bark beetles and in which the roots appeared to be dying. Wright visited these trees with Salman that year and made some root isolations from three diseased trees, measuring from 14 to 16 inches in diameter. He consistently isolated a single fungus, which later proved to be _F_. _annosus_, from these trees. He started some pathogenicity testing with this isolate, but was forced to discontinue those tests when he was transferred out of the state.

Later, in 1937, the problem was brought to the attention of Willis Wagener, who interested a young plant pathology student, Alver Olson, in the problem. Olson spent 3 years studying this disease in the greenhouse and in the field. In his paper on this disease Olson(1941) states, "The disease thus far has been found only at Lasco. The pine regions of California have been extensively inspected by Wagener and Salman, who state that they have not seen the disease elsewhere." Olson, in his first visit to Lasco in May of 1937, made the following observations. The area in which the mortality was occurring had been logged from 7 to 18 years earlier, and the soils were well drained soils of volcanic origin. The disease was found on the roots of only Jeffrey and ponderosa pines. The dead and diseased trees varied from 5 to 17 years old, and occurred in localized centers that were always observed to be in the vicinity of an old stump. The distance from the dead tree to the stump varied from touching to 19 ft. Diseased trees may be found on one or more sides of the stump, or they may completely surround it. Trees closest to the stump were usually affected first. Both ponderosa and Jeffrey pine stumps were involved. In later observations, Olson found that the tree mortality most commonly occurred during the onset of warm weather in early May and late June. Affected trees often exhibited yellowish-white pitch exudates on the surface of diseased roots. These diseased roots were always found to be in contact with an old dead root of the neighboring stump or with a diseased root from an adjacent diseased tree. In most cases these roots were in simple contact, but on occasion the contact involved a more intimate overgrowth of one root over its neighbor's root. Small lesions were found on the infected root where it came in contact with the initially infected root. Although only one root was infected initially, the entire root system was invaded by the time the tree died. This is an accurate description of this disease in pine as it is described today, some 50 years later.

Olson(1941) isolated species of _Cunninghamella_, _Penicillium_, and _Pythium_ from the diseased roots. He recognized _Pythium_ as the only known pathogen among the fungi he had isolated and made a series of pathogenicity tests using isolates of this fungus obtained from the roots of diseased pines. He was unable to reproduce the disease or to recover the _Pythium_ from the inoculated roots and came to the conclusion that _Pythium_ was not the cause of the disease. He returned to Lasco in the summer and fall of 1938 and made numerous isolations from widely scattered infection centers. _Cunninghamella_ was the only fungus consistently isolated from over 100 diseased trees. He isolated this fungus from cambial regions, the xylem, and the advancing margins of the pitch infiltrations of affected roots. He remembered Wright's similar experience of consistently isolating one fungus, and sent an isolate of _Cunninghamella_ to him. Wright responded that this was indeed the same fungus that he had isolated.

In 1939, Olson made several attempts to inoculate 1-year-old pine seedlings with _Cunninghamella_ in the greenhouse, but for one reason or another was unsuccessful in reproducing the disease. In May of 1939 Olson(1941), using artificially infested root pieces of Jeffrey and ponderosa pine, inoculated Jeffrey pines in the field by placing these root pieces adjacent to live roots of naturally established trees. In November of that year he examined the inoculations and found that all 10 of the inoculated Jeffrey pines had typical symptoms and he was able to re-isolate the fungus from these inoculated roots. In February 1940, Olson(1941) inoculated the tap roots of 2.5-year-old Jeffrey pine seedlings in the greenhouse with wheat grains infested with Cunninghamella, and this time was able to reproduce the disease. Olson(1941) wrote, "The production of the typical symptoms of pitch infiltration, and the recovery of Cunninghamell from the inoculated roots establishes this fungus as the organism causing the root disease" and "These experiments prove that the disease can be spread by root contact." Olson included other conifers (white fir, sugar pine, and incense cedar) in the inoculation trials but was unable to infect them with his isolates.

Still, neither Olson nor his major professors were aware that this pathogen, Cunninghamella, which Olson was working with, was F. annosus, and Olson, having seen only the asexual fruiting stages of this fungus, was under the impression that he had discovered a new root pathogen and disease. Thus, he described a new species of Cunninghamella and named it C. meineckella, unaware that he was mistakenly renaming the fungus after the person who first discovered this same fungus in its perfect stage in California some 32 years earlier. It was both ironic that the fungus should be mistakenly named after the person who had first found and correctly identified it years earlier and sad that Olson is now better remembered for his taxonomic mistake, than for his valuable contributions to forest pathology. Olson came so close to uncovering the role of the cut stump as the primary infection site that initiates the infection center, that one cannot help but wonder what might have happened if he had not gotten discouraged by his taxonomic mistake and had continued his research on this disease. Olson became a professional photographer and opened a store in Burney, not far from Lasco, where he had done his forest pathology work.

In May 1941, just a month after Olson's paper (1941) on annosus root disease was accepted for publication in Phytopathology, an unpublished office report was written by Donald De Leon, entomologist for the Department of Entomology and Plant Quarantine, describing a root fungus which appeared to be contributing to the dying of many pines marked for treatment in a bark beetle control program on Laguna Mountain in the Cleveland National Forest. These dying trees showed no evidence of bark beetle attack, but they did have a fungus mycelium which appeared to be killing the cambium under the bark at the root collar. Willis Wagener and De Leon made a joint examination and found that F. annosus and Armillaria mellea were active in these stands and were responsible for much of the Jeffrey pine mortality (Wagener and Cave 1946). It is interesting that 38 years later Wood and others(1979), in a Region 5 Forest Pest Management Evaluation reported that F. annosus was responsible for 48 percent of the high level of pine mortality on Laguna Mountain.

Wagener and Cave(1946) made some interesting comments in their paper which give an indication of the level of knowledge at that time. In this paper they state:

> "Prior to these discoveries (Olson's and De Leon's) fruit bodies of this fungus had been collected at a number of places in California, but almost entirely in connection with heart rot or from decayed stumps where the fungus had presumably developed as a saprophyte after the trees had been cut."... "In Europe, as already noted, the fungus has long been known for its desructiveness [sic], especially in pure coniferous plantations, but in North America, where it is widespread as a saprophyte on dead wood or as a butt rot of older conifers, it has been regarded as seldom attacking live parts of trees."... "Recent evidence indicates that in white fir (Abies concolor [Good. and Glen.] Hoppes) and in red fir (A. magnifica A. Murr) in California the fungus is also much more prevalent than previously supposed, producing a butt and root rot in these species but apparently seldom killing them through the killing of the bark and cambium at the base and roots as in pine. Englerth has found that it causes a prevalent butt rot of western hemlock (Tsuga heterophylla [Raf.] Sarg.) in western Oregon and Washington."

From these comments it appears that the western forest pathologists in the 1940's were as yet unaware of the role of the cut stump in becoming infected and starting an infection center in pines, although they noted the frequent association of this disease with stumps. They were aware of the frequent association of this fungus with true firs and hemlock, but appeared to be unaware of its pathogenicity to true firs. The forest pathologists had by then identified many areas in the eastside pine type forest as areas in which the disease was present, particularly the Lassen country and the mountains of southern California. They noted that the disease occurred more frequently on the light, friable, and sandy soils and less frequently on the heavier soils. They found that the soils harboring F. annosus were less acidic than most western forest soils, with pH's from 5.7 to 6.7. More research on these soil characteristics may prove useful in rating the hazard of sites for annosus root disease in the future. Wagener and Caves's paper also extends the pine host range to include sugar and Coulter pines.

Wagner and Cave (1946) state, "Killing of the bark and cambium of attacked trees by the fungus ordinarily extends little above the ground level... The balance of the trunk is usually invaded by bark- and wood-boring beetles before fading of the foliage occurs and thereafter the tree appears superficially no different from one killed primarily by bark beetles. This is one of the main reasons why the importance of this disease went unrecognized for so long in our western pine stands and why killing by this disease in the past was commonly charged to bark beetles." This important relationship between root diseases and bark beetles was re-emphasized and expanded by Cobb and others (1974) and Ferrell and Smith (1976).

Wagener and Cave (1946) further describe some symptoms they found helpful in diagnosing this disease, which to my knowledge are no longer used by present-day pathologists in diagnosing this disease. They are:

1. The bark at the root collar of infected and recently killed trees separates easily from the wood.
2. The separate surfaces of the infected inner bark of the root and root crown are usually a characteristic light brown to russet with finely penciled white streaks. This pattern of coloration is quite distinct for the disease in pine and it is readily recognized once one has become familiar with it.
3. A thin weft of whitish mycelium is also usually visible between the wood and bark of infected roots and root crown.
4. Thin partial felts of whitish to light buff mycelium are also found between the bark scales of infected roots.
5. The red turpentine beetle avoids making galleries in bark areas invaded by F. annosus.

It might be well to investigate the reliability of using these symptoms to diagnose annosus root disease in the future. I have found them to be reliable indicators of annosus root disease. Repeated culturing of specimens with these signs and symptoms will allow investigators to develop confidence in using this system to diagnose for F. annosus.

Lastly, Wagener and Cave (1946) state, "The common means of establishment of new centers in pine stands, and the reasons for apparent greater virulence of this fungus in California as compared to other parts of the United States are not yet known." and "A full appraisal of the status of the fungus as a killing agent in western pine stands has not yet been made. It is expected to increase in importance in the future."

Most of the forest pathology research on F. annosus between the mid 1940's and the 1950's was in reference to this fungus as a root and butt rot in nonresinous conifers. Englerth and Isaac (1944) reported that in the Pacific Northwest F. annosus commonly enters western hemlock through logging wounds. An article by Rhoads and Wright (1946) states that F. annosus is more commonly a wound pathogen than a root parasite of western hemlock in western Oregon and Washington. In a Forest Pest Leaflet Kimmey and Bynum (1965) summarize the 1950's work done with red and white firs. They state that white rots cause about four-fifths of the decay loss in true fir and that F. annosus was the second most important cause of white rot. In this period, Wright and Issac (1956) also found this fungus to be the most important and frequent decay fungus in hemlock and true firs in Oregon and Washington and reported that wounds on these infected trees were a common infection court of this fungus. It is unclear whether these forest pathologists were aware of the pathogenic effects of this fungus further down in the roots of these nonresinous conifers.

In the mid-1950's an important research finding by Rhishbeth (1950,1951) in East Anglia revealed that the initial entry of F. annosus into pine stands usually was through a freshly cut pine stump. These stumps were infected by spores of F. annosus which germinated and produced hyphae that colonized the stump and its root system. And then, as observed by Olson (1941) and other western forest pathologists, the fungus spread to adjacent living conifers via root contacts. This vital piece of information enabled the forest pathologist to completely describe the disease cycle and to explain heretofore puzzling observations.

In the 1960's there was an increased interest and awareness of F. annosus in western United States and western Canada. Some interesting observations were made and some important research information was obtained during this period. Several factors were responsible for this increased awareness. More forest pathologists had been employed in the west at this time. Some of these scientists had obtained their academic training in the east and in Europe where there was greater recognition of F. annosus as a forest problem. In the 1950's, in response to the post-World War II housing boom, logging in the western National Forests had greatly increased, thus increasing the opportunity for stump infection, which characteristically started to appear in the affected stands in the 1960's, about 10 years after logging (Bega and Smith 1966). Interest in the health and productivity of second-growth forests greatly increased as the supply of available old-growth forests decreased. Certain specific occurrences of F. annosus, such as its appearance in the Institute of Forest Genetics (Bega 1962) and in Yosemite National Park (Parmeter and others 1978), brought this disease to the attention of both foresters and forest pathologists. The predecessor of what has become Forest Pest Management was formed in the Regional Offices of the Forest Service around the country, and it was staffed with trained forest pathologists, who recognized the importance of F. annosus and brought it to the attention of both the forest manager and their fellow forest pathologists. There were also old-timers like Willis Wagener who had maintained an interest in this disease and who were willing and able to impart their experience and knowledge to the new generation of forest pathologists.

Bega (1962) reported the effects of annosus root disease in the arboretum of the Institute of Forest Genetics at Placerville, California. This report was noteworthy because it publicized the susceptibility of a large number of pine species, including numerous western pines, which were attacked and killed by this fungus. The attack by F. annosus was extended (1951 to 1962) and tree mortality was extremely high. Because this was a planted stand, it may have represented what could be expected in future plantations with frequent stand entries and high levels of management activities. Bega concluded his report with the statement "... as virgin timber diminishes with cutting in western United States, and plantation forestry becomes more prevalent, the importance of Fomes annosus will increase rather than decrease." Because of the high value of this collection of pines, new and radical attempts were made to control the disease. The infected trees were identified, the infested area delimited, the borders of the infection centers were trenched and all roots removed, and the infested areas inside the trenches fumigated with methyl bromide and tarped. Periodically, the boundaries (the original boundary trenches were filled back in after the roots had been removed) of the infested area were fumigated with carbon bisulfide to keep tree roots from growing across this root-free area and into the fumigated areas. A few years later the fumigated areas were replanted with pines. This control effort was partially successful. It did successfully eradicate the pathogen from the fumigated areas, but because accurate identification of the limits of the infection centers was not possible, some infested areas external to the boundaries remained unidentified and were not fumigated. The pathogen continued to spread from these areas radially outward into the plantation.

In 1967 Miller and Bega in an office memorandum reported their finding of F. annosus in fallen trees near recreation facilities in Yosemite National Park. Later, as a direct result of tree failures in the winter storms in 1969 and 1971, which resulted in two deaths and extensive property damage, the Park Service requested a joint Forest Service-University of California evaluation of the tree failures in developed sites in Yosemite Valley. Again root disease, caused by F. annosus, was found to be the major factor in predisposing the fallen trees to failure. In 1971, Felix, working with Parmeter (Parmeter and others 1978), identified 67 F. annosus infection centers in which over 1,100 trees had died within the developed recreation areas of the valley. The intensity of infection and the frequency of tree failure resulting in deaths and property damage in Yosemite vividly demonstrated the potential impacts of this root disease in the many recreation sites in California. Partially as a result of these experiences, the Forest Service now requires all freshly cut conifer stumps in forest recreation areas to be treated with borax to prevent stump invasion by F. annosus.

Up to this time western forest pathologists had been concerned about F. annosus as causing a root disease in pine and recognized the fungus as causing a butt and root decay in true firs and hemlock (Wallis and Reynolds 1970). Nelson (1963) reported on his investigations on the causes of progressive crown decline leading to death in subalpine fir. He noted that branch flagging was, in some cases but not always, associated with branch cankers; that flagged firs commonly occurred in groups with one to several dead trees toward the center of the group, and trees in various stages of flagging at the outer margins of the groups. He examined the roots of trees in various stages of crown decline and found a direct correlation between the amount of branch flagging and the percentage of rotten (nonfunctional) roots. F. annosus was the fungus most commonly isolated from the decayed roots. These were among the first research results that suggested F. annosus was also the cause of a slower, less dramatic death of true firs and not just the cause of a butt rot.

In the early 1970's, as many of the true firs (which had been released in the earlier pine high-grading harvests of the mixed conifer and eastside pine types) were approaching commercial size, an unexplained crown decline and tree death of pole-sized and larger white fir was observed. Investigations by several forest pathologists have yielded evidence that annosus root disease is a major factor causing this-crown decline and eventual death of the tree. Results of surveys by Parmeter and others (personal communication) show that annosus root disease is so common in true fir that it approaches being an epidemic and that it may become more of a problem in true fir forest management than it will be in pine forest management. Surveys by Forest Service, Forest Pest Management forest pathologists in California and southern Oregon show that F. annosus is a major cause of true fir mortality that until recently went unrecognized.

In the 1970's, pathologists in the west began to see the need for control of annosus root disease in the eastside-pine-type forests and in forest recreation areas. By now the work of Driver (1963) and associates in southern United States had shown that stump infection could be prevented rather cheaply and effectively with a light dusting of the freshly cut stump surface with dry powdered borax. Graham (1971) tested the effectiveness of borax in the west and found that it prevented infection of ponderosa and Jeffrey pine stumps in California. Because of an increased awareness of annosus root disease in true fir and the presence of this species in a large number of recreation areas, we saw the need to test the effectiveness of borax in preventing infection of the surface of freshly cut true fir stumps. Smith (1970) showed that borax also effectively blocks stump infection of true firs. Still, however, there is concern that F. annosus may enter true fir trees and stumps via their roots and that stump surface treatment with borax may not be completely successful in keeping this fungus out of true fir stands.

The history of H. annosum as prepared for this symposium is really the recorded history of the knowledge we had at various periods in the past of this fungus and the disease it causes. This is not to be confused with the real occurrence and role that H. annosum has played in past western forests. We can only guess and estimate what that might have been. We will never know more about the past than that which is written and this we must view with some question. Even our own recollections of past experiences and thoughts are clouded by our currently held views. This being the case, the readers of this history of H. annosum are obligated to take the parts of this history and their own experiences and formulate their own views of the true role of H. annosum in our past western forests.

REFERENCES

Bega, R.V. 1962. Tree killing by Fomes annosus in a genetics arboretum. Plant Disease Reporter 46: 107-110.

Bega, R.V.; Smith, R.S., Jr. 1966. Distribution of Fomes annosus in the natural forests of California. Plant Disease Reporter 50: 832-836.

Boyce, J.S. 1932. Decay and other losses in Douglas-fir in western Oregon and Washington. Tech. Bull. No. 286, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region; 60 p.

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. Canadian Journal of Research 27: 312-332.

Cobb, F.W., Jr.; Parmeter, J.R., Jr.; Wood, D.L.; Stark, R.W. 1974. Root pathogens as agents predisposing ponderosa pine and white fir to bark beetles. In: Proceedings Fourth International Conference on Fomes annosus; 1973 September; Athens CA; 8-15.

Driver, C.H. 1963. Further data on borax as a control of surface infection of slash pine stumps by Fomes annosus. Plant Disease Reporter 47: 1006-1009.

Driver, C.H.; Wood, R.E. 1968. Occurrence of Fomes annosus in intensively managed young-growth western hemlock stands. Plant Disease Reporter 52 :370-372.

Englerth, G.H. 1942. Decay of western hemlock in western Oregon and Washington. Bulletin 50. New Haven, CT: Yale University, School of Forestry; 53 p.

Englerth, G.H.; Isaac, L.A. 1944. Decay of western hemlock following logging injury. Timberman, Volume 45, Issue No.8, June, pp. 34,35,56.

Ferrell, G.T.; Smith, R.S., Jr. 1976. Indicators of Fomes annosus root decay and bark beetle susceptibility in sapling white fir. Forest Science 22: 365-369.

Graham, D.A. 1971. Evaluation of borax for prevention of annosus root rot in California. Plant Disease Reporter 55: 490-494.

Kimmey, J.W. 1964. Heart rots of western hemlock. Forest Pest Leaflet 90. Washington, DC: U.S. Department of Agriculture, Forest Service; 7 P.

Kimmey, J.W.; Bynum, H.H. 1961. Heart rots of red and white firs. Forest Pest Leaflet 52. Washington, DC: U.S. Department of Agriculture, Forest Service; 4 p.

Meinecke, E.P. 1914. Forest tree diseases common to California and Nevada: A manual for field use. Washington, DC: Department of Agriculture, Forest Service; U.S. Government Printing Office; 67 p.

Nelson, D.L. 1963. Studies on flagging and root and butt rot of subalpine fir, Abies lasiocarpa (Hook) Nutt. Logan, UT: Utah State University; 76 p.

Olson, A.J. 1941. A root disease of Jeffrey and ponderosa pine reproduction. Phytopathology 31: 1063-1077.

Parmeter, J.R., Jr; MacGregor, N.J.; Smith R.S.,Jr. 1978. An evaluation of Fomes annosus in Yosemite National Park. Report No. 87-2. San Francisco, CA; U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Forest Insect and Disease Management, 11 p.

Pegler, D.N.; Waterston, J.M. 1968. Heterobasidion annosum (Fomes annosus). Commonwealth Mycological Institute, Description of Pathogenic Fungi and Bacteria, No. 192, London, 2 p.

Rhoads, A.S.; Wright, E. 1946. Fomes annosus commonly a wound pathogen rather than a root parasite of western hemlock in western Oregon and Washington. Journal of Forestry 44: 1091-1092.

Rishbeth, J. 1950. Observations on the biology of Fomes annosus, with particular reference to East Anglia pine plantations. I. The outbreaks of the disease and ecological status of the fungus. Annals of Botany 14: 365-383.

Rishbeth, J. 1951. Observations on the biology of Fomes annosus, with particular reference to East Anglia pine plantations. II. Spore production, stump infection, and saprophytic activity in stumps. Annals of Botany 15: 1-21.

Smith, R.S., Jr. 1970. Borax to control Fomes annosus infection of white fir stumps. Plant Disease Reporter 54: 872-875.

Wagener, W.W.; Cave, M.S. 1946. Pine killing by the root fungus, Fomes annosus, in California. Journal of Forestry 44: 47-54.

Wallis, G.W.; Reynolds, G. 1970. Fomes annosus root and butt rot, a threat in managed stands in coastal British Columbia. Forestry Chronicle 46: 221-224.

Weir, J.R.; Hubert, E.H. 1919. A study of the rots of western white pine. Bulletin No. 799. Washington, DC; U.S. Department of Agriculture, Bureau of Plant Industry, 24 p.

Wood, R.E.; Schuft, M.J.; Schultz, D.E. 1979. Tree mortality in the Laguna Mountain Recreation Area, Cleveland National Forest. Report No. 79-1. U.S. Department of Agriculture, Forest Service, Region 5, Forest Insect and Disease Management; 21 p.

Wright, E.; Isaac, L.A. 1956. Decay following logging injury to western hemlock, Sitka spruce, and true firs. Technical Bulletin No. 1148, Washington, DC. U.S. Department of Agriculture, Forest Service, 34 p.

Wright, E.; Rhoads, A.S.; Isaac, L.A. 1947. Decay losses following logging injury in partially cut stands of western hemlock and Sitka spruce. Timberman, Volume 48, Issue No. 10, August, pp. 52,54,72,74,76.

Biology, Ecology and Genetics of *Heterobasidion annosum*

Genetics and Population Structure of *Heterobasidion annosum* with Special Reference to Western North America[1]

Thomas E. Chase[2]

Abstract: Recent advances in the genetics and population biology of Heterobasidion annosum are reviewed. H. annosum is a heterothallic (outbreeding) basidiomycete with a unifactorial, multiallelic incompatibility system which regulates mating. H. annosum in western North America consists of two intersterility groups (biological species) which can be identified through mating tests and isozyme analysis. Intersterility groups in western North America appear to be host specific. Intersterility between groups is attributable to specific genes. Intergroup hybrids have been formed in the laboratory, but have not been identified from the field.

Heterobasidion annosum (Fr.) Bref. [formerly Fomes annosus (Fr.) Karst.] has been the subject of numerous investigations because of its significance as a root- and butt-rot pathogen of many commercially important conifers (Koenigs 1960; Hodges and others 1971). Most research on H. annosum has been devoted to various aspects of its pathology, impact, ecology, physiology, and biological and chemical control. The sexuality, genetics, and population structure of H. annosum have received little attention until recently. Knowledge concerning the genetics and population structure of the pathogen has the potential to significantly enhance our efforts to manage disease losses resulting from H. annosum. This paper reviews research conducted over the past 10 years on the life cycle, sexuality, host specificity, and population structure of H. annosum. Publications in this area are relatively few, but some significant advances have been made nonetheless.

[1] Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, at Monterey, Calif.

[2] Research Plant Pathologist, Pacific Southwest Forest and Range Experiment Station, USDA Forest Service, Berkeley, Calif.

SEXUALITY AND LIFE CYCLE

Early efforts to examine the genetics of H. annosum were hampered by a lack of definitive knowledge regarding the sexuality and life cycle of the fungus. Recent studies have established, however, that H. annosum is a heterothallic (i.e., outbreeding) fungus (Korhonen 1978; Chase and Ullrich 1983) to which standard genetic techniques can be applied readily (Chase and Ullrich 1985). The major steps of the life cycle of H. annosum are now well established (figure 1). Individual basidiospores of the fungus, upon germination, give rise to homokaryotic mycelia that are characterized by simple septa (cell cross-walls) and multinucleate cells with identical haploid (n = single set of chromosomes) nuclei. Homokaryotic mycelia are self-sterile and under normal conditions do not differentiate to form a basidiocarp (fruiting body or conk). Mating must take place between two sexually compatible homokaryotic mycelia in order to form a mycelium capable of fruiting. Mating is initiated by anastomosis (fusion) of hyphae from different homokaryons. The mycelium arising from a compatible mating is termed a dikaryon. Individual cells of a dikaryon contain nuclei from both of the contributing homokaryons (n + n condition). During conjugate mitotic division of paired nuclei in the dikaryon clamped septa (also termed clamp connections) are formed, which are easily recognized under the light microscope (Raper 1966; Korhonen 1978; Chase and Ullrich 1983). A dikaryon will have simple septa as well as clamped septa. The percentage of clamped vs. simple septa varies among dikaryons.

There are two other species in the genus Heterobasidion. H. araucariae, a newly described species (Buchanan, 1988) from Australia, New Zealand, and possibly other areas of the Far East, was previously considered a variety or biological species of H. annosum (Chase and others 1985; Buchanan 1988). H. araucariae cannot be distinguished easily from H. annosum in culture, but it is homothallic (self-fertile) (Chase and others 1985). Thus, in contrast to H. annosum, monobasidiospore strains of H. araucariae, upon germination, give rise to clamped mycelia capable of fruiting to complete the life cycle without undergoing mating (Chase and others 1985). The

Mating
Homokaryon (n) X Homokaryon (n)

Multinucleate Dikaryon
(n + n)

Basidiocarp Formation

Karyogamy in basidia
(2n)

Meiosis
(2n - - 4n - - n + n + n + n)

Sporulation and Basidiospore Discharge

Basidiospores
(n)

Germination to form Multinucleate Homokaryon
(n)

Figure 1--Life Cycle of *Heterobasidion annosum*. The chromosome complement of nuclei is indicated as n = haploid, 2n = diploid. Conidia are produced on both homokaryotic and dikaryotic mycelia. Dikaryons yield conidia that may carry one or the other or both of the parental type nuclei. Basidiospores are binucleate as a result of an additional mitotic division following meiosis in the basidium.

third species, *H. insulare*, is readily distinguished from the other two *Heterobasidion* species on morphological differences in basidiocarps; little is known concerning its sexuality or life cycle (Buchanan 1988). It has been isolated from throughout much of the Far East (Buchanan 1988).

GENETICS OF *HETEROBASIDION ANNOSUM*

Mycelial interactions within *H. annosum* fall under two general categories, sexual and vegetative. Sexual interactions (i.e., mating) involve anastomosis (cell fusion), plasmogamy (cytoplasmic fusion), heterokaryosis (occurrence of dissimilar nuclei in a common cytoplasm), and dikaryosis (pairing of compatible nuclei). Formation of fruiting bodies, meiosis, and formation and discharge of basidiospores are dependent on successful mating. Consequently, important evolutionary processes such as genetic recombination and gene flow are also affected. Sexual interactions occur between homokaryons, or between dikaryons and homokaryons, with dikaryons acting as unilateral nuclear donors. Vegetative interactions involve only dikaryons. Typically, genetically dissimilar dikaryons exhibit mutually antagonistic reactions upon confrontation. Vegetative mycelial interactions thus represent self vs. non-self recognition and consequently may affect intra-specific competition and resource partitioning of individual substrates.

Incompatibility and Intersterility Systems

The ability of paired homokaryons to mate is governed by two distinct genetic systems that act in a coordinated manner: the intersterility and incompatibility systems. Intersterility genes delimit subpopulations or intersterility groups (ISGs) within *H. annosum.* ISGs have also been termed biological or sibling species because they are usually indistinguishable by the traditional morphological criteria used to separate species. Interfertile strains mate and form dikaryons, whereas intersterile strains do not. Generally speaking, interfertile strains belong to the same group, and intersterile strains belong to different groups. The incompatibility system affects the ability of homokaryons within an ISG to mate. Strains that are compatible can mate and attain the dikaryotic state. Homokaryons that are incompatible fail to form a dikaryon. Thus, intersterility genes define the limits of the population or ISG within which interbreeding and concomitant gene flow and genetic recombination can occur, whereas the incompatibility factor with its many mating-type alleles regulates the degree of inbreeding and outbreeding that can occur within the ISG.

Intersterility genes are epistatic to incompatibility genes, because strains must be interfertile in order for compatibility to be expressed. Conversely, strains in different ISGs have different incompatibility alleles but fail to mate because they are intersterile.

Both compatibility and interfertility in *H. annosum* are based on the ability of homokaryons to form a dikaryon when paired in culture (Chase and Ullrich 1983; Korhonen 1978). In *H. annosum* the two homokaryons being tested are inoculated about 0.5 cm apart on 1.25 percent malt extract agar in standard 9-cm Petri dishes and allowed to incubate at 23 C or at room temperature on a laboratory bench. Pairings are incubated for 10 days and then a subculture is made from the junction line of the pairing to fresh 1.25 percent malt extract agar. Subcultures are incubated 5 to 10 days before they are scored for the presence or absence of clamp connections. Clamp connections are easily observed through the inverted Petri dish (standard compound microscope, 150x magnification). Strains that form a dikaryon are interfertile and compatible. Negative mating reactions can be interpreted as either intersterile or incompatible only within the context of the experimental design and background of the strains utilized.

Genetics of the Incompatibility System

Incompatibility systems have been described in higher fungi for a number of species and groups (Raper 1966) and have been studied extensively in Schizophyllum commune (Raper 1966). Heterobasidion annosum is characterized by a bipolar (=unifactorial) system. Incompatibility is governed by a single incompatibility (mating-type) factor designated A. Many different mating-type alleles or variants of the A factor exist throughout H. annosum and can be designated as a numerical series (i.e., A1, A2, A3, etc.). Any two strains are capable of dikaryon formation when paired as long as they carry different mating-type alleles. Homokaryons carrying identical mating-type alleles cannot mate to form a dikaryon. Thus every dikaryon, upon fruiting, yields two mating-type alleles among its progeny homokaryons in a standard 1:1 Mendelian ratio. One of the consequences of this is that, among the progeny homokaryons from a single dikaryon, there will be a reduced level of compatibility (50 percent) and thus a reduction in inbreeding (Burnett 1965). Regulation of the degree of inbreeding appears to be the primary role of mating-type alleles in the basidiomycetes (Burnett 1965; Raper 1966; Ullrich 1977).

The number of mating-type alleles in the worldwide population of H. annosum is very high. For instance, forty different alleles were identified in a study of H. annosum from 31 unique dikaryons in four Pinus resinosa plantations in Vermont (Chase and Ullrich 1983). Other studies (Korhonen 1978; Stenlid 1985) have also documented the existence of large numbers of mating-type alleles in small samples. Although no attempt has yet been made to estimate the worldwide number of mating-type alleles, it is certainly safe to assume that there are hundreds of alleles in existence. As a consequence, outbreeding is highly favored in H. annosum, and a high potential for gene flow and genetic recombination exists within interbreeding populations of the fungus.

One of the useful features of mating type alleles is that they can be used as naturally occurring markers of the distribution of individual dikaryons in the field (Chase and Ullrich 1983; Stenlid 1985). Dikaryons of H. annosum with identical sets of incompatibility alleles have been found only in proximity to one another, either on the same stump or tree, or on adjacent trees or stumps, usually within 10-20 m. This is consistent with the concept of vegetative spread of H. annosum through root contacts of neighboring trees. The maximum extent for spread of clones seems to be much less for H. annosum than for species in the Armillaria mellea complex (Chase and Ullrich 1983; Piri and others 1989; Stenlid 1985). Piri and others (1989) showed that the average number of trees occupied by a clone of H. annosum is two, although some clones were shown to infect as many as 16 trees. Clones of A. mellea have been shown to be extensive, especially in the western United States. Anderson and others (1979) suggested that individual clones may extend as much as 500 m and infect large numbers of trees within these limits. There have been no large-scale studies utilizing genetic methods to assess clonal spread of H. annosum in western North America. Such studies would be very useful in assessing the spread of the fungus in individual disease centers. Evidence for clonal spread was seen in a small study of a western red cedar/grand fir plot in British Columbia (Chase 1985).

Vegetative Interactions

A vegetative compatibility test has recently been developed for H. annosum (Stenlid 1985). Individual dikaryons are paired in culture on Hagem agar, and those showing complete intermingling of mycelia at the junction zone are interpreted as being the same dikaryotic clone (i.e., vegetatively compatible). Dikaryons that form a zone of inhibited mycelial growth or mutual antagonism at the junction zone are interpreted to be genetically different clones (i.e., vegetatively incompatible). Vegetative compatibility tests are useful for several reasons. First, they provide a much more efficient way to conduct clonal distribution studies, because they allow complete sampling of a stand unrestricted by the availability of fruiting bodies or the need to induce fruiting of isolated dikaryons in the laboratory. Secondly, work load is reduced by not having to isolate homokaryons in order to test for identity of mating-type alleles. Last but not least, vegetative compatibility tests are also valuable because they can distinguish between dikaryons that are truly identical clones and those that simply have identical mating-type alleles (Stenlid 1985).

The genetic basis for vegetative incompatibility has not been elucidated in H. annosum or any other Basidiomycete. Since sibling-related dikaryons with identical mating-type alleles display vegetative incompatibility (Stenlid 1985), it is apparent that the incompatibility factor is not directly involved. Presumably some kind of polygenic system is indicated, since the strength of vegetative incompatibility reactions may vary over a wide range. The consequence of the existence of vegetative incompatibility in H. annosum is that a substrate may be occupied by a number of dikaryons each within a different space. The degree to which different dikaryons within a substrate undergo competition or cooperativity with one another is unknown.

Intersterility in *H. annosum*

In his studies on the breeding biology of *H. annosum,* Korhonen (1978) identified two intersterility groups in the Finnish population. He designated these the 'S' and 'P' intersterility groups. The 'S' group was isolated primarily from butt-rotted Norway spruce [*Picea abies* (L.) Karst.] and from seedlings of Scotch pine (*Pinus sylvestris* L.) growing adjacent to infected Norway spruce stumps. The 'P' group was isolated from a much broader range of host trees, primarily saplings and mature trees of Scotch pine, juniper (*Juniperus communis* L.), birch (*Betula* sp.), and alder (*Alnus incana* (L.) Moench.), but also including mature butt-rotted *P. abies*. Nearly all pairings (97 percent) between 'S' and 'P' group homokaryons failed to give rise to dikaryons. In contrast, virtually all pairings within a group gave rise to dikaryons except for the occasional cases in which homokaryons carried identical incompatibility mating-type alleles.

Korhonen (1978) extended his study to include dikaryons from a worldwide collection. Dikaryons were paired with the homokaryon testers (di-mon pairings; Raper 1966), because homokaryotic testers are capable of being dikaryotized only by dikaryons of the same group. The results showed that both the 'S' and 'P' groups were found throughout the world on a wide variety of hosts, but the conclusion was that "pine species are typically attacked by the 'P' intersterility group of *H. annosum*" (Korhonen 1978). Korhonen (1978) also described a third intersterility group, members of which failed to dikaryotize either 'S' or 'P' group testers. He designated these the '0' group, but subsequent studies (Chase and others 1985) have shown these to be the homothallic form since redescribed as *H. araucariae* (Buchanan 1988). Korhonen and others (1988) have described a new intersterility group ('F' group) from silver fir in the Appenine Mountains of Italy, which is interfertile with Finnish 'S' group strains but is intersterile with 'S' group strains from the Italian Alps.

Intersterility Groups in North America

The 'S' and 'P' groups are distributed throughout western North America, but so far only the 'P' group has been found in eastern North America (Chase 1989, Chase and Ullrich 1989a; Chase 1985). Homokaryotic North American strains were identified as belonging to the 'S' and 'P' groups on the basis of their reactions with Finnish tester strains (Chase and Ullrich 1989a: Chase 1985); however, the two groups were found to be partially interfertile. In some cases, the patterns of mating reactions suggested that intersterility was under the control of Mendelian-like determinants (i.e., genes). For instance, all the homokaryons isolated from an Alaskan dikaryon mated with 'S' testers from Finland but failed to mate with 'P' testers from Finland. However, half of the Alaskan homokaryons mated with Vermont strains (which mate with Finnish 'P' strains and not with Finnish 'S' strains), but the remainder did not. As many as 50 percent of pairings between eastern North American 'P' group homokaryons and western North American 'S' group isolates are interfertile and result in dikaryon formation. Partial interfertility exists between western North American 'S' group and the western North American 'P' groups but is not as pronounced. Dikaryons were formed in 57 out of 320 (18 percent) of pairings in preliminary experiments (T.E. Chase, unpublished data).

Genetics of Intersterility in *H. annosum*

The ability to mate some western North American 'S' group isolates with eastern North American 'P' group isolates provided the opportunity to examine the inheritance of intersterility determinants, since the strains being paired possessed diametrically opposed specificities for Finnish 'S' and 'P' strains (Chase and Ullrich 1989b). Progeny from these crosses were analyzed and segregation for intersterility genes was observed (Chase and Ullrich 1989b) allowing the formulation of a testable genetic model of how these genes interact as well as the construction of a simple genetic linkage map.

Five intersterility genes, each with two alternate alleles, have been identified (Chase and Ullrich 1989b) thus far and have been designated $\underline{S}^+/\underline{S}^-$, $\underline{P}^+/\underline{P}^-$, $\underline{V1}^+/\underline{V1}^-$, $\underline{V2}^+/\underline{V2}^-$, and $\underline{V3}^+/\underline{V3}^-$. Under standard laboratory conditions, dikaryon formation can occur between any two strains having a "positive" (+) allele in common at one or more of the five loci. For example, a strain with a $\underline{V1}^-\underline{V2}^-\underline{V3}^+\underline{S}^+\underline{P}^-$ can form a dikaryon when paired with a strain carrying a $\underline{V1}^-\underline{V2}^+\underline{V3}^+\underline{S}^-\underline{P}^+$ genotype, because $V3^+$ is common to both strains. Conversely, a strain with a $\underline{V1}^-\underline{V2}^+\underline{V3}^-\underline{S}^-\underline{P}^+$ cannot form a dikaryon in pairings with a strain carrying a $\underline{V1}^-\underline{V2}^-\underline{V3}^+\underline{S}^+\underline{P}^-$. Homoallelism for "negative" (-) alleles does not allow interfertility. As stated previously, dikaryon formation is also dependent on two strains having different mating-type alleles. Intersterility genes identified in various groups of *H. annosum* are shown in Table 1.

Under periods of prolonged incubation, intersterile pairings may give rise to clamped mycelia. Genetic analysis of such "illegitimate" matings suggests they could arise from pairing of parasexually derived recombinant nuclei that are interfertile and compatible with one of the original parental nuclei (Chase 1985). The extent to which "illegitimate" mating occurs in nature is unknown, but it is doubtful that it plays an

Table 1-- Representative intersterility genotypes of Heterobasidion annosum.

Intersterility group	Intersterility gene V1	V2	V3	S	P
Finland					
'S' group	-/-[1]	-/-	-/-	+/+[2]	-/-
'P' group	-/-	-/-	-/-	-/-	+/+
North America					
Eastern 'P' group	?[3]	+/+	+/+	-/-	+/+
Western 'S' group	+[4]	-/-	+/-[5]	+/+	-/-
'P' group	+	+/+	+/-	-/-	+/-

[1] -/-, all dikaryons examined are homozygous for - allele at locus.

[2] +/+, all dikaryons examined are homozygous for + allele at locus.

[3] Existence of $V1^+$ in Eastern North American 'P' group not confirmed.

[4] $V1^+$ exists in population, but no collection has been fully analyzed for heterozygosity.

[5] +/-, evidence has been found for heterozygosity at locus in dikaryons of population. Individual dikaryons may be heterozygous or homozygous for either allele.

important role in allowing gene flow between intersterility groups. This conclusion is supported by recent isozyme surveys indicating a lack of evidence for gene flow between North American 'S' and 'P' groups (Otrosina and others 1989).

POPULATION STRUCTURE AND HOST SPECIFICITY RELATIONSHIPS OF H. ANNOSUM IN WESTERN NORTH AMERICA

A detailed picture of the population structure of H. annosum in western North America is beginning to emerge. Data from intersterility studies have delineated two biological species (Chase 1985; Chase and Ullrich 1989a), and data from isozyme studies have confirmed initial conclusions (Otrosina and others 1989). Most important for forest managers is the clear indication these studies have given that the two biological species of H. annosum have major differences in host specificity.

Chase and Ullrich (1989a) determined the intersterility genotypes of dikaryons isolated from various host species in North America. Dikaryons of the 'S' group were associated with infection and mortality in several host species including white fir, grand fir, western hemlock, and western red cedar. Dikaryons of the 'P' group were associated with infection and mortality in red pine and loblolly pine (both from eastern United States), and ponderosa pine in the western United States. Host specificity was not apparent in isolates from stumps. For instance, isolates from spruce stumps in New Hampshire were of the 'P' group, and isolates of the 'S' group were sampled from both pine and fir stumps in California. These data suggested that pathogenic activity (i.e., infection of host trees) is specific, whereas saprotrophic colonization of stumps is not.

Subsequently, a more detailed cooperative study involving the USDA Forest Service Pacific Southwest Forest and Range Experiment Station and the University of California at Berkeley has been undertaken. In this study, sets of mono-basidiospore isolates were established from fruiting bodies collected from stumps of true fir (Abies) and hard pines throughout much of the Sierra Nevada, southeastern Oregon, and from the San Bernardino Mountains. Both 'S' and 'P' group isolates were identified from ponderosa and Jeffrey pine stumps. True fir stumps yielded only 'S' group isolates; however, nearly all fir stumps sampled were left from trees infected before felling, as evidenced by characteristic decay patterns. Samples from fallen giant sequoia and true fir stumps in the vicinity of fallen giant sequoia yielded only 'S' group isolates.

Isozymes were analyzed for dikaryons isolated from the context tissue of the same conks used as sources for monobasidiospore isolates (Otrosina and others 1989). A strict concordance between isozyme and intersterility data was seen, indicating the existence of two genetically isolated populations of H. annosum. Subsequent sampling of recently killed or dying trees in the Sierra Nevada and the San Bernardino Mountains is consistent with the hypothesized concordance between intersterility groups and host range of H. annosum isolates (W.J. Otrosina, T. Chase, and F.W. Cobb, unpublished data). All isolates from naturally infected ponderosa and Jeffrey pine trees have the isozyme profile associated with the 'P' group. All isolates from true fir displayed the 'S' group isozyme profile. All isolates from naturally infected incense cedar, manzanita, juniper, Coulter pine, and Pinyon had the 'P' group isozyme profile, but only a few isolates from each of these hosts were examined.

Although the concordance between inter-sterility group and host range has been consistent thus far, it would be desirable to obtain information from controlled inoculation studies to support these conclusions. Worrall and others (1983) conducted inoculation trials on pine and fir seedlings in the greenhouse with isolates from ponderosa pine and true fir. The intersterility groups of the isolates were unknown, but differences in "host specialization" between the two groups of isolates were demonstrated. Recently completed seedling inoculation experiments utilizing well characterized 'S' and 'P' isolates and nine different host species also suggest differences in host specificity between the groups (F.W. Cobb, T.E. Chase, and W.J. Otrosina, unpublished data).

In addition to controlled inoculation studies, we will need more survey data from a variety of sampling situations and localities. Data for outplanted seedlings as well as mixed conifer stands, and a variety of other ecological situations are needed. For instance, are both groups able to attack outplanted seedlings of fir and pine? And does the isolation of the 'P' group from incense cedar reflect host specificity or rather the proximity of incense cedar to pine in mixed stands? Another important question is to determine whether host specificity is maintained under adverse conditions such as drought and bark beetle attack.

Answering these questions will strengthen our understanding of the population structure and perhaps indicate possibilities for stand manipulation and biological control.

Lack of Evidence for Inter-Group Hybrids

Despite the existence of genes allowing hybridization, there is no evidence as yet for the existence of natural hybrids between the 'S' and 'P' groups in North America. The reasons for this are not apparent. One possibility is that such hybrids might be at a selective disadvantage because they carry genes allowing host recognition and defense systems of both pine and fir to operate against them. Another possibility is that, in nature, hybrids might have a reduced ability to compete, a reduced capability for fruiting, or a reduced spore viability. An alternative possibility is that sampling to date has simply failed to identify "hybrid zones" of H. annosum which may have a limited geographic or unusual host distribution.

CONCLUSIONS

The sexuality and life cycle of Heterobasidion annosum have been clarified, and utilization of techniques from fungal genetics and biochemistry is beginning to yield a detailed picture of the population structure of the fungus. Heterobasidion annosum is a heterothallic fungus with a well-defined sexual stage allowing mating and genetic recombination. In the western United States and Canada, H. annosum consists of at least two intersterility groups (ISGs) or biological species that are reproductively and genetically isolated from each other. The two ISGs have important differences in host range that have the potential to be exploited in making management decisions and developing biological controls. Further research should be allocated to continued sampling of populations in a variety of ecological situations and to means of silviculturally manipulating stands to reduce losses. Basic research should continue to focus on the nature of the intersterility genes as well as the genetic and biochemical nature of the host-pathogen specificity interaction. Information from both applied and basic research should be useful in generating realistic predictive models for disease dynamics and losses.

This study was supported, in part, by competitive USDA grant #87-FSTY-9-0236 to the USDA Forest Service Pacific Southwest Forest and Range Experiment Station and the University of California, Berkeley.

REFERENCES

Anderson, J.B.; Ullrich, R.C.; Roth, L.F.; Filip, G.M. 1979. Genetic identification of clones of Armillaria mellea in coniferous forests of Washington. Phytopathology 69: 1109-1111.

Buchanan, P.K. 1988. A new species of Heterobasidion (Poloyporaceae) from Australia. Mycotaxon: 32: 325-337.

Burnett, J.H. 1965. The natural history of recombination systems. In: Raper, J.R.; Esser, K., eds. Incompatibility in fungi. Berlin: Springer; 98-113.

Chase, T.E. 1985. Genetics of sexuality and speciation in the fungal forest pathogen Heterobasidion annosum. Burlington: University of Vermont; 244 p. Dissertation.

Chase, T.E.; Ullrich, R.C. 1983. Sexuality, distribution, and dispersal of Heterobasidion annosum in pine plantations of Vermont. Mycologia 75: 825-831.

Chase, T.E.; Ullrich, R.C. 1985. Fruiting and genetic analysis of Heterobasidion annosum. Mycologia 77: 464-471.

Chase, T.E.; Ullrich, R.C. 1989a. Genetic basis of biological species in Heterobasidion annosum: Mendelian determinants. Mycologia (in press).

Chase, T.E.; Ullrich, R.C. 1989b. Five genes determining intersterility in Heterobasidion annosum. Mycologia (in press)

Chase, T.E.; Ullrich, R.C.; Korhonen, K. 1985. Homothallic isolates of Heterobasidion annosum. Mycologia 77: 975-977.

Chase, T.E.; Ullrich, R.C.; Otrosina, W.J.; Cobb, F.W.; Taylor, J.W. 1989. Genetics of intersterility in Heterobasidion annosum. In: Proceedings of the seventh international conference on root and butt rots of forest trees; 1988 August 9-16; Vernon and Victoria, British Columbia, Canada; 11-19. Victoria: Forestry Canada.

Hodges, C.S.; Koenigs, J.W.; Kuhlman, E.G.; Ross, E.W. 1971. Fomes annosus: A bibliography with subject index--1960-1970. Res. Paper SE-84. Asheville, NC: Southeastern Forest Experiment

Station, Forest Service, U.S. Department of Agriculture; 75 p.

Koenigs, J.W. 1960. Fomes annosus. A bibliography with subject index. Occas. Paper 181. Asheville, NC: Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 35 p.

Korhonen, K. 1978. Intersterility groups of Heterobasidion annosum. Communicationes Instituti Forestalis Fenniae 94: 1-25.

Korhonen, K.; Capretti, P.; Moriondo, F.; Mugnai, L. 1988. A new breeding group of Heterobasidion annosum found in Europe; In: Proceedings of the seventh international conference on root and butt rots of forest trees; 1988 August 9-16; Vernon and Victoria, British Columbia, Canada; 20-26. Victoria: Forestry Canada

Otrosina, W.J.; Chase, T.E.; Cobb, F.W., Jr.; Taylor, J.W. 1989. Isozyme Structure of Heterobasidion annosum isolates relating to intersterility genotype. In: Proceedings of the seventh international conference on root and butt rots of forest trees; 1988 August 9-16; Vernon and Victoria, British Columbia, Canada; 406-416. Victoria: Forestry Canada.

Piri, T.K.; Korhonen, K.; Sairanen, A. 1989. Clonal spreading of Heterobasidion annosum in pure and mixed spruce stands on south Finland. In: Proceedings of the seventh international conference on root and butt rots of forest trees; 1988 August 9-16; Vernon and Victoria, British Columbia, Canada; 592. Victoria: Forestry Canada.

Raper, J.R. 1966. Genetics of sexuality in higher fungi. New York: Ronald Press; 283 p.

Stenlid, J. 1985. Population structure of Heterobasidion annosum as determined by somatic incompatibility, sexual incompatibility, and isoenzyme patterns. Canadian Journal of Botany 63: 2268-2273.

Ullrich, R.C. 1977. Natural distribution of incompatibility factors in basidiomycetous fungi. Mycologia 69: 714-719.

Worrall, J.J.; Parmeter, J.R.; Cobb, F.W. 1983. Host specialization of Heterobasidion annosum. Phytopathology 73: 304-307.

Biology, Ecology, and Epidemiology of *Heterobasidion annosum*[1]

William J. Otrosina Fields W. Cobb, Jr.[2]

Abstract: Pertinent literature on the biological aspects of annosus root disease is reviewed. Key features of the life cycle of Heterobasidion annosum such as stump infection, stump colonization, host-parasite relations, and interactions of various physical and biological factors are discussed in relation to forest stands in the western United States. This review suggests our knowledge of the pathology of this disease is limited on most affected tree species. Further research on various aspects of the life cycle of this fungus is essential to minimizing losses to this disease.

The literature on Heterobasidion annosum (Fr.) Bref. before 1970 contains over 1,000 titles dealing with various aspects of the fungus and the disease it causes (Hodges and others 1971; Koenigs 1960). A preliminary literature review conducted by Otrosina estimates at least 850 titles dealing with H. annosum have been published during the period 1970 to 1988. This paper is not intended to be a review and will not attempt to address all aspects of the biology of H. annosum; it will highlight pertinent research on the biological and ecological relationships as they pertain to the pathology of pine and true fir in the western coastal states of the United States. The disease as it relates to other hosts in other geographic areas is discussed elsewhere in these proceedings.

STUMP SUSCEPTIBILITY AND INFECTION

The most crucial stage in the disease cycle of H. annosum is the entry or invasion of the fungus into the stand where it can then move from tree to tree through roots. The primary mode of stand entry in pines is through freshly cut stump surfaces (Begs 1963) (fig. 1). We believe that stump infection is important in fir as well, though there are other modes of entry in Abies (fig. 2). Stump surfaces act as ideal semi-selective media for germination of deposited basidiospores of the fungus. Susceptibility of stump surfaces of various hosts has been studied by a number of investigators (Rishbeth 1951; Yde-Andersen 1962; Cobb and Barber 1968). The general consensus of these studies is that stumps of most susceptible species can remain receptive to invasion by the fungus for up to 45 days, depending upon season and host species. On the other hand, Cobb and Schmidt (1964) found eastern white pine (Pinus strobus L.) stumps to be highly susceptible for only a few days after felling. In the western United States, ponderosa pine (Pinus ponderosa Laws.) stumps may remain susceptible for at least 4 weeks, although susceptibility drops markedly after 1 to 2 weeks (Cobb and Barber 1968). Susceptibility of stumps also was greater in the autumn than in the spring. This was attributed to higher resin content of cut stump surfaces in the spring-felled trees than in those felled in the fall. Not all susceptible tree species are colonized through stump surfaces at the same rates or conditions as ponderosa pine. For example, spore inoculation studies of incense cedar (Calocedrus decurrens (Torr.) Florin) suggest substantially more resistance to colonization under the same conditions that allow ponderosa pine stumps to be colonized (Hunt and others 1974).

Temperature is an important factor in determining successful infection of stump surfaces by H. annosum. The optimal temperature for growth of the fungus in pure culture is 23-26 C for a wide variety of host and geographic origins of isolates (Cowling and Kelman 1964). The fungus is also capable of considerable growth at lower temperatures, averaging 21 percent of optimum at 8 C. In general, the fungus does not grow at temperatures above 32 C. The upper temperature limit has important implications regarding stump infection in certain climates. Ross (1969) found basidiospores and conidia of the fungus to be inactivated after 60 minutes at temperatures above 45 C. There is an apparent difference in temperature effects between mycelia and spores. Actively growing mycelia can become inactive or killed at temperatures above 35 C (Gooding 1964). In California, stumps in ponderosa pine stands may be exposed to temperatures greater than 35 C during the summer months. For example, Cobb and Barber (1968) noted ambient temperatures greater than 33 C during a study involving artificial inoculation of stumps, but they detected stump

[1] Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, at Monterey, California.

[2] Research Plant Pathologist, Pacific Southwest Forest and Range Experiment Station, Berkeley, California; and Professor, Department of Plant Pathology, University of California, Berkeley.

infection by H. annosum during this period of high temperature. They so found that sumps exposed to direct solar radiation in stand openings were infected at the same level as stumps under more closed canopies. In the southeastern United States, recommendations for controlling annosus root disease in southern pine stands revolve around thinning stands in the warm summer months, during which ambient temperatures are above the 35 C inactivation point for the fungus (Ross 1973). Studies conducted by Cobb and Barber (1968), Gooding (1964), and Rose and others (1980) suggest high stump temperatures may not be the sole factor responsible for lowering rates of stump infection. Gooding (1964) studied survival of H. annosum in inoculated bolts of loblolly pine (Pinus taeda L.) incubated at various temperatures. He was unable to recover the fungus from bolts incubated at 35 C and above that were not surface sterilized before inoculation. On surface sterilized bolts, however, the fungus was reisolated at temperatures up to 40 C. These results suggest microbial activity at the stump surface plays some synergistic or interactive role in stump infection at higher temperatures. Rapid replacement of H. annosum by Trichoderma viride Pers. ex Fr. in a greenhouse inoculation study was attributed to high soil temperatures (Towers and Stambaugh 1968). Also, T. viride may act together with other fungi such as the saprotrophic colonizer Phlebia (Peniophora) gigantea (Fr.) Masses to inhibit H. annosum (Curl and Arnold 1964). The stump infections observed in California during the hot, dry summer months may indicate differences in kinds and quantity of microorganisms present on stump surfaces between climatic and geographic regions. The warm, humid climate of the southeastern United States tends to favor fungi such as Trichoderma and Phlebia, where they can often be observed fruiting on stump surfaces. However, these fungi are rarely observed in this manner in California.

The inoculum potential of the fungus in the form of airborne spores (largely basidiospores) is another important determinant of stump infection. Spore deposition rates have been measured almost everywhere annosus root disease is a problem. Edmonds and others (1984) found deposition rates in precommercially thinned stands of western hemlock (Tsuga heterophylla (Raf.) Sarg.) to be up to 8 times greater (up to 19,577/m^2/hr) in

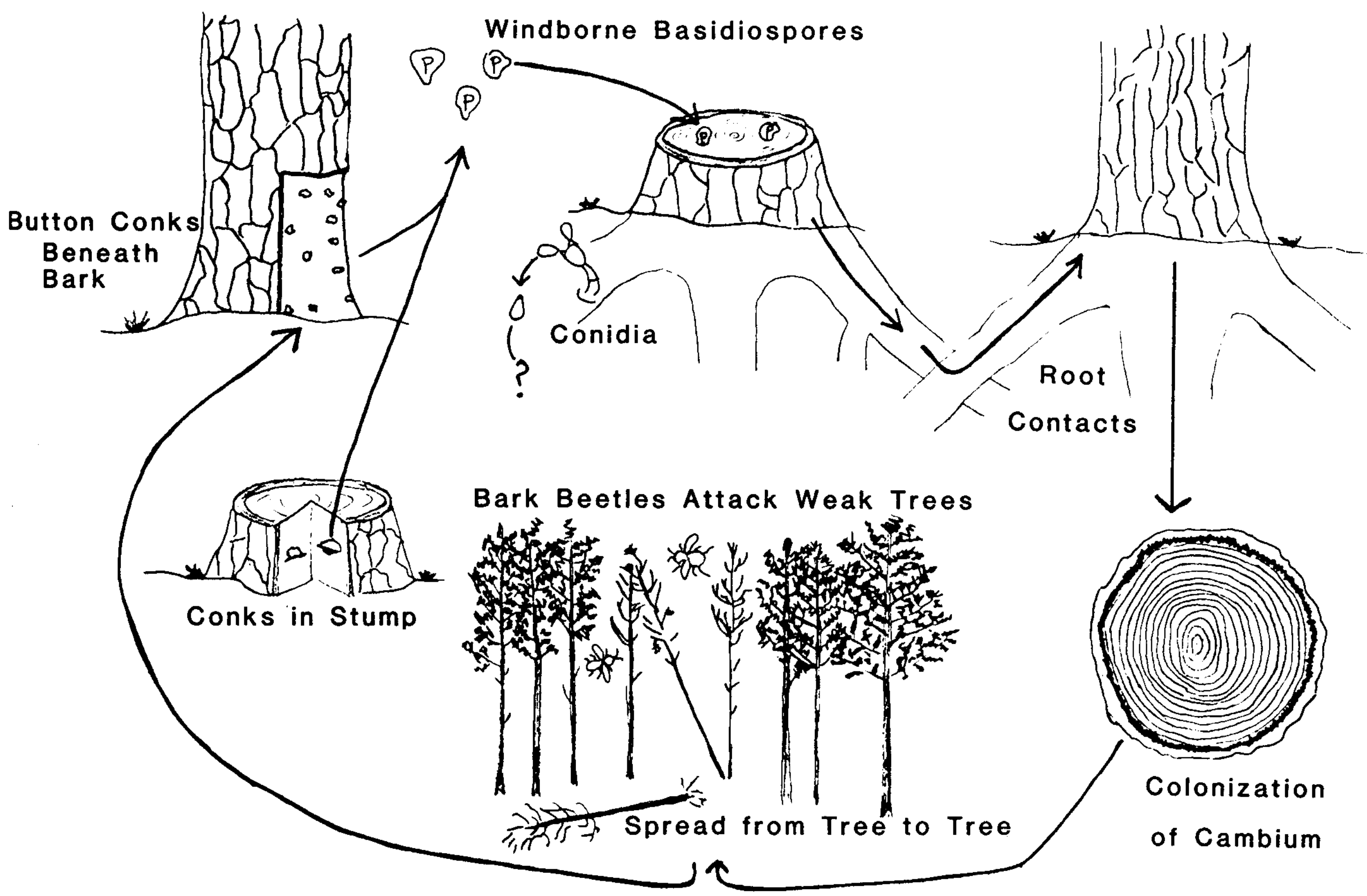


Figure 1--Infection cycle of Heterobasidion annosum in Pinus.

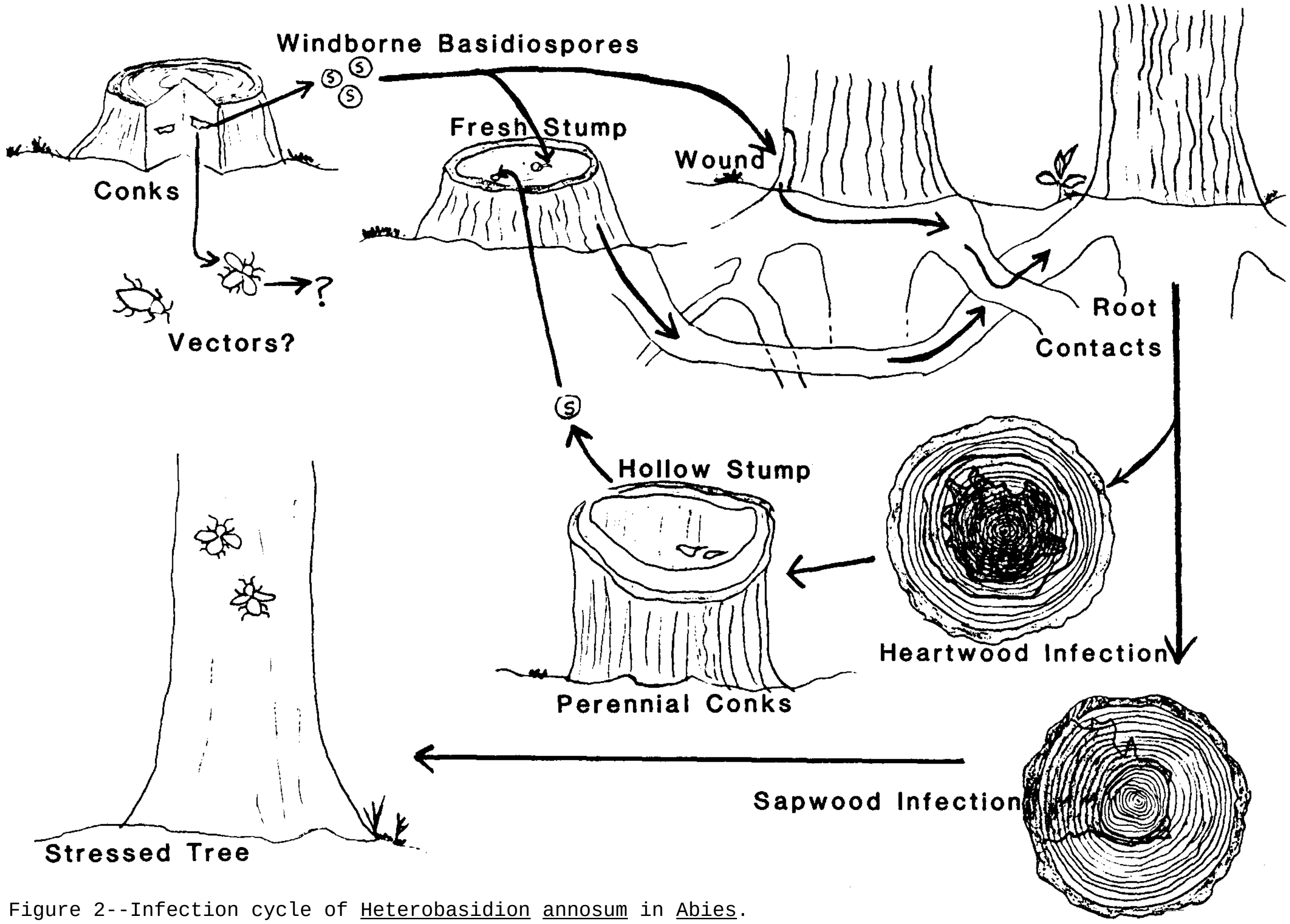


Figure 2--Infection cycle of Heterobasidion annosum in Abies.

precommercially thinned than in commercially thinned stands. In California, spore deposition rates in mixed conifer forests ranged from 3 to 796 spores/m^2/hr, depending on geographic location and season (James and Cobb 1984). Generally, the highest rates occurred in the autumn in these forests whereas in the southeastern United States, greatest spore deposition rates are observed during the winter months (Drummond and Bretz 1967; Ross 1969).

Because H. annosum has an asexual spore state, Oedocephalum lineatum Bakshi (=Spiniger meineckellus (Olson) Stalpers), the question has arisen as to its function in nature, is., whether the asexual conidiospores are an important etiological agent. Kuhlman and Hendrix (1964) found conidial inoculum inferior to basidiospore inoculum as measured by stump colonization 9 months after inoculation with spore suspensions. They did not indicate the relative spore concentrations in their inoculum solutions, but check inoculations on pine disks indicated comparable initial viability of inocula. Conidial inoculum has been used successfully numerous times by others in the study of stump infection and colonization (James and others 1980b). Conidia have been shown to survive in field soils having extremely low water potentials for several months, although survival declines over time to a greater extent in sandy soils than in clay loans (Kuhlman 1969a). The potential for direct root infection by spores of H. annosum exists, and may be responsible for initiation of some root infections, particularly in injured stump roots created after felling (Kuhlman 1969b).

COLONIZATION

The colonization phase of the infection process refers to the establishment and growth of the fungus through stump and root tissues distally from exposed stump surfaces. Saprotrophic colonization of these woody tissues by the fungus provides the inoculum necessary for infection of adjacent, previously uninfected trees. Not all stump surface infections progress to the point of colonization of the woody root tissues. Factors such as temperature, tree species, climate, type of microflora, and inoculum density can interact to reduce successful stump colonization.

Most of the research regarding stump and root colonization by H. annosum has been conducted on various pine species in different parts of the world (Driver and Ginns 1969; Rishbeth 1951). Hunt and coworkers (1976) studied stump colonization in the western United States. They investigated factors affecting colonization of ponderosa pine (Pinus ponderosa Dougl. ex Laws.) and to a more limited extent, Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) and sugar pine (Pinus lambertiana Dougl.). Interestingly, they could not study colonization of white fir (Abies concolor (Gord.)Lindl. ex Hildebr.)) because many trees in the study area were found to be infected before felling. Under their experimental conditions, colonization of sugar pine and Douglas-fir stumps lagged behind that of ponderosa pine in the rate at which inoculated stump roots became colonized. They also found colonization of ponderosa pine stumps to be characterized by the formation of "tubes" which are vertically oriented channels formed by disintegrating conductive tissue in the sapwood-bark interface. These tubes, along with beetle galleries containing mycelium, may serve to hasten spread of the fungus to distal portions of large stump roots by providing suitable microsite conditions for unrestricted hyphal growth. Rainwater may also carry conidia formed in tubes or beetle galleries to lower portions of stump root systems. The spores may then germinate and form new infection foci along the sapwood-bark interface. Conidia have been observed in these structures 2.5 to 12 months after inoculation of ponderosa pine stumps and may be an important agent in the early stages of colonization. Such a mechanism can provide for rapid stump root colonization, 0.2 to 0.5 cm/day, as reported by Hunt, et al. (1976), who noted very few root collars becoming infected from the portion of the fungal mycelia growing deeper within the sapwood. Because the fungus moves rapidly along the sapwood-bark interface and because H. annosum can grow readily into bark scales from this interface, rapid spread to adjacent host root systems can be realized through root contacts.

Role of insects in stump colonization

Insects may function in the spread of H. annosum in at least two ways: 1) as vectors transporting propagules of the fungus between stumps and 2) as facilitators in the local spread of the fungus within stump roots.

The black turpentine beetle, Dendroctonus terebrans Oliv., has been shown to carry and transmit H. annosum when various stages of the insect were placed on disks of fresh loblolly pine (Rimes and Skelly 1972). In the western United States, Dendroctonus valens Leconte, closely related to D. terebrans, is associated with trees infected by H. annosum. After detailed study of colonization of stumps and trees by various insects including D. valens, Hunt and Cobb (1982) concluded that insects are not major agents in the dissemination of H. annosum in ponderosa pine. They provided evidence indicating that stump-colonizing insects may introduce fungi such as Phlebia gigantea and Ophiostoma (Ceratocystis) spp. that act as competitors to H. annosum, although none of the introduced fungi colonized stump surfaces enough to reduce colonization by H. annosum.

Within stumps, however, insects may have considerable opportunity to spread the fungus for short distances (several centimeters). Such local spread could be important in aiding rapid establishment of the fungus in larger stump roots, although there is currently no experimental evidence to support this possibility. However, data reported by Hunt and others (1976) and Hunt and Cobb (1982) regarding timing of appearance of conidia in pine stumps and insect colonizers suggest that this topic deserves further study. Virtually no information is available regarding spread of H. annosum by insects in true fir.

SPREAD TO ADJACENT TREES

Role of Root Contacts and Root Grafts

Knowledge of factors affecting spread of this pathogen to adjacent uninfected trees in forest stands is key to our ability to quantify and predict infection rates and losses in these stands. Unfortunately, our knowledge of these factors and how they affect pathogen spread is incomplete, particularly in western forests. It has been known for some time that tree-to-tree spread of the fungus is accomplished through root contacts or root grafts (Rishbeth 1950). Because the fungus readily colonizes the sapwood-bark interface in roots and grows ectotrophically through bark scales, inoculum of the fungus can be potentially available for infection at considerable distances from the site of the initial stump infection. The importance of root contacts or root grafts in the infection process is reflected by the incapability of H. annosum to grow more than a few millimeters through soil (Srago 1973).

In contrast to acting as a means for inoculum transfer to adjacent trees, root grafting can be responsible for slowing the spread of the disease. There is evidence that progress of infection by H. annosum is reduced in Douglas-fir and western hemlock stumps that have root systems grafted to living residual trees (Morrison and Johnson 1978). Resistance mechanisms of the host could be operating in root systems of grafted stumps. The occurrence and importance of root grafting to disease spread need to be determined in the ponderosa pine, mixed conifer, and true fir type. Such information is necessary in predicting losses from this disease in these forest stands.

Morrison and Johnson (1978) report that Armillaria sp. appears to be an effective competitor against H. annosum in Douglas-fir and western hemlock root systems because in some cases, Armillaria sp. colonized the root systems of trees by rhizomorphs before to felling.

Armillaria colonizes the outer tissues of root systems, thereby reducing opportunity for spread of H. annosum. In contrast, stumps of trees root grafted to residuals may remain alive and receptive to infection for some time, with host resistance excluding opportunistic saprotrophic fungi that may compete with H. annosum.

Observations in California suggest a more complex interaction between H. annosum and Armillaria species in true firs. Armillaria appears to be ubiquitous in Abies, often growing along roots as in oak. In many cases, colonization of fir by H. annosum appears to favor pathogenic colonization by Armillaria, thus enabling both fungi to exist as significant pathogens in true firs. Otrosina (unpublished data) has isolated H. annosum from tissues of firs having abundant rhizomorphs and characteristic rot of Armillaria. The relationships between these two pathogens on true fir need to be studied in detail.

Edaphic factors and disease spread

Rishbeth (1950) noted a relationship between soil pH and severity of root disease caused by H. annosum in Scots pine (Pinus sylvestris L.) plantations in England. He showed that alkaline soils had higher infection rates than acidic soils. The relationship between soil pH and disease severity may not be pronounced in North America, where coniferous forest soils are usually acidic and the disease can be extremely severe.

In searching for easily measured or observed factors associated with severity and non-severity of the disease in the southern United States, Froelich and coworkers (1966) found that severe damage from the disease was associated with a low level of soil organic matter, slightly higher pH (5.65 vs 5.23 in undamaged stands), high sand content or very high clay content, and sparse grass cover. In stands of loblolly pine (Pinus taeda L.) in the piedmont and coastal plain of Virginia, Morris and Frasier (1966) associated sandy soils having an A horizon depth of 30 cm or more and a water table greater than 45 cm with high disease hazard. Alexander and others (1975) also found strong correlations between disease severity and high sand content, low level of organic matter, and low field capacity to be associated with high-hazard sites. There was also evidence of considerable growth loss of infected trees on sites classified as low hazard that approached the growth loss due to mortality on the high-hazard sites. Although these guidelines can serve as a generalized tool for the land manager, there are notable exceptions to these soil/site factors relating to disease hazard (Froelich and others 1977). Stands of loblolly pine in several soil series having low sand content also demonstrate high mortality due to H. annosum. These exceptions indicate our incomplete understanding of these relationships, a situation especially acute in forests of the western United States.

Information on soil microbial activity and disease severity is sparse, although knowledge of these relationships can be important in understanding risk of disease development in conjunction with other soil/site relationships. Few studies have investigated these factors. In the southeastern United States, Veech and Boyce (1964) found lower numbers of soil microfungi, actinomycetes, and bacteria in soils from a severely diseased slash pine (Pinus elliotii Engelm.) plantation than from a relatively unaffected stand. Both stands had similar cultural histories. Also, Adams and others (1964) found more stylet-bearing nematodes under diseased slash pine than in uninfected trees in various sites.

Srago (1973) and Srago and Cobb (1974) studied various soil physical and microbiological factors affecting H. annosum in California. They showed that the fungus was inhibited by soil microorganisms, and that hyphae of the fungus lysed after exposure to microbially active soils, demonstrating the inability of this pathogen to grow more than a few millimeters through the soil. Microbial inhibition may explain reduced spread of the pathogen in certain stands. In other situations, increased populations of soil microorganisms have been observed on severely disturbed sites that have been stabilized by establishment of grasses (Otrosina and others 1984). It is interesting to note that increased organic matter and grass cover are highly correlated with reduced disease severity in pine stands in the southern United States (Froelich and others 1966). Inhibition of H. annosum by the interaction of saprotrophic fungi on different soil substrates has been demonstrated (Curl and Arnold 1964).

Besides possible direct inhibition of H. annosum by soil microbial activity, reduced disease spread in certain stands may be the result of increased decomposition rates of distal portions of root systems of infected stumps. Rapid invasion of distal portions of root systems by saprotrophic fungi can reduce the probability of infection of adjacent uninfected trees by reducing root contacts with infected tissue. These proposed mechanisms are highly speculative, and much research relating soil microbial activity and other soil factors to disease severity in the western United States remains to be done. Knowledge of the factors and mechanisms relating soil characteristics to disease severity has obvious value in the development of predictive models for the land manager.

HOST-PARASITE INTERACTIONS

Characteristics of the Infection Process in Living Host Tissues

Next, we will discuss the current information on mechanisms of disease resistance and the host-pathogen interactions potentially affecting it.

Resistance begins to play a role at the point in the disease cycle when the fungus has become established in the stand (figs. 1 & 2). At this point, long-lasting reservoirs of inoculum from previously infected stumps and large root segments are present and serve as sources of infection for adjacent trees. Under conditions present in the western United States, inoculum can remain viable for 60 years in many sites (Morrison and Johnson 1978). There is currently little information on resistance of coniferous tree species to H. annosum root disease or to any other diseases of woody root tissues. Knowledge and use of resistance to this root disease is one of the potential long-term solutions to the problem.

One of the most definitive series of experiments designed to study mechanisms of host response to infection by H. annosum was conducted by Shain (1967, 1971) and Shain and Hillis (1971). They described reaction zone formation in Norway spruce (Picea abies (L.) Karst) and loblolly pine in response to infection by H. annosum and noted similarities and differences between these two species. In loblolly pine, the reaction zone is a nonspecific response to sapwood injury and is qualitatively similar to heartwood formation. The reaction zone moves up the stem or root as the fungus advances, leaving behind the pathological heartwood formed in former sapwood. This pathological heartwood is characterized by death of parenchyma, loss of starch, accumulation of phenols, and increases in oleoresin content. The dynamic, advancing front of the pathogen at the reaction zone is characterized by release of phytotoxic metabolites by the fungus or host, subsequent death of parenchyma, resin accumulation, partial inhibition of fungal advance (possibly a key process in host resistance), metabolism of accumulated fungitoxic compounds by the fungus, and decay of host cells. Unlike loblolly pine, the reaction zone of Norway spruce differs in that there is less accumulation of fungitoxic compounds in spruce heartwood than in pine, possibly explaining the typical heartrot in spruce caused by H. annosum. Spruce reaction zones are not resin soaked as in pine. The other characteristics of reaction zones discussed earlier are similar in both species and serve to slow progress of the pathogen.

H. annosum does not infect living tissues or cells. Living host cells are killed in advance of the fungus either by hypersensitive host reactions or by production of toxic metabolites of fungal origin (Shain 1971). A sesquiterpene, given the trivial name fomannosin, has been characterized from pure cultures of H. annosum (Bassett and others 1967). Pure preparations of this compound were shown to induce reaction zone formation near the point of application that has characteristics similar to those observed during fungal pathogenesis. Fomannosin is apparently produced in senescing cultures of H. annosum as a product of hyphal autolysis, but it has not been detected in host tissues undergoing infection by H. annosum. Oleoresins accumulating in the reaction zone inhibit the fungus (Cobb and others 1968) and may stimulate fungal synthesis and translocation of fomannosin from older mycelium in the food base (Bassett and others 1967). The balance of host defense mechanisms on one hand versus fungal compounds involved in pathogenesis on the other may explain observed variability in tree-to-tree spread as well as the difficulty encountered in experimentally establishing infections by artificial inoculation of larger trees (Shain 1967). That H. annosum usually requires a large food base for infection of living trees makes the study of resistance even more complex. Understanding the interactions among these processes is essential to finding quantifiable disease resistance mechanisms.

Effect of stress on infection

Intuitively, we can state that any factors that diminish the capacity of the host tree to respond to infection will enable more rapid host colonization by the fungus. Several studies involving different types of stress support this statement.

In a study of the effects of photochemical oxidant on susceptibility of ponderosa and Jeffrey pine (Pinus jeffreyi Grev. & Balf.) to infection by H. annosum, James and coworkers (1980b) found greatly increased vertical colonization of stumps to be associated with severe oxidant injury of the host tree before cutting. Their data indicate a sharp decrease in stump colonization rate by the fungus in stands relatively uninjured by photochemical oxidant. Also, James and coworkers (1980a) showed increased susceptibility of roots of oxidant-damaged ponderosa pine to infection by H. annosum. They noted that resin production was greatly diminished in infected roots of trees severely injured by air pollution, an indication of diminished host resistance.

Suppression has also been implicated in increased infection by H. annosum. Shain (1967) reported penetration of the fungus in sapwood of suppressed loblolly pine to be nearly nine times that of non-suppressed trees. The effects of suppression may play an important role in the incidence and spread of H. annosum in many overstocked pine and true fir stands.

Another potentially important factor affecting this root disease is water stress. Towers and Stambaugh (1968) found soil moisture stress decreased the resistance of roots of loblolly pine to infection by H. annosum, but there have been no studies on the effects of drought on spread or infection rates in stands in the west. Moisture is deficient in many soils and stands in the western United States during the hot, dry summer months. Such situations are common in the California Sierra Nevada and can be severe during drought years when the winter snow pack is considerably below optimal. Increased infection and spread can lead to buildup of bark beetle populations and further mortality of stressed trees (Ferrell and Parmeter, in press).

SUMMARY

Numerous factors can affect the development and severity of annosus root disease. Stump susceptibility and infection are influenced by temperature, host species, competing or antagonistic microorganisms, inoculum potential, and the interactions among these and other factors. Successful colonization of woody tissues of stumps and subsequent infection of adjacent trees are determined by interactions of insects, host stress, soil type, soil microbial activity, host species, host-fungus interactions, presence of other root-infecting fungi such as Armillaria, and root grafting or root contacts. Much of our knowledge of these processes in forests of the western United States has been derived from studies conducted on pine species. Little is known about how factors affecting the disease process interact in true fir, and the processes associated with wound and other non-stump originated infections in Abies and other conifer genera. A more complete understanding of biological and ecological relationships between various hosts and H. annosum will allow development of sound silvicultural methods that will minimize losses to this disease.

REFERENCES

Adams, John T; Witcher, Wesley; and Lane, C.L. 1964. Microorganisms in soil from Fomes annosus infected pine stands. USDA Plant Disease Reporter 48:114-118.

Alexander, S.A.; Skelly. J.M.; Morris, C.L. 1975. Edaphic factors associated with the incidence and severity of disease caused by Fomes annosus in loblolly pine plantations in Virginia. Phytopathology 65:585-591.

Bassett, Colin; Sherwood, R.T.; Kepler, J.A.; and Hamilton, P.B. 1967. Production and biological activity of fomannosin, a toxic sesquiterpene metabolite of Fomes annosus. Phytopathology 57:1046-1052.

Bega, Robert V. 1963. Fomes annosus. Phytopathology 53:1120-1123.

Cobb, F. W., Jr.; Barber, H. W. 1968. Susceptibility of freshly cut stumps of redwood, Douglas-fir, and ponderosa pine to Fomes annosus. Phytopathology 58:1551-1557.

Cobb, F.W., Jr.; Krstic, M.; Zavarin, E.; Barber, H.W., Jr. 1968. Inhibitory effects of volatile oleoresin components on Fomes annosus and four Ceratocystis species. Phytopathology 58:1327-1335.

Cobb, F. W., Jr.; Schmidt, R. A. 1964. Duration of susceptibility of eastern white pine stumps to Fomes annosus. Phytopathology 54:1216-1218.

Cowling, Ellis B.; Kalman, Arthur. 1964. Influence of temperature on growth of Fomes annosus isolates. Phytopathology 54:373-378.

Curl, E.A.; Arnold, M. M. 1964. Influence of substrate and microbial interactions on growth of Fomes annosus. Phytopathology 54:1486-1487.

Driver, C.H.; Ginns, J.H., Jr. 1969. Ecology of slash pine stumps: fungal colonization and infection by Fomes annosus. Forest Science 15:2-10.

Drummond, D.B.; Bretz, T.W. 1967. Seasonal fluctuations of airborne inoculum of Fomes annosus in Missouri. Phytopathology 57:340. Abstract.

Edmonds, R.L.; Leslie, K.B.; Driver, C.H. 1984. Spore deposition of Heterobasidion annosum in thinned coastal western hemlock stands in Oregon and Washington. Plant Disease 68:713-715.

Ferrell, George T.; Parmeter, John R., Jr. 1989. Interactions of root disease and bark beetles. (These proceedings).

Froelich, R.C.; Dell, T.R.; Walkinshaw, C.H. 1966. Soil factors associated with Fomes annosus in the Gulf states. Forest Science 12:356-361.

Froelich, R.C.; Kuhlman, E.G.; Hodges, C.S.; Weiss, M.J.; Nichols, J.D. 1977. Fomes annosus in the South - guidelines for prevention. USDA Forest Service, State and Private Forestry, Southeastern Area, Atlanta, Georgia. 17pp.

Gooding, G.W., Jr. 1964. Effect of temperature on growth and survival of Fomes annosus in freshly cut pine bolts. Phytopathology 54:893-894. Abstract.

Himes, W.E.; Skelly, J.M. 1972. An association of the black turpentine beetle, Dendroctonus, terebrans and Fomes annosus in loblolly pine. Phytopathology 62:670. Abstract.

Hodges, Charles S., Jr.; Koenigs, Jerome W.; Kuhlman, E. George; Ross, Eldon W. 1971. Fomes annosus: A bibliography with subject index. Res. Paper SE-84. Asheville, NC: Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 75p.

Hunt, R.S.; Cobb, F.W., Jr. 1982. Potential arthropod vectors and competing fungi of Fomes annosus in pine stumps. Canadian Journal of Plant Pathology 4:247-253.

Hunt, Richard S.; Cobb, Fields W., Jr.; Parmeter, John R., Jr. 1976. Fomes annosus stump colonization and fungus development in the California mixed conifer type. Canadian Journal of Forest Research 6:159-165.

Hunt, R.S.; Wilcox, W.W.; Cobb, F.W., Jr. 1974. Resistance of stump tops to colonization by Fomes annosus. Canadian Journal of Forest Research 4:140-142.

James, R.L; Cobb, F.W., Jr. 1984. Spore deposition by Heterobasidion annosum in forests of California. Plant Disease 68:246-248.

James, R.L.; Cobb, F.W., Jr.; Miller, P.R.; Parmeter, J.R., Jr. 1980a. Effects of oxidant air pollution on susceptibility of pine roots to Fomes annosus. Phytopathology 70:560-563.

James R.L.; Cobb, F.W., Jr ; Wilcox, W.W. 1980b. Effects of photochemical oxidant injury of ponderosa and Jeffry pines on susceptibility of sapwood and freshly cut stumps to Fomes annosus Phytopathology 70:704-708.

Koenigs, Jerome. W. 1960. Fomes annosus: a bibliography with subject index. Occasional Paper 181. New Orleans: Southern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 35 p.

Kuhlman, E.G. 1969a. Survival of Fomes annosus spores in soil. Phytopathology 59:198-201.

Kuhlman, E.G. 1969b. Number of conidia necessary for stump infection by Fomes annosus. Phytopathology 59:1168-1169.

Kuhlman, E.G; Hendrix, F.F. 1964. Infection, growth rate, and competitive ability of Fomes annosus in inoculated Pinus echinata stumps. Phytopathology 54:556-561.

Morris, C.L; Frasier, D.H. 1966. Development of a hazard rating for Fomes annosus in Virginia. U.S. Department of Agriculture Plant Disease Reporter 50:510-511.

Morrison, D.J.; Johnson, A.L.S. 1978. Stump colonization and spread of Fomes annosus 5 years after thinning. Canadian Journal of Forest Research 8:177-180.

Otrosina, W.J.; Marx, D.H.; May, J.T. 1984. Soil microorganism populations on kaolin spoil with different vegetative covers. Reclamation and Revegetation Research 3:1-15.

Rishbeth, J. 1950. Observations on the biology of Fomes annosus with particular reference to East Anglian pine plantations. I. The outbreaks of the disease and ecological status of the fungus. Annals of Botany 14:365-383.

Rishbeth, J. 1951. Observations on the biology of Fames annosus, with particular reference to East Anglian pine plantations II. Spore production, stump infection, and saprophytic activity in stumps. Annals of Botany 15:1-21.

Rose, Sharon L.; Li, Chang-Yan; Hutchins, Anita Stiebrs. 1980. A streptomycete antagonist to Phellinus weirii, Fames annosus, and Phytophthora cinnamomi. Canadian Journal of Microbiology 26:583-587.

Ross, Eldon W. 169, Thermal inactivation of conidia and basidiospores of Fomes annosus. Phytopathology 59:1798-1801.

Ross, Eldon W. 1973. Fomes annosus in the southeastern United States: Relation of environmental and biotic factors to stump colonization and losses in the residual stand. U.S. Department of Agriculture Forest Service Tech. Bull. No. 1459. Asheville, North Carolina. 26p.

Shain, Louis. 1967. Resistance of sapwood in stems of loblolly pine to infection by Fomes annosus. Phytopathology 57:1034-1045.

Shain, Louis. 1971. Response of sapwood of Norway spruce to infection by Fomes annosus. Phytopathology 61:301-307.

Shain, Louis; Hillis, W.E. 1971. Phenolic extractives in Norway spruce and their effects on Fomes annosus. Phytopathology 61:841-845.

Srago, Michael D. 1973. The influence of soil biological and physical factors on the growth of Fomes annosus. Dissertation. University of California; Berkeley: 76 p.

Srago, Michael D; Cobb, Fields W., Jr. 1974. Influence of soil biological factors on the mycelial growth of Fomes annosus. In: Proceedings of the Fourth International Conference on Fomes annosus. Kuhlman E.G; ed. September 17-22, 1973. Athens, Georgia: Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; pp. 218-226.

Towers, Barry; Stambaugh, W. J. 1968. The influence of induced moisture stress upon Fames annosus root rot of loblolly pine. Phytopathology 58:269-272.

Veech, Joseph A; Boyce, John S. 1964. Soil microorganisms in two Georgia slash pine plantations with annosus root rot. U.S. Department of Agriculture Plant Disease Reporter 48:873-874.

Yde-Andersen, A. 1962. Seasonal incidence of stump infection in Norway spruce by air-borne Fomes annosus spores. Forest Science 8:98-103.

Symptoms and Diagnosis

Symptoms and Diagnosis of Annosus Root Disease in the Intermountain Western United States[1]

James W. Byler[2]

Abstract: Stand patterns of annosus root disease include various degrees and patterns of tree mortality; tree crown, root collar, and root symptoms; and the condition and location of stumps. In the Intermountain states of Montana, Idaho, and Utah, annosus root disease is found in the ponderosa pine, mixed conifer and high-elevation fir forests. Stand patterns are of value in diagnosing the disease in each of these forest types, but other root pathogens may cause similar symptoms. Confirmation of annosus root disease depends upon further steps in the diagnosis process.

Annosus root disease, which is caused by Heterobasidion annosum, is one of several important root diseases of the Intermountain States of Montana, Idaho, and Utah. In the first section of this paper I will discuss stand patterns of annosus root disease. Other root diseases cause similar patterns, however. In the second section I will discuss annosus root disease diagnosis in the three major Intermountain area forest types: ponderosa pine, mixed conifer, and high-elevation fir.

THE USE OF STAND PATTERNS IN ANNOSUS ROOT DISEASE DIAGNOSIS

Stand indicators of annosus root disease are based mainly on various degrees and patterns of tree mortality; tree crown, root collar, and root symptoms; and the condition and location of stumps. Each of these will be discussed.

Degree and Pattern of Tree Mortality

The main effect of annosus root disease is that it kills trees, either directly by destroying their roots or indirectly by predisposing them to bark beetles and other agents. But trees die from many other causes. How can tree mortality from annosus root disease be distinguished from that resulting from other causes?

First, tree mortality resulting from annosus root disease tends to be concentrated in centers or patches rather than distributed at random in a stand. This pattern is due to the unique tree-to-tree spread of root pathogens through contacting root systems. Trees that do not belong to a recognizable center of mortality are sometimes killed, and many groups include only a few trees. However, the typical mortality pattern for most annosus root disease is what is referred to as the annosus root disease "center," "pocket," or "patch."

A second characteristic of tree mortality caused by annosus root disease is that it is chronic. Root disease patches enlarge slowly as the pathogens spread from diseased trees to the roots of uninfected neighbors, and in turn are killed and become avenues of spread for the pathogen to still other neighbors. Bark beetle attack can kill a group of trees, but unless a root pathogen is also present, bark beetle outbreaks usually do not last more than 2 or 3 years. Tree killing by annosus root disease may persist for decades, resulting in stand openings that are ringed with dead and dying trees, and that contain older tree kills in various stages of decay farther into the opening.

Attack by bark beetles or wood borers can be an indicator of annosus root disease, whether or not the trees are killed immediately. The presence of root disease is particularly likely in trees attacked by bark beetle species that prefer weakened trees. These are Dendroctonus valens, Dendroctonus brevicomus, Scolytus ventralis, Dryocetes confusus, and except when it is in the outbreak stage, Dendroctonus pseudotsugae.

Annosus root disease may be suspected when trees of various size or age classes are killed. Many insects and pathogens tend to attack and kill trees of a particular size class. Many bark beetles, for example, attack the larger size tree classes. The annosus root pathogen kills large overstory trees, but also smaller trees in the patch including regeneration of seedlings and saplings of susceptible species that come up in stand openings caused by the root disease.

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2]Supervisory Plant Pathologist, USDA Forest Service, Region 1, Missoula, Montana.

Tree Crown and Root Symptoms

Trees may live for many years following infection by the annosus root disease pathogen. The progressive killing and decay of a tree's root system results in a gradual decline of its crown.

The decline of sapling-sized trees is expressed in reduced height growth for a few years before death. Compare the lengths of recent leader growth on dead trees and living trees suspected of being diseased with the lengths of their earlier growth and the growth of leaders of similar-aged neighbors. Young trees also may become chlorotic before death and may have reduced needle retention. Closely examine trees whose needles are more yellow than those of others in the stand and that have shorter lengths of needle-bearing branches.

Terminal growth of both pole-sized and mature trees may be reduced for many years, resulting in a distinctly rounded top compared with healthy trees in the stand. Foliage may be chlorotic. Needles, especially older needles, are cast prematurely and the crown becomes thin. Thinning is most noticeable in the lower and interior parts of the crown.

Mature trees may also produce an abundant cone crop immediately before death. The stress cones may remain on the tree for several years following tree death, after all foliage is gone.

Finally, symptoms of root disease may be present at the root collar and in the roots of infected trees. Root and root collar symptoms include excessive pitch production, stringy, white root decay, root lesions, and various types of stains in the root and bole.

Condition and Location of Stumps

Not all root infection results in tree death. The true firs and hemlocks are especially prone to annosus root and butt rot, for example. The presence of root disease in stands of these species is most easily detected by examining stumps from an earlier harvest for the presence of butt rot or stump cavities.

The mere presence of stumps in and near groups of dead trees is itself an indication of root disease. Stump-centered tree mortality is one of the best indicators of annosus root disease. Airborne spores of the pathogen are transferred to the freshly cut surface of the stump where it germinates and establishes an infection. The annosus root rot pathogen then uses the stump as a food base from which to spread through its roots to neighboring trees forming a new center of annosus root disease.

DIAGNOSING ANNOSUS ROOT DISEASE IN THE INTERMOUNTAIN WESTERN UNITED STATES

It is a common practice to classify annosus root disease by forest type. These classes include (1) annosus root disease of ponderosa pine in the pine type forest, (2) annosus root disease of grand fir, white fir, and sometimes other species in the mixed conifer-type forest, (3) annosus root disease of subalpine fir or red fir in high-elevation forests, and (4) annosus disease of western hemlock in the coastal hemlock type forests. Three of these forest classes are present in the Intermountain area. The amount of damage can vary greatly, but annosus root disease can be found in these forest types in each of the Intermountain States--Montana, Idaho, and Utah.

Ponderosa Pine Type

Ponderosa pine is killed by annosus root disease in low-elevation, dry, pine forests where ponderosa pine or Douglas-fir is the climax species. The mortality usually occurs as small pockets, but disease centers also can be quite large. In diagnosing this disease, look for single affected pines or groups of pines that are associated with pine stumps from logging 10 or more years earlier. Large or small pines or both may be killed. Evidence of attack by the western pine beetle, pine engraver, or other beetles may be present. Infected trees may exhibit crown symptoms, but those are often subtle and easily overlooked. Similar mortality is sometimes caused by *Ceratocystis wageneri* or *Armillaria obscura*, although most *A. obscura* killing occurs on wetter sites where Douglas-fir is the climax species.

Mixed Conifer Type

Annosus root disease is found in grand fir and several other species, including Douglas-fir, in mixed conifer forests. These are on sites where grand fir, hemlock, or cedar is climax. Tree mortality may occur in large or small patches that may or may not be related to stumps from an earlier timber harvest. Annosus root disease may also cause decay in grand fir roots and butts without causing subsequent mortality. To diagnose this disease in mixed-conifer forests, look for butt rot in stumps and old-growth true fir trees. Tree mortality similar to that in grand fir and Douglas-fir may also be caused by *Phellinus weirii* and *Armillaria ostoyae*. In fact, the presence of two or more of these pathogens is common in the same stands and in the same trees in northern Idaho. The association may be particularly close between annosus root disease and Armillaria root diseases there.

Signs and symptoms of *A. ostoyae* are usually found on grand firs and Douglas-firs showing crown symptoms of root disease on the Clearwater and

Nezperce National Forests, for example. Root collars of such trees exude pitch, and chopping into them reveals the typical mycelial fans of *Armillaria*. On a number of occasions we have also confirmed the presence of annosus root disease in these trees by culturing the pathogen from decay in deeply positioned roots or uprooted or excavated trees. In addition, we have cultured the pathogen on both species on stained portions of disks cut from boles near the soil line. So another key in diagnosing annosus root disease in the mixed conifer type is to look for annosus root decay and evidence of stain columns in stems of true firs or Douglas-fir species infected by *Armillaria*.

High-Elevation Fir Forests

Annosus root disease tree mortality or butt rot or both has also commonly been found in subalpine fir forests of the Intermountain area. It occurs as pockets of mortality. *Dryocoetes confusus* is typically present. *Armillaria ostoyae* also causes similar damage, and both pathogens may be present in the same trees, especially in north Idaho. The diagnosis is similar to that on grand or white fir.

CONCLUSION

Annosus root disease is active in ponderosa pine, mixed conifer, and subalpine fir forest types in Idaho, Montana, and Utah. Stand patterns of tree mortality, tree crown symptoms, and tree stump characteristics are helpful in diagnosing this disease. However, several other root pathogens may cause similar stand mortality patterns, and a complex that includes two or more of these greatly complicates diagnosis. Stand patterns alone are not sufficient for diagnosis, but it is the first step.

REFERENCES

Hadfield, J.S.; Goheen, D.V.; Filip, G.M.; and others. 1986. Root diseases in Oregon and Washington conifers. Portland, OR: United States Department of Agriculture, Forest Service. Pacific Northwest Region. R-6-FPM-250-86; 27 pp.

Hagle, S.K.; Tunnock, S.; Gibson, K.E.; and others. 1987. Field guide to diseases and insect pests of Idaho and Montana forests. Missoula, MT: United States Department of Agriculture, Forest Service, Northern Region; 123 pp.

Holsten, R.H.; Hennon, P.E.; Werner, R.A. 1985. Insects and diseases of Alaskan forests. United States Department of Agriculture, Forest Service. Alaska Region; Rept. 181. 217 pp.

Schmitt, C.L.; Parmeter, J.R., Jr.; Kleijunas, J.T. 19**. Annosus root disease of western conifers. United States Department of Agriculture, Forest Service. Forest Pest Leaflet **. (In press).

Smith, R.S., Jr. 1979. Root diseases. *In*: Bega, R.V., ed. Diseases of Pacific Coast conifers. United States Department of Agriculture, Agriculture Handbook No. 521.

Diagnosis of Annosus Root Disease in Mixed Conifer Forests in the Northwestern United States[1]

Craig L. Schmitt[2]

Abstract: Recognizing annosus root disease affecting conifers in northwestern United States forests is discussed. Field diagnosis can be made by observing characteristic stand patterns, wood stain and decay, ectotrophic mycelium, and sporophores. Most seriously affected trees include hemlocks, grand fir, white fir and Pacific silver fir. Ponderosa pine and other true firs may also be damaged. Wounded trees, especially hemlocks and true firs, are readily colonized by *Heterobasidion annosum* and wounds can be used as an indicator of infection. Laboratory analysis can be used to confirm field diagnosis.

Annosus root disease, which is caused by *Heterobasidion annosum* (Fr.) Bref. (= *Fomes annosus* (Fr.) Karst.) is a common cause of root and butt decay of conifers in the northwestern United States. All conifers can be infected, but there are species differences in degree of susceptibility and types of damage. Species most susceptible to infection and damage include western hemlock (*Tsuga heterophylla*), mountain hemlock (*T. mertensiana*), grand fir (*Abies grandis*), white fir (*A. concolor*) and Pacific silver fir (*A. amabilis*). The damage resulting from infection may include butt decay, probably reduced growth rates, windthrow, attack by secondary pests, and direct mortality. Species less commonly infected include ponderosa pine (*Pinus ponderosa*), noble fir (*A. procera*), subalpine fir (*A. lasiocarpa*), and California red fir (*A. magnifica*) (Hadfield and others, 1986). Other conifers are seldom damaged severely enough to cause a forest management concern.

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, Calif.

[2]Zone Pathologist, USDA Forest Service, Wallowa-Whitman National Forest, Forest and Range Sciences Laboratory, LaGrande, Oreg. 97850

RECOGNITION

Recognition and correct diagnosis of annosus root disease is an important step toward reducing current and future root disease losses, and achieving the highest possible productivity from our forests.

Annosus root disease is more difficult to identify than other common root diseases of conifers. The pathogen is found on many host species over a wide range of ecological conditions. Throughout the pathogen's range there is considerable diversity in the symptoms and signs expressed by infected hosts.

On-Site Indicators

In infected conifer stands, annosus root disease usually occurs in discrete infection centers. Verifying infection by *H. annosum* in these centers can best be done by observing several of the signs and symptoms characteristic of annosus root disease. In resinous species, such as pines, and in true firs, dead or dying trees or both or understocked areas can be readily identified and should be suspect. Upon encountering suspect centers, look for evidence of periodic tree dying in gradually expanding foci. Within centers, old infected stumps, snags and (less frequently) scarred trees may be found. The most reliable method of diagnosing annosus root disease is to locate the fruiting bodies of *H. annosum*. Trees killed by annosus root disease occasionally have fruiting bodies of the pathogen on their roots or root collar or both. Groups of dead and symptomatic dying trees frequently are found around old stumps containing conks of *H. annosum* in the interior rotted portions.

Trees in advanced stages of infection may exhibit crown symptoms typical of root-diseased trees: chlorotic and sparse foliage, reduced vertical and radial growth, and distress cones. Crown symptoms are most commonly observed on resinous species. Western hemlock, a non-resinous species, seldom displays obvious crown symptoms, even when extensive butt and root decay is present. True firs often display typical root-disease symptoms; however, extensive decay without obvious crown symptoms is not uncommon, especially if associated with large wounds.

Identifying annosus root disease with a high degree of certainty requires recognition of indicators more or less specific to the disease and then lowering or eliminating the probability that other primary pathogens may be involved. Secondary pathogens, such as Armillaria ostoyae (Romagn.) Herink (= A. mellea sensu lato), are frequently found on trees infected by H. annosum. Positive verification of infection by H. annosum requires finding fruiting bodies on the trees in question or cross-checking field diagnosis against laboratory identification of the pathogen.

Heterobasidion annosum seldom kills hemlocks directly. Butt rot, the most common damage, is usually found during harvest. Root disease-induced windthrow sometimes occurs. More often, decay caused by H. annosum is found in hemlocks that had large wounds on the lower bole, root collar, or roots; and those large wounds often are colonized by H. annosum. Thus, large wounds are an important indicator of decay caused by H. annosum in hemlock. Most hemlocks with significant amounts of decay are over 120 years old (Goheen and others, 1980). Old-growth hemlocks (150+ years) are occasionally killed or windthrown as a result of infection by H. annosum.

True firs infected by H. annosum usually become infested by fir engraver beetles (Scolytus ventralis LeConte) after they have been weakened by the pathogen. When beetle populations are high, particularly during a drought, firs may be attacked and killed before readily-identifiable indicators of infection can be found.

True firs that become infected via bole wounds often have compartmentalized stem decay caused by H. Annosum. In such cases, H. annosum is not acting as a tree-killing root disease. Cambium killing on roots and root collars of true firs is usually associated with pathogen spread via root contacts and ectotrophic mycelium colonizing the surfaces of root systems. Such trees are readily weakened and killed (Schmitt and others, 1984). Annosus root disease in true fir stands frequently is centered around large stumps of true fir trees that were cut at least 20-25 years ago. Stumps larger than 18 inches (2.54 cm/in.) are almost always the source of infection. These stumps commonly contain conks of the fungus in hollow pockets.

Ponderosa pine is most susceptible to infection and damage on xeric, marginally productive sites. Infection centers usually occur around large pine stumps. Because of the wide-reaching root systems of old open-grown pines, these disease centers may be up to 100 feet across.

Douglas-fir stands generally are not sufficiently damaged by H. annosum that the disease becomes a management concern. However, Douglas-fir saplings and small poles may become infected and killed on certain sites. Specifically, Douglas-fir planted on several high-elevation mixed-conifer sites in Washington and Oregon that were at the upper elevation range of naturally occurring Douglas-fir were found to have a moderate to high incidence of infection and mortality. Infection was associated with true fir stumps that had became infected at time of harvest.

Signs

Conks

Heterobasidion annosum produces fruiting bodies, or conks, on infected host material. In the Pacific Northwest, the presence of fruiting bodies of the fungus is the easiest and most reliable way to verify presence of the fungus. On most infected pines and less frequently on true firs killed by annosus root disease, conks may be found on the outer bark at the root collar in the duff layer. Conks found in such locations usually are small and buff-colored, leathery, and 0.125-0.25 inch (25.4 mm/in.) in diameter. On most infected species of conifers, small buff-colored pustules that resemble fruiting bodies can be found scattered on the surface of dead infected roots.

Conks, 2 to 3 inches across, may be found in crevices of the root collar of infected, dead western hemlocks. Large conks, up to 10 inches across, can be found in the interior of old hollow or extensively decayed hemlock, true fir, and ponderosa pine stumps. On pine stumps they are frequently found just under the bark or at the sapwood-heartwood interface. Conks have concentric furrows, a buff- to dark brown-colored upper surface, and a smooth, cream-colored under-surface that has tiny pores and a narrow sterile (non-pored) margin. Conks are perennial and may have more than one tube layer.

Ectotrophic Mycelium

A dull white ectotrophic mycelium may be found on the exterior of infected roots of pines, true firs, and Douglas-fir. This growth is one mechanism of spread across root contacts. Some other root disease fungi also form similar ectotrophic mycelium so its occurrence alone cannot be used to diagnose the disease.

Stain and Decay

The appearance of wood stain and decay caused by _H_. _annosum_ is quite variable. In true firs and hemlocks, infected roots and butt wood usually develop a red-brown to purplish heartwood stain that has an irregular outer margin. Stain is not common in pines, although a resinous flecking is sometimes present. Advanced wood decay in pines and true firs is initially laminated, separating at the annual rings. Small, elongated pits roughly 0.04-0.08 inch (25.4 am/in.) long may be found, but only on one side of delaminated sheets. Commonly in hemlock, true firs, and Douglas-fir, but less common in pine, advanced decay will be wet, spongy, and stringy with large white streaks and scattered small black flecks. This type of decay is often found in the interior of infected roots.

Laboratory Verification

Laboratory techniques for diagnosis of _H_. _annosum_ infection may be needed because conks cannot always be found, decay appearance is highly variable and "masked" by other pathogens. Fortunately, _H_. _annosum_-infected wood readily yields characteristic asexual fruiting structures (conidia and conidiophores) of its imperfect stage, _Spiniger_ _meineckellus_ (Olson) Staplers (=_Oedocephalum_ _lineatum_ Bakshi), where incubated in high humidity, or cultured on nutrient media.

CONCLUSIONS

Recognition and diagnosis of annosus root disease will most likely remain difficult in many affected forest stand types. General increased awareness of forest pests through training and intensive forest resource management should also improve the recognition skills of foresters, silviculturists, and field crews. Field diagnosis skills can be improved by cross-checking signs and symptoms found on hosts with culturing or incubation of suspect material. This is especially true in timber types not yet well investigated for susceptibility to annosus root disease.

Investigators need to look more closely at the role of _H_. _annosum_ in root disease complexes. Field diagnosis of root disease will frequently miss the presence of _H_. _annosum_ when other pathogens are present. This pathogen is probably responsible for considerably more damage than has yet been attributed to it.

REFERENCES

Goheen, D.J.; Filip, G.M.; Schmitt, C.L.; Gregg, T.F. 1980. Losses from decay in 40- to 120-year-old Oregon and Washington western hemlock stands. R6-FPM-045-1980. Portland, OR: Forest Pest Management, Pacific Northwest Region, U.S. Department of Agriculture, Forest Service; 19 p.

Hadfield, J.S.; Goheen, D.J.; Filip, G.M.; Schmitt, C.L.; Harvey, R.H. 1986. Root diseases in Oregon and Washington conifers. R6-FPM-250-86. Portland, OR: Forest Pest Management, Pacific Northwest Region, U.S. Department of Agriculture, Forest Service; 27 p.

Schmitt, C.L.; Goheen, D.J.; Goheen, E.M.; Frankel, S.J. 1984. Effects of management activities and dominant species type on pest-caused mortality losses in true fir on the Fremont and Ochoco National Forests. FPM Office Report. Portland, OR: Forest Pest Management, Pacific Northwest Region, U.S. Department of Agriculture, Forest Service; 34 p.

Characteristics of Annosus Root Disease in the Pacific Southwest[1]

Gregg A. DeNitto[2]

Abstract: Annosus root disease is mainly a concern in pines and true firs in California. It is most serious on the east side of the Sierra Nevada and Cascade crest, in the mountains of southern California, and in higher elevation fir forests. Symptoms caused by the disease include crown decline and decay and resinosis of roots. Several signs of the fungus may be found. Conks are most common in stumps. Mycelial sheets on the inner bark and popcorn conks on thin-barked roots are diagnostic. Declining trees or recent mortality are best for diagnosis. Wood samples should be symptomatic but not well decayed. Laboratory procedures are available to confirm the presence of H. annosum.

In the southwestern United States, annosus root disease, caused by Heterobasidion annosum (Fr.) Bref., in fir and pine forests is primarily a concern in California. However, stands of these species in areas of western Nevada, Arizona, and New Mexico also are affected. Within this broad area, specific forest types in which the disease is likely to be found and may cause damage have been identified. These higher "hazard" areas are identifiable by host species affected and forest type. The disease is prevalent, mainly in pine (Pinus spp.), on the east side of the Sierra Nevada and Cascade mountains. A second area in California with higher levels of the disease is in the mountains of the southern part of the state, again mainly on pine, but also on white fir (Abies concolor (Gord. and Glend.) Lindl.). This includes the San Bernardino and San Gabriel mountains. A third, broader area is at higher elevations where true firs (Abies spp.) are often infected.

In California, the forest types most severely affected are the mixed conifer (Society of American Foresters forest cover type 243), ponderosa pine (SAF 245), white fir (SAF 211), and red fir (SAF 207) types. In Arizona and New Mexico, the disease is found in the mixed conifer and southwestern ponderosa pine forest types (SAF 237). Not all areas within these forest types are infested, and not all trees within them are highly susceptible to infection. Therefore, each site must be evaluated individually for incidence of the disease.

A wide range of conifer species are host to this fungus. Within forest types, various species are differently affected depending on the isolate of the fungus involved (Otrosina and Cobb 1989). The main commercial hosts affected in California include ponderosa pine (P. Ponderosa Laws.), Jeffrey pine (P. jeffreyi Grev. and Balf.), white fir, red fir (A. magnifica Murr.), and incense-cedar (Libocedrus decurrens Torr.) (Bega and Smith 1966, Smith and others 1966, Wagener and Cave 1946). Several hardwoods and brush species have been identified as hosts, including Pacific madrone (Arbutus menziesii Pursh) (Bullen and Wood 1979), manzanita (Arctostaphylos spp.), and big sagebrush (Artemisia tridentata Nutt.) (Smith and others 1966).

FIELD RECOGNITION

Symptoms and Silts

Some of the symptoms and signs used to recognize annosus root disease are similar among all hosts. Many of them are present regardless of what root disease or root malfunction is present. The emphasis in this paper will be on the symptoms and signs present on the forest tree hosts in California and the characteristics specific to individual host species. In the Pacific Southwest, two groups of trees show distinct symptoms: resinous species, such as pines, and the non-resinous species, including the true firs.

Following infection, annosus root disease usually takes from several to many years to cause tree mortality of pines and true firs. Mortality of pines is more rapid. During this period, an increasing number of roots are killed and most trees begin to exhibit some evidence of crown decline. Gradual reduction in terminal growth is a good indicator. Decreasing leader growth over a period of several years usually indicates a root-related problem. This is more evident in pines than in true firs. A second characteristic

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2]Plant Pathologist, Shasta-Trinity National Forests, Forest Service, U.S. Department of Agriculture, Redding, Calif.

is the loss of older foliage and shortening of younger foliage. The result is an appearance of the crown thinning and the tree generally shows poor vigor. As the disease progresses, branches begin to die. The pattern of crown thinning and branch mortality usually begins in the lower crown and advances upward.

At the other end of the tree, symptoms can be found in the roots. In roots that have been infected for a while, a white stringy rot will be present. Root decay is more commonly found in true firs than in pines. Other fungi can cause a similar type of decay, so this symptom alone is not sufficient to identify annosus root disease. On the outer bark of infected roots, signs of the fungus may be present (fig. 1). These are usually in the form of "popcorn conks," small white to buff-colored cushions of fungal material that erupt between the bark scales. This fungal material is similar to that of mature fruiting bodies and does not tear readily. These popcorn conks are much smaller, however, and do not have any pore surface. Their presence is highly diagnostic for the disease in California. While searching the roots for signs of H. annosum, it is useful to be observant for other problems, especially indicators of other root diseases, that cause similar aboveground symptoms.

In pines, resin soaking of roots is indicative of some type of injury, and often it is caused by fungal infection. Copious amounts of resin may be produced and actually infiltrate the surrounding soil. On the wood surface of pine roots, brown streaks may be found that run parallel with the axis of the root. Small silver-to-white mycelial sheets may develop on the inside of the inner bark. These sheets are not thick like mycelial fans, but are small accumulations of mycelia that fill pits in the inner bark.

Root decay is more commonly found in true firs and incense-cedar. Even roots several inches in diameter may be completely decayed before aboveground symptoms become obvious. Stumps of fairly recent origin, infected by H. annosum, have a distinct decay pattern. They exhibit laminar decay, usually of the center of the stump or a sector of the center of the stump. Decay of the more recent sapwood is not normally seen, unless the entire stump is involved. Other individual tree symptom characteristics are not diagnostic for annosus root disease in true firs.

Some stand and site characteristics have been identified in true firs where it appears that H. annosum is more common. Stands that are relatively pure fir, especially red fir, have a higher incidence of the disease. Dense, older stands with a history of logging also are more likely to be infected. These are discussed in greater detail in other papers in these symposium proceedings (Slaughter and Parmeter 1989).

Figure 1--Small, white popcorn conks of H. annosum on roots of ponderosa pine seedlings.

Field Diagnosis

When trying to detect the presence of annosus root disease it is best to look at recent mortality or trees with advanced symptoms. Older mortality may be too far gone to reveal useful symptoms. I have found that the best type of tree to examine is a declining or recently dead seedling or sapling, if available. This is true for pines and firs. Because of their smaller roots, symptoms seem to advance to the root collar more rapidly. Also, the smaller roots have thinner bark, and popcorn conks and other symptoms are easier to find. More of the root system can be dug up and examined when a tree is smaller. Lastly, digging up a small tree is a lot easier than digging up a big tree. If a sapling is not available, a main lateral root must be excavated and examined for two to three feet outward from the bole.

After examining the total stand, mortality pockets, and individual trees, if another cause has not been identified and indicators suggest annosus root disease, it is time to become a stump buster and look for conks. It is not worth the effort to try to break up hard stumps of pines, unless only the surface is case hardened and it is obvious that there are decay pockets within the stump. More recently cut stumps of pines that have not started to decay may have fruiting bodies of H. annosum in the wood-bark interface, if they have them at all. Peeling the bark off these stumps may be fruitful. Stumps that have decayed may have conks in decay pockets within the stump where there are higher moisture levels. In California, only rarely do we find conks exposed above ground around the root collars of trees.

Conks occur in a variety of sizes, shapes, and stages of development. On pines, they are usually attached to relatively solid wood and not on wood that is already decayed. Pulling decayed wood away from these solid columns in a stump often reveals conks, especially popcorn conks. In true firs, annosus root disease produces a heart rot, and conks usually can be found in the hollow center of stumps. Removing some decayed wood in the center of these stumps or just looking into them when they are hollow often reveals conks.

The time of year often determines the ease of finding and the condition of conks. Fresh, well-developed conks are usually found in the spring and early summer when moisture levels are high. Later, as stumps dry out, one has to dig deeper into the stump and conk remnants may be easier to find than fresh ones. Conk remnants may be the only signs of the pathogen that are present. They can be recognized by their chocolate brown color, characteristic nonporoid margin, and pores on the lower surface. Elevation also influences the ease of finding conks. At higher elevations, fresh conks can be found later in the growing season because stump drying is delayed.

Laboratory Diagnosis

In some cases, definitive evidence of annosus root disease cannot be found. From your experience, however, you feel quite certain that it is present. At these times, you may need to involve a forest pathologist who can perform the necessary laboratory work. What is done in the laboratory is not a secret or necessarily difficult, but does require a microscope and drawings or pictures of what to look for. If you can get a forest pathologist on the site, do so, and let them collect the material that they consider most useful. The alternative is to collect some suspicious roots and send them to the appropriate laboratory. The following are some general suggestions. Collect woody tissue from declining or recently dead trees. Do not collect from older dead trees or rotted wood. It is usually more productive to find roots that are still solid, but have symptoms or signs of infection, such as resinosis, mycelial felts, or brown streaking. Collect root segments 8 to 12 inches (20 to 30 cm) long, shake off the loose soil, wrap them in newspaper, and mail them as soon as possible. Do not let them dry out or expose them to the sun. If all goes well, you should expect an answer within 3 to 4 weeks. A negative result does not necessarily indicate the absence of annosus root disease, but it may suggest the need for a visit by an experienced forest pathologist.

When root samples are received at the laboratory, two methods can be used to determine whether H. annosum is present. The first of these methods is the use of standard isolation techniques on artificial media. Semi-selective media are available for isolating the fungus (Hendrix and Kuhlman 1962). Wood chips from symptomatic tissue are plated on the media and incubated for 1 to 2 weeks (fig. 2). Conidiophores of the imperfect stage of the fungus are produced on the surface of the media and on the wood chips. The second method involves washing the woody tissue samples with water and incubating them. Incubation involves wrapping the woody tissue in some material that holds moisture---moist newspaper is ideal---and keeping them moist in plastic bags. After incubation for 7 to 10 days at room temperature, examine the material for the presence of the imperfect stage of H. annosum (fig. 3).

The imperfect stage is Spiniger meineckellus (Olson) Stalpers (syn. Oedocephalum lineatum Bakshi) (fig. 4). The appearance of S. meineckellus is distinctive and after some experience can be recognized under a stereoscope. This fungus produces hyaline conidiophores with globose heads of dry conidia. The hyaline

Figure 2--Six-week-old culture of S. meineckellus on potato dextrose agar.

Figure 3--Cross-section of white fir incubated for H. annosum. White conidiophores produced around decay column.

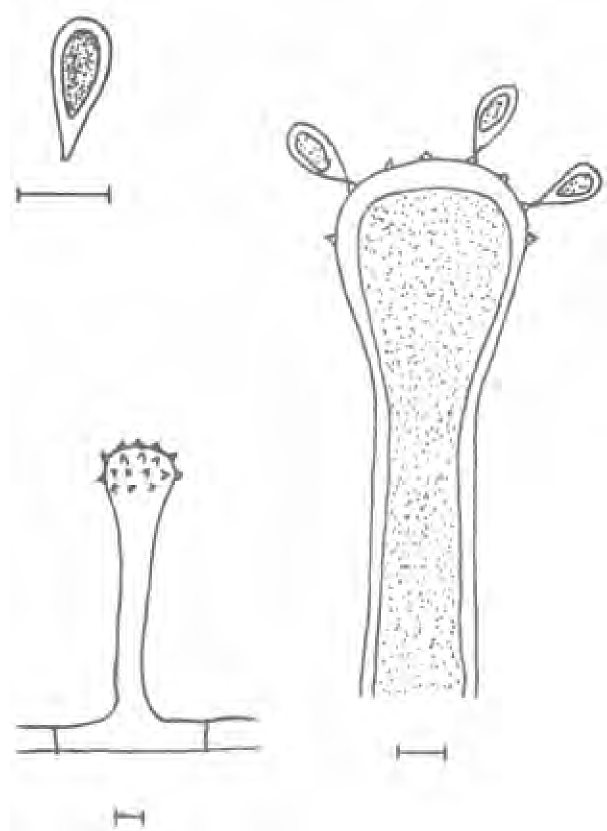


Figure 4--Conidiophores and conidia of S. meineckellus, imperfect stage of H. annosum. Each scale bar = 5 µm.

conidia are borne on spines on the naked head of the conidiophore. The conidia are 4-8 by 2.5-5 µm. After the spores fall, the spiny heads are quite distinctive and recognizable, although magnification stronger than a stereoscope is necessary. In pines, conidiophores of the fungus are usually found in the sapwood and near the cambium. In the true firs, the fruiting structures can be found anywhere on the woody surface, especially around decayed areas.

CONCLUSION

One should not go out into a forest with the intention to diagnose annosus root disease. When you need to make a pest diagnosis, you should do just that. Look at the situation from a broad perspective and use a methodical approach. Examine the stand and site conditions to determine overstocking or low site quality. Decide what insects, pathogenic organisms, and animals are, or have been, present. Evaluate which of these may have caused the type of damage you observe. Do not expect just one organism to be involved in the damage. They often combine forces to overcome a tree.

When you are comfortable with diagnosing pest situations, you may be able to take shortcuts and more readily find the cause. This is true with annosus root disease. In certain areas, such as the eastside pine forests, this disease produces rather characteristic symptoms and you may be able to determine its presence and involvement quickly. However, do not be comfortable in looking at typical aboveground symptoms and determining that annosus root disease is involved. Get down in the dirt and expose some roots. Break apart a stump. Try to find more conclusive evidence of the fungus on the site to confirm your suspicions.

REFERENCES

Bega, Robert V.; Smith, Richard S., Jr. 1966. Distribution of Fomes annosus in natural forests of California. Plant Disease Reporter 50: 832-836.

Bullen, Susan.; Robert E. Wood. 1979. Fomes annosus on Pacific madrone. Plant Disease Reporter 63: 844.

Hendrix, F.F., Jr.; Kuhlman, E. George. 1962. A comparison of isolation methods for Fomes annosus. Plant Disease Reporter 46: 674-676.

Otrosina, William J.; Cobb, Fields W., Jr. Life cycle, infection biology, ecology, and host specificity in Heterobasidion annosum. 1989 [These proceedings].

Slaughter, G.; Parmeter, John R., Jr. True fir and annosus root disease in California national forests: losses, stand, and tree characteristics. 1989 [These proceedings].

Smith, Richard S., Jr.; Bega, Robert V.; Tarry, Jerry. 1966. Additional hosts of Fomes annosus in California. Plant Disease Reporter 50: 181.

Wagener, Willis W.; Cave, Marion S. 1946. Pine killing by the root fungus, Fomes annosus, in California. Journal of Forestry 44: 47-64.

Losses and Impact by Region

Distribution and Impacts of Annosus Root Disease in Forests of the Northern Rocky Mountains[1]

Ralph E. Williams[2]

Abstract: Annosus root disease is widely € distributed in the northern Rocky Mountains. € Stump infection often results in tree mortality € occurring in progressively expanding root disease € centers, in groups of various sizes, and as € scattered individuals. €

Distribution and relative abundance of € annosus root disease vary by host species and € geographic area. Most conifer species are € infected, but true firs and ponderosa pine are € most commonly infected. Infection by *H*. *annosum*€ is frequently observed in managed stands, often € associated with bark beetles and other fungal € root pathogens. €

Effects of tree mortality resulting from € infection by *H*. *annosum* may have both positive € and negative impacts on resource and ecosystem € values for a single site. Insofar as possible, € the net effect of annosus root disease must be € determined on a site-specific basis if impacts € are to be accurately assessed. To do this, as € well as to assess site associations and to € determine management implications, much more € information relating to distribution and € abundance of annosus root disease must be € obtained. €

Distribution and impacts of *H*. *annosum* in € forests of Idaho, western Montana, and northern € Utah--the northern Rocky Mountains--are reported € here. Forest types and disease expression are € relatively similar throughout the area. € Although, occasionally, deciduous trees and € shrubs become infected, the emphasis in this € report is on the infection of coniferous tree € species. €

Generally, annosus root disease of conifers € occurs in progressively expanding disease € centers, in tree groups of various sizes, and in € scattered individuals. One or more host species € may be involved in disease centers which often € originate around stumps and contain dead and € dying trees on the margins. Groups of infected € trees may involve from several to hundreds of € trees with detection being most often associated € with bark beetle activity. Individual tree € infection occurs as scattered trees, and, as with € group mortality, detection is often associated € with bark beetle activity. €

Information about the distribution and € abundance of annosus root disease in the northern € Rocky Mountains contained in this report is based € on a limited number of available literature € reports, discussion with pest management € specialists and researchers in the northern Rocky € Mountain area[3], and personal observations. Few € surveys of distribution and abundance have been € reported. Available information is, thus, very € subjective being based largely on chance € examination of trees that have attracted € attention, primarily windthrown trees or those € with unhealthy or dead crowns. €

Impacts of root diseases, including annosus € root disease, to forest trees have not been well € quantified. Effects of root diseases on various € forest resource management objectives, except in € site-specific cases, have been even less well € quantified. Impact considerations of annosus € root disease in forest resource management are € discussed. €

[1]Presented at the Symposium on Research and € Management of Annosus Root Disease in Western € North America, April 18-21, 1989, Monterey, € California €

[2]Boise Field Representative, Forest Pest € Management, Intermountain Region, U.S. Department € of Agriculture, Forest Service, Boise, Idaho. €

[3]A.D. Partridge, College of Forestry, € Wildlife, and Range Sciences, University of € Idaho, Moscow; J. Byler and S. Hagle, Northern € Region, Cooperative Forestry and Pest Management, € U.S. Department of Agriculture, Forest Service, € Missoula, Mont.; N. Martin, U.S. Department of € Agriculture, Forest Service, Intermountain Forest € and Range Experiment Station, Moscow, Idaho; J. € Schwandt, State of Idaho, Department of Lands, € Coeur d'Alene, Idaho; B. Tkacz, Southwestern € Region, Forest Pest Management, U.S. Department € of Agriculture, Forest Service, Flagstaff, Ariz. €

DISTRIBUTION €

In the northern Rocky Mountains, most € coniferous tree species are affected by annosus € root disease, but distribution and relative € abundance vary considerably by species. This € information is summarized in table 1 and is € discussed in more detail by specific host or host € group below. €

Ponderosa Pine (*Pinus ponderosa* Laws.)€

Annosus root disease occurs throughout € ponderosa pine type forests in the northern Rocky € Mountains. Sapling and pole-size ponderosa pines € are affected in expanding disease centers, € frequently, but not always, originating around € stumps. These centers, generally less than 0.25 € acres (0.1 hectares) in size, are common in € southern Idaho and western Montana--they are € occasionally noted in northern Idaho. €

Table 1--Distribution and relative abundance of annosus root disease in conifer € host tree species in the northern Rocky Mountains. €

	Disease centers			Scattered individual/€ group infection
Host	Location[1]	Abundance	Size (Acres)	Abundance
Ponderosa pine	N.ID	Occasional	0.1-1.0	Occasional
	SW.ID	Common	<0.25	Occasional
	W.MT	Common	0.1-1.0	Common
Douglas-fir	N.ID	Common	>10.0	Common
	S.ID	Rare	<0.05	Rare
	W.MT	Occasional	0.1-5.0	Rare
	N.UT	Not Observed		Rare
Engelmann Spruce	N.ID	Not Reported		Common[2]
	S.ID	Not Reported		Occasional[2]
	W.MT	Occasional	0.1-20.0	Common[2]
Lodgepole Pine	N.ID	Not Reported		Rare
	S.ID	Not Reported		Rare
Western Larch	N.ID	Not Reported		Rare
Grand Fir	N.ID	Common	1.0-10.0	Common[2]
	SW.ID	Occasional	<0.05	Common[2]
	W.MT	Common	1.0-5.0	Occasional[2]
White Fir	N.UT	Not Reported		Rare
Western White Pine	N.ID	Occasional	>0.25	Common[2]
	W.MT	Not Reported		Occasional[2]
Western Red Cedar	N.ID	Not Reported		Rare
	W.MT	Not Reported		Rare
Western Hemlock	N.ID	Rare	0.1-1.0	Occasional
	W.MT	Not Reported		Rare
Subalpine Fir	N.ID	Common	>10.0	Common[2]
	S.ID	Occasional	>20.0	Common[2]
	W.MT	Common	>10.0	Common[2]
	N.UT	Occasional	1.0-5.0	Common[2]
Whitebark Pine	ID	Not Reported		Rare

[1]Locations are the northern (N.), southern (S.) and western (W.) and € southwestern (S.W.) portions of Idaho (ID), Montana (MT), and Utah (UT). €

[2]Occurs as root and butt rot. €

In southwestern Idaho it is not uncommon to detect two to four disease centers per acre in cutover ponderosa pine stands regenerated with ponderosa pine. In one such area near Boise, Idaho, annosus root disease centers have been monitored for a number of years (Marshall and Hoffman 1983). In this area, 34 disease centers scattered throughout a 14-acre (5.6 hectare) ponderosa pine stand were identified 10 years following establishment of regeneration. Disease centers originated around stumps which ranged in size from 9 inches (22.5 centimeters) to 37 inches (81.4 centimeters). About one-third of the stumps initiated centers. At last measurement, centers ranged in size from 15 square feet (1.4 square meters) to 935 square feet (84.15 square meters), and about half of them continued to be active.

Annosus root disease in older ponderosa pines may occasionally result in either direct mortality of individual scattered trees (Williams and Haglund 1976) or it may predispose trees to bark beetle attack. Direct mortality associated with annosus root disease is often found in western Montana and only occasionally in Idaho. Annosus root disease is often found in pines attacked by bark beetles in other western forests (Cobb et al 1974), but this relationship has not been thoroughly evaluated in the northern Rocky Mountains.

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.)

Douglas-fir is infected by *H. annosum* throughout its range, but infection is less frequent than on ponderosa pine. Infection occurs primarily as a root rot and is often associated with bark beetle activity (Partridge and Bertagnole, unpublished[4]).

Root disease centers, involving Douglas-fir of all sizes and several root pathogens including *H. annosum*, are common only in northern Idaho. They are less frequent in western Montana and southwestern Idaho and have not been observed in southeastern Idaho or northern Utah. In southwestern Idaho, Douglas-fir is rarely affected in disease centers except when ponderosa pine is involved. In this area, other root pathogens are not frequently associated with infection by *H. annosum*.

Size of disease centers seems to vary directly with abundance. Large centers, up to 10 acres in size (4 hectares), are present in northern Idaho; smaller centers occur in southwestern Idaho.

Annosus root disease also occurs on scattered individual and small groups of pole-size and larger Douglas-fir trees. Annosus root disease is relatively common in scattered Douglas-fir in northern Idaho (Hagle personal communication 2/89), while in southern Idaho infection is rarely observed (Partridge and Canfield 1978). In a summary of information concerning excavation of root systems of about 450 green and declining Douglas-fir trees throughout northern and southern Idaho, Partridge and Bertagnole (unpublished[4]) report that 2 to 3 percent of the trees were infected with *H. annosum*. Over 90 percent of the infected trees were found at elevations above 5,000 feet (1,520 meters). In western Montana and northern Utah, annosus root disease of scattered trees has been rarely observed.

Engelmann Spruce (*Picea engelmanii* Parry)

Annosus root disease of Engelmann spruce has been reported only in Idaho and western Montana. Disease centers caused by *H. annosum* have been reported only in western Montana where they reach 20 acres (8 hectares) in size.

Infection of individual pole-size and larger spruce trees results in a root and butt rot. Infection of individual trees occurs commonly in western Montana, occasionally in northern Idaho, rarely in southern Idaho, and not at all in northern Utah.

Grand Fir (*Abies grandis* (Dougl.) Lindl.)

Infection of grand fir by *H. annosum* results in a root and butt rot throughout this host's range often in association with other fungal root pathogens and/or bark beetles.

Root disease centers, often involving *H. annosum*, commonly occur in northern Idaho and western Montana but only occasionally in southwestern Idaho. Size of disease centers ranges from 0.1 acre (0.04 hectares) to more than 10 acres (4 hectares). Root disease centers are estimated to occupy about 3 to 5 percent of the forested acreage on northern Idaho forests (Williams and Leaphart 1978, James and others 1984).

Infected individual or small groups of dead, pole-size and larger trees are observed more abundantly than disease centers throughout the range of grand fir. Infected trees are often attacked by the fir engraver beetle, *Scolytus ventralis* LeConte (Partridge and Miller 1972).

---

[4]Unpublished data on file at the College of Forestry, Wildlife, and Range Sciences, University of Idaho, Moscow.

Several fungal root pathogens may be involved € with root disease of grand fir. Pathogens € involved vary by geographical area. In northern € Idaho, Phellinus weirii (Murr.) Gilbn. and € Armillaria spp. occur with much greater frequency € than H. annosum. Miller and Partridge (1973) € report that in excavation studies of grand fir € about 4 percent of all trees examined and 6 € percent of all root-rotted trees examined were € infected by H. annosum. In southern Idaho, the € opposite is true with H. annosum being by far the € most commonly encountered root pathogen. The € fungus can be easily found almost anywhere grand € fir occurs in southern Idaho. €

Endemic activity of the fir engraver beetle € regularly exposes a few scattered individual or € small groups of trees. But, during drought € years, beetle activity and exposure of diseased € trees often increases dramatically. Such has € been the case in Idaho in 1987 and 1988. During € that period, thousands of dying trees were € detected during routine aerial surveys € (Livingston and others 1988, Knapp and others € 1989). It is likely that not only root disease € but also moisture stress, resulting from several € consecutive years of below-normal precipitation, € predisposed trees to beetle attack. €

Western White Pine (*Pinus monticola* Dougl.)€

Annosus root disease centers occur € occasionally in western white pine in northern € Idaho. They often originate around stumps and € involve seedling- and sapling-size white pines in € patterns reminiscent of annosus disease centers € in ponderosa pine (Partridge, personal € communication 2/89). Seldom do they exceed 0.25 € acre (0.1 hectare) in size. This pattern of € activity has not been reported in the western € white pine forests in western Montana. €

Heterobasidion annosum is sometimes found in € conjunction with Armillaria spp. in old growth € western white pine trees. Infection commonly € results in a root and butt rot in northern € Idaho--less commonly in western Montana. Annosus € root disease is most often detected as scattered € individual trees which have been attacked by the € mountain pine beetle (Dendroctonus ponderosae€ Hopkins) (Ehrlich 1939). €

Lodgepole Pine (*Pinus contorta* Dougl.), Western€ Larch (*Larix occidentalis* Nutt.), White Fir€ (*Abies concolor* (cord. & Glend.) Lindl.) and€ Whitebark Pine (*Pinus albicaulis* Engelm.)€

Infection of these species reportedly occurs € rarely, only on scattered individuals, and varies € by geographical area. Annosus root disease has € been observed on lodgepole pine in Idaho and € western Montana, on western larch and whitebark € pine in Idaho, and on white fir in northern Utah. €

Western Red Cedar (*Thuja plicata* (Donn)) and€ Western Hemlock (*Tsuga heterophylla* (Raf.)€ Sarg.)€

Annosus root disease has not been frequently € reported on either of these species anywhere in € their respective ranges. Western hemlock is € rarely affected in disease centers that approach € 1 acre (0.4 hectare) in size (Hagle, personnal [sic]€ communication 2/89). Disease centers involving € western red cedar have not been reported. €

Heterobasidion annosum occurs occasionally in € scattered western hemlock but rarely on scattered € western red cedar (Partridge and Miller 1972, € Koenigs 1969). When detected, infection often € appears to be associated with stumps exposed € during harvest activities. €

Subalpine Fir (*Abies lasiocarpa* (Hook.) Nutt) €

Heterobasidion annosum infects subalpine fir € throughout its range resulting in a root and butt € rot. Progressively expanding root disease€ centers involving all sizes of trees commonly € occur in northern Idaho and western Montana. € Disease centers occur occasionally in southern € Idaho and rarely in northern Utah. Size of € disease centers varies from less than 0.1 acre € (.04 hectare) to 20 acres (8 hectare). €

Scattered individual or small groups of trees € are commonly infected throughout this host's € range (Partridge and Miller 1972, Knapp and € others 1988, Tegethoff 1973). Infection is most € often detected in pole-size and larger trees € attacked by the western balsam bark beetle, € Dryocetes confusus Swaine (Dubreuil 1982, Tkacz € 1983). In Utah, root-diseased subalpine fir are € often infected by both H. annosum and Armillaria€ spp. (Tkacz 1983). €

Thousands of subalpine fir were killed by the € western balsam bark beetle throughout southern € Idaho and Utah in the early 1980's (Knopf 1980). € Heterobasidion annosum has been detected in these € trees in some cases, but surveys to determine € degree of association have not been conducted. €

As noted above, pathologists have a fair idea € regarding how and where annosus root disease € affects the various conifer species in the € northern Rocky Mountains. Nevertheless, few € systematic surveys have been conducted, reports € often conflict, and few substantiated site or € stand associations can be made as has been done € in the southeastern United States (Anderson and € others 1980). To remedy these problems, € additional information concerning annosus root € disease must be collected. €

IMPACT CONSIDERATIONS

The traditional connotation of tree root disease is that it results in tree mortality and growth loss, thus having a negative effect on fiber or board production. Evaluating effects of annosus root disease on tree growth and mortality might appear rather simple--so many board feet of lumber can be obtained from a dead tree of a certain size or so many trees can be grown on a given area occupied by root disease centers. However, before impacts of root disease on the timber resource can be realistically evaluated, several questions must be addressed. These include:

* What is the market value of the particular tree species being affected?
* Could or would affected trees be harvested?
* What is the effect of tree mortality on long-term harvest scheduling and economics?
* What is the long-term effect of implementing management actions that greatly enhance the probability of stump infection and pathogen spread?
* How does infection, either in scattered trees or in disease centers, affect tree regeneration?
* How large will disease centers become?

All things considered, tree mortality associated with annosus root disease in commercial forest areas generally has a negative effect on the timber resource value.

Other resource values in a forest environment may also be affected, either positively or negatively. Major non-timber resource values include: esthetics and recreation, wildlife, water production, and livestock range. These non-timber resource values are receiving increased attention as a result of planning efforts and resource allocations on National Forests in the northern Rocky Mountains.

Esthetics and recreation opportunities are of prime importance in developed forest sites such as campgrounds and associated areas, administrative sites, around dwellings, and in other areas heavily used by people. While tree mortality results in degradation of esthetic values, loss is substantially compounded when root-decayed trees fail resulting in damage to area improvements or causing personal injury. Discussion of root diseases that affect trees in campgrounds are contained in several publications (Wagener 1963, Mills and Russell 1981). Potential for impact is directly proportional to tree size, proximity to improvements, and, of course, the extent of disease development (Paine 1971). Tree mortality generally has a negative effect on esthetic and recreation resource values. Value of trees used for these purposes is often considerably greater than for trees used for timber.

The value of root-diseased trees relative to the wildlife resource is much more difficult to assess. Depending on site-specific management emphases, dead trees may be much more valuable than green trees, or the opposite may be true. For example, the value of dead trees as perch trees for raptors, for maintaining populations of rare and endangered species of cavity-nesting birds, or of fallen trees for debris recruitment to aid fisheries may be very high. Conversely, the value of green trees for providing hiding and thermal cover to big game animals may be very high.

Other forest resource values are likewise variably affected by annosus root disease.

In addition to the effects of root disease on vegetation, effects on other facets of the ecosystem must also be factored into impact considerations. Some values of trees to the ecosystem, such as abatement of soil erosion by wind or water, are obvious. More profound values, such as the relationship of green trees to global climate or the value of decaying wood to soil improvement (Jurgenson and others 1977; Franklin and others 1981), have only recently received much attention.

On any given site, tree mortality caused by annosus root disease or other pests can have both positive and negative effects on resource or ecosystem values. The determination of net effect requires knowledge of site-specific resource or ecosystem values as well as specific knowledge of distribution and abundance of annosus root disease.

REFERENCES

Anderson, R.L.; Fisher, V.; Mistretta, P. 1980. How to recognize annosus-prone forest sites. Forest Farmer October, 1980; 6-7.

Cobb, F.W., Jr.; Parmeter, J.R., Jr.; Wood, D.L.; Stark, R.W. 1974. Root pathogens as agents predisposing ponderosa pine and white fir to bark beetles. In: E.G. Kuhlman, ed., Proceedings of the fourth international conference on Fomes annosus. September 17-22, 1973; Athens, Georgia. Southeastern Forest Experiment Station. U.S. Department of Agriculture, Forest Service; 8-15.

Dubreuil, S.H.; Tunnock, S.; Dooling, O.J. 1982. Bark beetle history and root disease on the Hungry Horse District, Flathead National Forest. Report 82-12. Missoula, Mont.: Cooperative Forestry and Pest Management Report 82-12., U.S. Department of Agriculture, Forest Service; 11 p.

Ehrlich, J. 1939. A preliminary study of root diseases in western white pine. Paper No. 1, Missoula, Mont.: Northern Rocky Mountain Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service; 10 P.

Franklin, J.F.; Cromack, K., Jr.; Denison, W.; € Mckee, A.; Maser, C.; Sedell, J.; Swanson, € F.; Juday, G. 1981. Ecological € characteristics of old-growth Douglas-fir € forests. Report PNW-118. Corvallis, Ore.: € Pacific Northwest Forest and Range Experiment € Station, U.S. Department of Agriculture, € Forest Service; 48 p. €

Hagle, S., Forest Pathologist, Northern Region, € Cooperative Forestry and Pest Management, € U.S. Department of Agriculture, Forest € Service, Missoula, Mont. (Telephone € conversation and computer communications with € R. Williams) February, 1989. €

James, R.L., Stewart C.A.; Williams, R.E. € 1984. Estimating root disease losses in € northern Rocky Mountain National Forests. € Canadian Journal of Forest Research 14: € 652-655. €

Jurgenson, M.F., Larson, J.J.; Harvey, A.E. € 1977. Effects of timber harvesting on soil € biology. In: Proceedings of the Society of € American Foresters 1977 National Convention, € October 2-6, 1977. Albuquerque, N.M. Society € of American Foresters: Washington, D.C.; € 244-250. €

Knapp, K.A.; Weatherby, J.; Hoffman, J.; Kalve, € V; LaMadeleine, L. 1989. Forest insect and € disease conditions: Intermountain € region--1988. Ogden, Ut.: Intermountain € Region, Forest Pest Management, U.S. € Department of Agriculture, Forest Service; 35 € P. €

Knopf, J.A.E. 1980. Forest insect and disease € conditions: Intermountain Region--1980. € Ogden, Ut.: Intermountain Region, Forest € Pest Management, U.S. Department of € Agriculture, Forest Service; 14 p. €

Koenigs, J.W. 1969. Root rot and chlorosis of € released and thinned western redcedar. € Journal of Forestry 67: 312-315. €

Livingston, R.L; and others. 1988. Idaho Forest € Pest Conditions and Program Summary 1987. € State of Idaho, Dept. of Lands Report No. 88-€ 1; 28 p. €

Marshall, J.P.; Hoffman, J.T. 1983. Evaluation of € longevity and spread of annosus root rot in € the BLM's Idaho City ponderosa pine tree € improvement plantation. Report No. 83-13. € Ogden, Ut.: Intermountain Region, Forest Pest € Management, U.S. Department of Agriculture, € Forest Service; 7 p. €

Miller, D.L.; Partridge, A.D. 1973. Fungus € associations in root rots of grand fir. € Plant Disease Reporter 57: 346-348. €

Mills, L.J.; Russell, K. 1981. Detection and € correction of hazard trees in Washington's € recreation areas: A how-to guide for € recreation site managers. Report No. 42. € Olympia, Wash.: Washington State Dept. of € Natural Resources; 37 p. €

Paine, L.A. 1971. Accident hazard: evaluation € and control decisions on forested recreation € sites. Research Paper PSW-68. San Francisco, € Calif.: Pacific Southwest Forest and Range € Experiment Station, U.S. Department of € Agriculture, Forest Service; 10 p. €

Partridge, A.D., Professor, College of Forestry, € Wildlife, and Range Sciences, University of € Idaho, Moscow, Idaho [Telephone conversation € with R. Williams, 2/89]. €

Partridge, A.D.; Canfield, E.R. 1978. A report € regarding mortality of Douglas-fir in the € Boise National Forest. Moscow, Id.: € University of Idaho, College of Forestry, € Wildlife and Range Sciences; 9 p. €

Partridge, A.D.; Miller, D.L. 1972. Bark € beetles and root rots related in Idaho € conifers. Plant Disease Reporter 56: € 498-500. €

Tegethoff, A.C. 1973. Known distribution of € Fomes annosus in the Intermountain Region. € Plant Disease Reporter 57: 407-410. €

Tkacz, B.M. 1983. An evaluation of disease and € insect conditions in a spruce-fir stand on € the Beaver Ranger District, Fishlake National € Forest. Report R-4-83-7; Ogden, Ut.: € Intermountain Region, Forest Pest Management € Report; U.S. Department of Agriculture, € Forest Service; 12 p. €

Wagener, W.W. 1963. Judging hazard from native € trees in California recreational areas--A € guide for professional foresters. Research € Paper-Pl. Berkeley, Calif.: Pacific Southwest € Forest and Range Experiment Station, U.S. € Department of Agriculture, Forest Service; 29 € P. €

Williams, R.E.; Leaphart, C.D. 1978. A system € using aerial photography to estimate area of € root disease centers in forests. Canadian € Journal of Forest Research 8: 214-219. €

Williams, R.E.; Haglund, S. 1976. Fomes annosus€ in roots of mature ponderosa pine in western € Montana. Plant Disease Reporter 60: € 101-103. €

Heterobasidion (Fomes) Annosum Incidence in Pre-Commercially Thinned Coastal Washington Western Hemlock Stands[1]

Willis R. Littke **John E. Browning**[2]

Abstract: Heterobasidion annosum infects western hemlock (Tsuga heterophylla) and causes a root and butt-rot disease. A disease survey was initiated in thinned Southwestern Washington hemlock stands to determine current disease incidence caused by H. annosum.

Eleven stands were selected which had been pre-commercially thinned in the interval 5-11 years ago. Ten replicate 1/50th acre plots were established per stand and' all hemlock trees were cored with increment borers. Core samples were cultured to isolate decay fungi and to determine decay incidence and the occurrence of "wetwood".

Levels of infection by H. annosum in pre-commercially thinned western hemlock stands were low (0-8 percent). Merchantable volume loss from decay ranged from 0-1 precent [sic]. Infection levels were not correlated with site characterisitics, [sic] "wetwood" incidence, cutstump frequency or tree diameter class. No control measures appear warranted for thinnings in hemlock stands where similar low infection potentials exist.

Heterobasidion annosum (Fr.) Bref. infects western hemlock (Tsuga heterophylla (Rfn.) Sarg.) and causes a root and butt-rot disease (Russell and others 1973, Driver and Edmonds 1970). Nearly two decades ago, it was recognized that thinning initiated root disease could be a potentially limiting factor in intensive hemlock management (Morrison and Johnson 1970, Wallis and Reynolds 1970, Driver and Edmonds 1970). Epidemiological and disease incidence studies were initiated because of concern over this disease potential (Edmonds and others 1989).

Disease incidence surveys conducted in non-thinned hemlock stands in Washington and Oregon indicate that infection levels ranged from 10 to 67 percent (Schmidt 1979). Likewise, Goheen and others (1980) reported lower levels of infection (0-30 percent) for a similar hemlock stand series. At two non-thinned Washington sites (Raymond and Snoqualmie), we determined that 0-15 percent of the residual western hemlock trees were infected.[3]

More dramatic disease increases have been reported following hemlock thinning. Chavez and others (1980) reported significant disease increases at Clallam Bay, Washington, over infection levels reported a decade earlier by Edmonds (1968). Ten years after thinning, Chavez determined that some 85 to 95 percent of the residual stand was infected, in contrast to prethinning infection levels of 4 to 12 percent (Edmonds 1968).

Edmonds and others (1989) report that current (pct+20 years) infection levels on the same study site of Chavez (1980) fail to confirm that a disease increase occurred. This apparent conflict in disease incidence observations following thinning has not been fully explained (Edmonds and others 1989). We feel that variation in wood incubation techniques and the mistaken identity of "wetwood" as incipient H. annosum root decay may have led to conclusions by Chavez and others (1980) that a disease increase had occurred, when in fact it had not. To better understand current annosus root disease levels and its impact, a disease survey was initiated in thinned coastal western hemlock stands in Washington.

Our hypothesis was: hemlock stands thinned from high initial stocking densities (>3000 trees per acre [TPA]) and older age classes >20 years) have a higher incidence of annosus root disease, than younger stands thinned from lower initial stocking densities.

The specific study objectives were:
(1) identify site and stand characteristics associated with high disease incidence
(2) determine current infection levels by H. annosum in thinned hemlock stands and
(3) determine current disease impact.

---

[1] Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2] Pest Management Scientist and Pest Management Technician, respectively, Weyerhaeuser Company, Centralia Research Facility, Centralia, Washington.

[3] Unpublished data on file at Centralia Research Center Library, Centralia , Washington.

METHODS

Site Descriptions

Sample sites were located in southwest Washington in Pacific, Grays Harbor, and Lewis counties. Figure 1 shows the study site locations, relative to Aberdeen, Washington. Stands were identified by name of nearest major road system (name-line) or by nearest access road number. The study included portions of the Falls Creek C-Line, Lund A-line, Nemah X&Y-Lines, Palix A&D-Lines, and Trap Creek D-line (Figure 1).

Hemlock soil site index values were 100 or 110 feet at breast height age 50 years (Steinbrenner and Duncan 1969). This index refers to average height growth of western hemlock on a site at stand age 50 years. The soils are of volcanic origin and are classified in the Bunker, Katula, Knappton, or Vesta series (Table 1). Stand elevation varied from 500 to 2500 feet, and slopes ranged between 17 and 53 precent [sic].

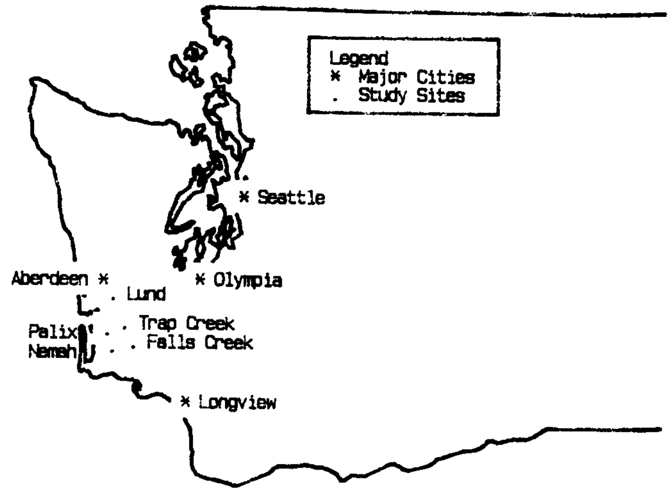


Figure 1--Locations of western hemlock stands sampled for infection by _Heterobasidion annosum_ in Washington State

Table 1--Site characteristics of western hemlock stands in Washington State surveyed for _Heterobasidion annosum_ incidence

Stand name	Soil site index[1]	Soil series[2]	Elevation	Slope
			feet	percent
Falls Creek C2600[3]	100	Bunker	2500	35
Falls Creek C6700	100	Bunker	2500	25
Falls Creek C6790	100	Bunker	2500	17
Lund A800	100	Bunker	500	24
Nemah X130	110	Knappton-Vesta	550	53
Nemah Y1710	110	Knappton	550	19
Palix A2100	110	Knappton-Vesta	600	31
Palix A2710	110	Knappton-Vesta	600	28
Palix D2000	100	Vesta	2200	23
Palix D2300	110	Knappton-Vesta	2200	26
Trap Creek D920	100	Katula	1750	47

[1] Soil site index - height in feet at breast height age 50 years (Steinbrenner and Duncan 1969).

[2] Soil series classification (Steinbrenner and Duncan 1969).

[3] Major access line and road number respectively.

TPA € pre-thin € density €	Stand Age at Thinning (Yrs) € 15-20	>20 €
<3000 €	Lund A800[1] Palix A2100 Palix A2710	Falls Creek C2600 Falls Creek C5700 Nemah X130 Nemah X1710 Trap Creek D920
>3000 €	NS*	Falls Creek 6790 Palix D2000 Palix D2300 Bishop A450

* NS - no samples present €

[1€] Stand name designated by service road € (name) and access road number (letter and number) €

Figure 2--Relative position of survey stands to € sampling matrix constructed using plot measurement € data for pre-thin stand age density and stand age. €

Plot Design and Measurements€

Survey transects at 5-chain intervals were € overlaid on stand maps. Ten circular 1/50th acre € plots per stand were established at randomly € selected points from this overlay. Tree diameters € were measured for plot trees larger than 4.5 € inches in diameter at breast height (dbh). Cut-€ stumps from previous thinning activities and all € other similar-aged tree stumps within a 3-foot € radius of each plot tree were tallied. Pre-€ thinning and current stocking levels were calcu-€ lated for each stand by using plot residuals and € cutstump tallies. This plot data filled a sampling € matrix of stocking density by stand age combina-€ tions. Figure 2 shows the sample matrix breakdown € by density and age. €

Hemlocks on each plot were cored at stump € height (6 inches) with an increment borer. Cores € were extracted through the bole to the stem pith € region and perpendicular to an imaginary line € through the stem to the nearest cutstump. This € was determined by experience to give the greatest € probability of intersecting a decay column, if € present. Extracted cores were stored at the end € of each day in a cold room at 33°F, and plated € within 2-3 days. €

Disease Status €

Tree disease status was visually determined € from the cores and later confirmed by fungal € isolations as: (1) infected with H. annosum, (2) € containing other decay fungi, or (3) having € "wetwood" stain with or without other decay fungi. €

Fungal Isolations €

Cores were dipped in 70 percent ethanol and € flame sterilized prior to fungal isolation. Cores € partitioned into 2-inch long pieces were plated € onto media selective for H. annosum (Kuhlman and € Hendrix 1962). Plates were incubated 3 weeks at € 25°C and examined for the Oedocephalum. €

Sporophore Occurrence €

Fruiting bodies of H. annosum were collected € from survey plots and their age was estimated by € counting successive hymenial surface layers. More € than one hymenial layer can be formed in a year, € but a maximum potential age for the individual € sporophores can be calculated in this manner. €

Analysis €

Study results were tested for significant € differences (p = .05) between stand infection € levels and various stand and site parameters by € using ANOVA PC/SAS Version 6 (SAS Institute Inc. € 1987). €

RESULTS/DISCUSSION €

Stand Characteristics€

Western hemlock was the predominate com-€ ponent (97 percent) in our study (Table 2), with € minor components of Douglas-fir (Pseudotsuga€ menziesii Mirb. Franco.), silver-fir (Abies€ amabilis Dougl. Forb.), and Sitka spruce (Picea€ sitchensis Bong. Can.) present in some stands. € Our study concentrated on hemlock stands currently € 26-39 years old (Table 2). Stand age was ex-€ pressed as the time since the previous harvest, € and not actual tree age. We found that tree age € and stand age could differ by as much as 15 years, € because some trees could be nonmerchantable€ carry-overs from the previous stand. €

All stands had been regenerated naturally € following harvest. The Falls Creek sites were € slash-burned, and the remaining sites were not € (Table 2). Site preparation affected the occur-€ rence of hemlock dwarf mistletoe (Arceuthobium€ tsugense (Rosendahl) G.N. Jones). This disease € was common in nonburned stands,, but absent in € slash-burned units. €

Stand density at thinning was calculated to € range from 1485 to 4205 trees per acre (TPA) € (Table 2). These stands were subsequently precom-€ mercially thinned with chainsaws between 5 and 11 € years ago. Cut-stumps were not treated with€ borax. Post-thinning stocking levels varied from € 260 TPA to 570 TPA. €

Table 2--Stand description of site preparation, western hemlock composition, current stand age, holding time since pre-commercial thinning (PCT), pre-thin stocking density (TPA), and current stocking levels. Data based on ten 1/50th-acre plots per stand

Stand name[1]	Site prep	Hemlock composition	Current[1] stand age	Years Since Thinning	Stand density[3] Pre-thin	Current
		Percent	Years		TPA	TPA
Falls Creek C2600	Burned	91	36	8	2380	335
Falls Creek C6700	Burned	99	36	6	1880	385
Falls Creek C6790	Burned	99	36	6	3000	350
Lund A800	None	96	26	8	1485	260
Nemah X130	None	100	29	5	2260	315
Nemah Y1710	None	100	29	5	2790	345
Palix A2100	None	99	30	11	2855	360
Palix A2710	None	86	30	11	2015	270
Palix D2000	None	100	31	10	4205	570
Palix D2300	None	100	30	9	3620	340
Trap Creek D920	None	95	32	6	2115	305

[1] The letter and number designations that follow the stand names identify the road line (letter) and secondary access road number.

[2] Years since last harvest and not actual tree age.

[3] TPA - stand density in trees per acre.

Disease Survey Data

The survey data were used to determine disease incidence, decay levels, and to identify factors related to infection levels. Disease status was based on examination of cultures from 769 hemlock tree cores. We distinguished between incipient and advanced decay caused by *H. annosum* and "wetwood." The occurrence of sporophores of *H. annosum* and cutstump frequency were measured as disease factors.

Levels of Infection by *Heterobasidion annosum*

Levels of infection caused by *H. annosum* in precommercial thinned western hemlock stands throughout this study were low; they ranged from 0 to 8 percent (Table 3). The Lund A800 site had the highest infection level. Infection levels of 0 to 2.9 percent were observed in the Falls Creek stands. At Trap Creek D920 3.4 percent of the trees were infected with *H. annosum*. The fungus was not isolated from plots of the Palix A2100, Falls Creek C2600, A2710, D2300 or Nemah Y1710 stands.

Our results indicate that infection levels of *H. annosum* in pre-commercially thinned western hemlock stands are much lower than previously reported. Schmidt (1978) observed that stand elevation and geographic location had an effect on stand infection levels. He found higher levels (40-50 percent) in Pacific County (Washington), and slightly lower levels (30-50 percent) in Washington Cascade stands. In similar locations, Coheen and others (1980) reported disease levels to be from 5-20 percent and 20-30 percent for non-thinned and thinned stands, respectively. Chavez and others (1980) reported that 85 to 95 percent of hemlock residuals in a Clallam Bay, Washington, thinned stand were infected. New unpublished data obtained by the authors and others (Edmonds and others 1989) do not support these earlier study results. In contrast, we suggest that infection levels in the range of 0 to 15 percent may be typical for thinned or nonthinned western hemlock stands under 50 years of age.

In our case, the post-thinning holding time period (5 to 11 years) should have been long enough to allow for sufficient pathogen movement from cutstumps to residual trees based on published fungal growth rates -- 0.75m/year (Wallis and Morrison 1975, Chavez and others 1980). We did not see a trend in our data for more disease with longer holding period. Other studies sampled stands following similar post-thinning periods. For example, Goheen and others (1980) sampled stands 12-21 years after thinning, while Chavez and others (1980) reported on a 10-year post-thinning holding period.

The distribution of hemlock trees infected by H. annosum by diameter class has not been previously reported in the literature. Table 4 illustrates that infected trees occurred throughout the diameter distribution of our study sites.

Decay In Trees

Decay frequency, including that caused by H. annosum, is shown in Table 3. H. annosum was the most frequent pathogenic root decay fungus isolated. Earlier studies have shown H. annosum to be a major component of decay in western hemlock (Shea 1960, Goheen and others 1980, Wallis and Morrison 1975).

Advanced bole decay was observed in residual hemlocks in all stands except Nemah Y1710. Decay may also result from other fungal species. Armillaria sp. (ostoyae) was isolated from decayed cores of two trees. Perenniporia subacida and other fungal species were isolated infrequently. Fungi Imperfecti and bacteria associated with decay were isolated but these were not identified.

Decay impact on a stand level was minimal owing to the low infection levels. Merchantable losses from decay were estimated to be less than 1 percent of stand volume. This is less than the 2 to 3 percent merchantable volume loss measured by Goheen and others (1980). Decay development over the remaining portion of the rotation (20 years or so) will add additional impact, as the column of decay continues to develop.

Wetwood Stain

Dark-stained, water-soaked core wood in western hemlock has been termed "wetwood" (Schroeder and Kozlik 1972). This type of wood has been associated with warping, annual ring separation (shake), and drying problems in western hemlock.

In our study, 45 percent of sampled trees contained "wetwood" stain at the stump level (Table 3). "Wetwood" was most prominent in the Palix D2000 unit, and it was least common in an adjacent stand, Palix D2300 (57 percent versus 31 percent, respectively).

"Wetwood" is believed to arise from branch origin, but may also be a by-product of wood-decaying microorganisms (Edmonds and others 1989). Because of its appearance, "wetwood" has been

Table 3--Summary of disease data from sampled stands of western hemlock showing percentages of infection by Heterobasidion annosum, percent trees with bole decay, and "wetwood" occurrence. Data based on averages from ten replicate 1/50th-acre plots per stand

Stand name[1]	H. annosum infection[2]	Decay trees[3]	"Wetwood"
	Percent	Percent	Percent
Falls Creek C2600	0 a[4]	3.8 ab	49 abcd
Falls Creek C6700	1.3 a	1.3 ab	45 abcd
Falls Creek C6790	2.9 ab	4.4 ab	31 cd
Lund A800	8.0 b	8.0 a	46 abcd
Nemah X130	4.8 ab	6.0 ab	54 abc
Nemah Y1710	0.0 a	0.0 b	48 abcd
Palix A2100	0.0 a	1.4 ab	37 bcd
Palix A2710	0.0 a	0.1 ab	47 abcd
Palix D2000	0.9 a	0.9 ab	57 ab
Palix D2300	0.0 a	4.4 ab	31 cd
Trap Creek D920	3.4 ab	6.9 ab	53 abc

[1] The letter and number designations that follow the stand names identify the road line (letter) and secondary access road number.

[2] Percent age of trees with H. annosum.

[3] Percent trees with incipient or advanced decay including those with H. annosum.

[4] Means followed by different letters are significantly different at P = 0.05 as determined by Duncan's New Multiple Range T-test.

mistakenly identified as a symptom caused by € H. annosum in infected wood. Our isolations € confirm that "wet-wood" is a poor indicator of € incipient infection by H. annosum. Bacteria and € various Fungi Imperfecti (Trichoderma sp., etc.) € were consistently isolated from "wetwood." €

Disease Factors€

Sporophore Occurrence €

Fruiting bodies (sporophores) are the source€ of airborne inoculum of H. annosum that infects € freshly cut stumps and wounded trees. The € presence of sporophores has important bearing on € stand infection levels, because sporophores con-€ firm that the fungus is present and producing € spores which could contribute to more infections. € We frequently observed active sporophores on € stumps and logging slash from the previous stand, € and less frequently on thinning-aged slash. The € quantity of sporophores present on a area sampling € basis differed between stands (Table 5). € Sporophores could not be found in the slash burned € stands at the Falls Creek sites (C6700, C2600, and € C6790). Slash burning might inhibit or delay € fruiting through decreased initial infection € rates, consuming substrates where fruiting might € occur, or by changing the fruiting microenviron-€ ment. The interactions between fire and€ H. annosum have been poorly studied (Russell and € others 1989). €

Other factors (such as elevation) could af-€ fect sporophore production. The Falls Creek € sites, where no fruiting of H. annosum was € observed, were at the highest elevation (2500 € feet) sampled. Infection rates and fungal growth € might be adversely affected at higher elevations, € further contributing to delayed fruiting. €

Table 4--Distribution of H. annosum infected trees € and the percent of trees infected in each 1 inch € DBH diameter class. €

DBH Diameter class	No. trees	No. infected trees	Percent € infection€
4.5 - 5.0	16	0	0
5.5 - 6.0	30	3	10
6.5 -7.0	64	1	1.6
7.5 - 8.0	116	2	1.7
8.5 - 9.0	133	4	3
9.5 - 10.0	117	2	1.7
10.5 - 11.0	110	2	1.8
11.5 - 12.0	73	0	0
12.5 - 13.0	47	1	2.1
13.5 - 14.0	34	0	0
14.5 - 15.0	18	0	0
15.5 - 16.0	9	0	0
16.5 - 17.0	4	0	0
17.5 - 18.0	1	0	0
18.5 - 19.0	1	0	0
19.5 - 20.0	1	0	0

In contrast to the Falls Creek site, non-€ burned stands had varying populations of active € sporocarps. Sporophores were observed on 20 € percent of the plots in four stands (Trap Creek. € D920, Palix D2300, D2000; and Lund A800), while € higher sporophore concentrations (40 percent of € the sample area) occurred in the Nemah X130 and € Palix A2710 units. The greatest numbers of € sporophores were observed in the Nemah Y1710 unit € where 90 percent of the plots had active € sporophores. The availability of suitable woody € substrates (stumps and logs) appeared related to € fruiting abundance, but this was not quantified in € this study. €

Sporophore age ranged from 3 to 6 years old € in most units, with occasional older "conks" being € from 11 to 16 years old. These data indicated € that peak sporophore occurrence did not coincide € with stand thinning date. Thinning was done when € relatively few active sporophores were present in € these stands. This could explain the low correla-€ tion between current sporophore density and stand € infection levels. €

Previous researchers reported high levels € of stump infection, but gave no clue as to in-€ oculum source (Driver and Edmonds 1970). We sug-€ gest that in our study, stands were thinned when € low background levels of inoculum were present. € The source of this inoculum could be from the € relatively few sporophores present in the stand € and from sources outside the stand.Risk of € tree infection within a stand could be augmented € if greater sporophore density coincided with thin-€ ning, since spore sources and suitable fresh cut-€ stumps would be in close proximity. €

Other fungi might successfully compete with € H. annosum for available substrates, resulting in € low infection rates. We observed numerous € sporophores of Perenniporia subacida, Ganoderma€ oregonensis, Neamatoloma capnoides, Pholiota sp., € and Fomitopsis pinicola on stumps and logging € debris, and on thinning slash. The beneficial € role that these competing fungi may play in dis-€ ease reduction in hemlock stands has not been € quantified. €

Cutstump Distribution €

Cutstumps are a primary infection court for € H. annosum, although wounds and animal damage also € provide infection counts (Chavez and others 1980). € Our initial hypothesis stated that stands thinned € from a higher stand stocking density would € develop higher levels of disease than those € thinned from lower initial stand stocking den-€ sities. This hypothesis assumed that greater € cutstump frequencies around individual trees would € create greater infection potential. €

The average cutstump frequency for our € stands is shown in Table 5. Falls Creek C6700 was € characterized as a stand with low cutstump density €

(0.7 stumps/per tree). In contrast, the Palix units D2300 and D2000 averaged 3.8 cutstumps per residual tree. Overall, some 30 percent of the study trees did not have a cutstump within a 3-foot radius. Figure 3 displays a histogram of the varying number of trees with increasing numbers of cutstumps. The frequency of trees decreased rapidly with increasing cutstump classes. The maximum number of cutstumps surrounding a single tree was 17 (Palix D2000).

We found no significant relationship (P = 0.05) between cutstump frequency within 3 feet of residual trees and the tree's risk of infection by <u>H. annosum</u>. This is due to the fact that probability of infection did not increase with increasing numbers of cutstumps (Table 6). The average infection probability in cutstump classes up to five stumps per tree was (P = 0.022). No infected trees were encountered in cutstump frequency classes greater than six stumps per residual.

These findings do not support the initial hypothesis that disease initiation increased with higher cutstump frequencies. They indicate that cutstumps may not be the rate-limiting infection factor. This places greater importance on spore loads as a limiting infection factor in our survey stands. Theoretically, infection rates should increase linearly if both spores and cutstumps are not limiting. This is not shown by the data in Table 6.

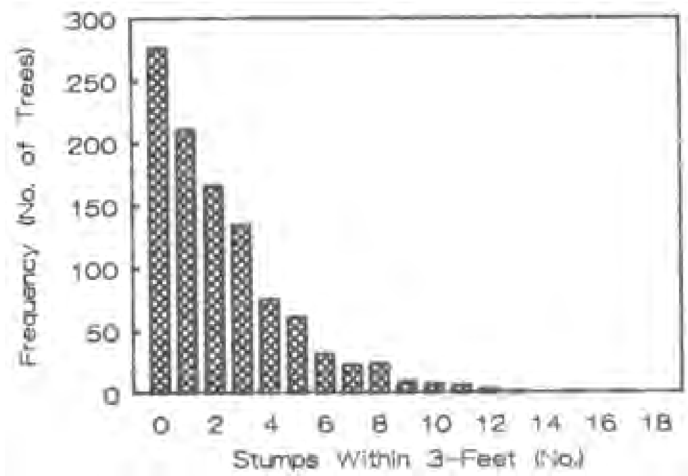


Figure 3--Frequency distribution showing the number of pre-commercially cutstumps within three feet of individual residual western hemlock trees, in stands surveyed for <u>H. annosum</u> in Washington State.

Table 5--Summary of disease factors associated with <u>Heterobasidion annosum</u> in survey stands of western hemlock, including sporophore occurrence, and mean pre-commercial thinning (PCT) cutstump density around stand residuals

Stand name[1]	Sporophore Occurrence[2]	Cut-stump density[3]
	<u>Percent of area</u>	<u>Mean</u>
Falls Creek C2600	0	1.9
Falls Creek C6700	0	0.7
Falls Creek C6790	0	1.0
Lund A800	0	1.3
Nemah X130	40	2.2
Nemah Y1710	90	2.3
Palix A2100	40	2.8
Palix A2710	40	2.2
Palix D2000	20	3.8
Palix D2300	20	3.8
Trap Creek D920	20	1.4

[1] The letter and number designations that follow the stand names identify the road line (letter) and secondary access road number.

[2] Percent of sample plots with sporophores of H. annosum.

[3] Mean number of PCT-stumps in a 3-foot radius of plot residuals based on ten 1/50th acre plots per stand.

Table 6--The probability of a residual western hemlock in different cutstump[1] classes becoming infected by *Heterobasidion annosum* following pre-commercial thinning (PCT)

Cutstumps[1] per residual	No. of trees	Infected[2]	Infection probability
no.	total	no.	percent
None	230	5	2.2
1	147	5	3.4
2	115	1	0.9
3	93	2	2.2
4	60	0	0
5	47	2	4.3
6-17	7	0	0
Totals (trees)	769	15	Average 2.0

[1] Number of PCT-stumps within 3-foot radius of individual residual western hemlock.

[2] Number of confirmed H. annosum infected trees.

We suggest that lack of significance between cutstump frequency and infection by *H. annosum* in this study might be explained by: (1) variable infection rates for different sized stumps, (2) low infection rates under low incident spore loads, and (3) changes in root grafting frequency at different stocking levels, or combinations of the above. The role these variables play in the infection process needs to be quantified.

CONCLUSIONS AND DISEASE MANAGEMENT CONSIDERATIONS

Southwestern Washington currently contains many overstocked stands of western hemlock. Present pre-commercial thinning practices reduce stand stocking to optimize residual tree growth and log size. The increase of root disease caused by *H. annosum* after thinning has been demonstrated, but its magnitude and impact are still being debated (Edmonds and others 1989).

Currently, no disease-control measures, such as borax-stump treatment, are practiced, as has been advocated in earlier studies (Russell and others 1973). Our results indicate that no control measures are warranted in hemlock stands thinned in the 15 to 20-year-old age class (or younger), and under low infection potential (low sporophore incidence).

Results of this study demonstrated that:

1). Levels of infection caused by *H. annosum* in residual trees in thinned coastal Washington western hemlock stands are low (0 to 8 percent). Current merchantable volume in decay ranges from 0 to 1 percent. *H. annosum* was the most frequent cause of root decay in the western hemlock trees in this study.

2). Infection levels were not correlated with slope, elevation, or other stand characteristics.

3). No correlation was found between the frequency of cutstumps and increased individual tree risk to infection by *H. annosum*.

4). Trees infected by *H. annosum* occur across a wide variety of diameter classes.

5). No sporocarps of *H. annosum* were observed in slash-burned units. Fruiting in non-burned units varied from 20 to 90 percent of sample area. No relationship was found between current fruiting occurrence and current levels of infection by *H. annosum*.

6). "Wetwood" occurred in some 45 percent of the sampled trees and it was not indicative of incipient infection by *H. annosum*.

7). No disease control measures are warranted for hemlock stands thinned under similar low infection potentials.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Jerry Gutzwiler, land and timber manager for the Weyerhaeuser Washington Twin Harbors Region, and that of his staff, who helped us obtain PCT-records and stand maps. Special thanks to Dr. Tom Terry, Rod Meade, Paul Figueroa of the Weyerhaeuser Centralia Research facility for helping with technical support, data analysis, and manuscript preparation; and Mike Moore of J&M Forestry Consultants (Elma, Wash.) for the field work and assistance with measurement and preparation of samples. Norma J. Lupkes assisted in the preparation of this manuscript.

REFERENCES €

Chavez, T.D. Jr., R.L. Edmonds, and C.H. Driver. € 1980. Young growth western hemlock stand € infection by Heterobasidion annosum 11-years € after pre-commercial thinning. Can. J. For. € Res. 10:389-394. €

Driver, C.H. and R.L. Edmonds. 1970. Fomes an-€ nosus in young growth western hemlock. € University of Washington, College of € Forestry Resources. Contemporary Forest € Paper. Contribution No. 9. 12 p. €

Edmonds, R.L. 1968. Natural occurrence and con-€ trol of Fomes annosus in pre-commercially € thinned stands of western hemlock. M.S. € Thesis University of Washington, College of € Forestry Resources, Seattle, WA. €

Edmonds, R.L., D.C. Shaw, T. Hsiang, and C.H. € Driver. 1989. Impact of pre-commercial € thinning on development of Heterobasidion€ annosum in western hemlock. (Symposium on € Research and Management of Annosus Root Dis-€ ease (Heterobasidion annosum) in Western € North America. April 18-21, 1989, Monterey, € CA. €

Goheen, D.J., G.M. Filip, C.L. Schmitt, and T.F. € Gregg. 1980. Losses from decay in 40- to € 120-year old Oregon and Washington western € hemlock stands. USDA Forest Service, € Pacific Northwest Region R6-FPM-045-1980, € Portland, OR. 19 p. €

Kuhlman, E.G. and F.F. Hendrix, Jr. 1962. A € selective media for the isolation of Fomes € annosus. Phytopathology 52:1310-1312. €

Littke, W.R. 1988. Unpublished data on Annosus € root disease levels at Pack Sack and Rattle-€ snake units. On file at Weyerhaeuser € Research Center, Centralia, WA. €

Morrison, D.J. and A.L.S. Johnson. 1970.€ Seasonal variation in stump infection by € Fomes annosus in coastal British Columbia.€ Forestry Chronicle 46:200-202. €

Russell, K.W., J.H. Thompson, J.L. Stewart, and € C.H. Driver. 1973. Evaluation of chemicals € to control infection in stumps by Fomes€ annosus in pre-commercially thinned western € hemlock stands. DNR Report No. 33. € Washington Department of Natural Resources. € 15 p. €

Russell, K.W., W.G. Thies, D.L. Campbell, R.I. € Cara, and W.R. Littke. (1989). Effects of € slash burning on forest damage from animals, € insects, disease, and adverse environment. € IN: The burning decision: regional perspec-€ tive on slash/ Edited by D.P. Hanley, J.J. € Kammenga, and C.D. Oliver. College of€ Forest Resources, University of Washington, € Institute of Forest Resources Contribution € No. 66 p. 95-112 €

SAS Institute INC. SAS/STAT™ Guide for Personal € Computers, Version 6 Edition. Cary, NC: SAS € Institute INC, 1987. 1028 p. €

Schmitt, C.L. 1979. Detection and incidence of € Fomitopsis annosa in unthinned western hem-€ lock in Washington and Oregon. MFR, Profes-€ sional Paper, Univ. of Washington, College € of Forestry Resources, Seattle, WA. 45 p. €

Schroeder, H.A. and C.J. Kozlik. 1972. The € characterization of wetwood in western hem-€ lock. Wood Science and Technology. 6:85-94. €

Shea, K.R. 1960. Decay in logging scars in west-€ ern hemlock and Sitka spruce. Weyerhaeuser € Company Forestry Research Note No. 25. 6 p. €

Steinbrenner, E.C. and S.H. Duncan. 1969. Soil € Survey of the Clemons tree farm. € Weyerhaeuser Company, Tacoma, WA. €

Wallis, G.W. and D.J. Morrison. 1975. Root rot € and stem decay following commercial thinning € in western hemlock and guidelines for reduc-€ ing losses. For. Chronicles 51:1-5. €

Wallis, G.W. and G. Reynolds. 1970. Fomes an-€ nosus root and butt rot: a threat in managed € stands in coastal British Columbia. € Forestry Chronicle 46:221-224. €

Losses Caused by Annosus Root Disease in Pacific Northwest Forests[1]

Ellen Michaels Goheen Donald J. Goheen[2]

Abstract: Annosus root disease affects three tree species groups in the Pacific Northwest--the hemlocks, the pines, and the true firs. The disease causes significant decay and stem breakage in old growth western hemlock stands but little damage in young managed stands. Losses in ponderosa pine are minor over most of the region but can be substantial in selectively harvested stands on dry plant association types in southeastern Oregon. Annosus root disease is very damaging in white and grand fir stands east of the Cascades. The disease may limit management of these species in stands that have experienced more than one selective harvest entry.

In the Pacific Northwest, annosus root disease, caused by Heterobasidion annosum, results in losses in three tree species groups--the hemlocks, the pines, and the true firs.

HEMLOCKS

Western hemlock (Tsuga heterophylla (Raf.) Sarg.) in westside stands and mountain hemlock (T. mertensiana (Bong.) Carr.) in the high Cascades are commonly infected by Heterobasidion annosum. Mountain hemlock is currently not an important species for forest management in the Pacific Northwest, but western hemlock is very important and becoming more so. H. annosum-infected western hemlocks 150 years old or older suffer significant amounts of decay loss and considerable mortality due to stem breakage (Buckland and others 1949, Foster and others 1954). However, stands under 150 years old, though frequently highly infected, seldom suffer unacceptable losses (Goheen and others 1980). There is almost no mortality due to annosus root disease in young managed stands, decay loss is generally below 4 percent of the merchantable cubic foot volume, and there appears to be no growth loss associated with the disease.

PINES

Heterobasidion annosum is widespread in pine stands in eastern Oregon and Washington (Hadfield and others 1986). Lodgepole pine (Pinus contorta var. murrayana (Grey. and Balf.) Engelm. is commonly infected in central Oregon, but as yet there is little evidence of significant loss (Schmitt 1982). Routine pest surveys throughout the region commonly reveal the presence of H. annosum fruiting bodies in ponderosa pine (Pinus ponderosa Laws.) stumps. Significant ponderosa pine mortality, however, is not common over the range of the fungus. In the Pacific Northwest, it is apparently limited to localized sites that have certain site characteristics.

On the Bly and Lakeview Ranger Districts, Fremont National Forest, and the Lakeview District of the Bureau of Land Management (BLM), annosus root disease is very damaging in some ponderosa pine stands. In a pest evaluation of 700 acres of BLM land in this area, annosus root disease was found in 30 percent of all survey plots (40 BAF variable radius plots located on a 100 by 100 meter grid) within the pine-stocked portion of the unit (Goheen 1983). Six percent of the ponderosa pine greater than 6 inches in diameter at breast height (DBH) (containing 5 percent of the basal area) was dead due to annosus root disease. Another 7 percent of the pine over 6 inches DBH (containing 5 percent of the basal area) although still alive, had detectable infection by H. annosum. Trees of all size classes were affected. The disease had been active in the stand for some time and had greatly affected stocking in disease pockets. Overall pine stocking in disease pockets was reduced to 77 percent of that in healthy portions of the stand. Basal area reduction was even more dramatic. Disease pockets averaged only 44 percent as much square foot basal area as healthy areas. Western juniper, growing in the vicinity of infected ponderosa pine stumps, was also being severely affected by

[1] Presented at the Symposium on Research and Management of Annosus Root disease in Western North America, April 18-21, 1989, Monterey, California.

[2] Plant Pathologists, Forest Pest Management, Pacific Northwest Region, USDA Forest Service, Portland, Oregon 97208

annosus root disease. The area surveyed was an uneven-aged, multistoried ponderosa pine-western juniper stand interspersed with sagebrush flats, grassy creek swales, and lava beds. At least two past selective harvest entries had occurred on the site.

Surveys of two similar stands on the Bly Ranger District showed active annosus root disease in 25 and 21 percent of the plots (20 BAF variable radius plots on a 40 by 100 meter grid) on 50 and 30 acres respectively.[3] In the first stand, basal area was reduced 54 percent in plots with disease, and in the second stand, basal area was reduced 31 percent.

The Panelli Seed Orchard, also located on the Bly District, is experiencing significant losses due to annosus root disease. The plant association is ponderosa pine/juniper/ mountain-mahogany/bitterbrush/big sagebrush/ fescue (CP-C2-11), which is indicative of a dry site. Trees were planted in 1981 after stumps had been treated with borax. Stumps were cut flush with the ground in August 1982 and were not borax-treated. Seedling mortality was first noticed in 1984. By 1986, mortality, confirmed as annosus-caused, was scattered throughout the plantation. Twenty-six high-value orchard trees were dead due to annosus root disease in 1987. By 1988, an additional 48 trees had been killed.

Centers of mortality caused by annosus root disease in other southeast Oregon stands are also commonly associated with very dry sites. In an attempt to characterize the type of site where annosus root disease could become a management concern, fifty infection centers on the Bly District, Fremont National Forest, were visited by the Area Ecologist and Forest Pest Management pathologists (Hopkins and others 1988). Mortality was found to be centered around large old ponderosa pine stumps, normally in excess of 18 inches diameter inside bark (DIB). Ten- to thirty-year-old regeneration was most commonly killed, but mortality could involve trees of any size or age class located within 30 feet of infected stumps. Western juniper was frequently killed. Significant mortality apparently did not develop for 10 to 15 years following logging. It was observed mostly around 15- to 30-year-old stumps. Distance from stumps to dying trees appeared consistent with a spread rate of approximately 1 foot per year.

Most of the diseased tree sites evaluated had a high degree of disturbance. All had had multiple harvest entries and had been grazed for many seasons by livestock. Many had displaced or compacted soils. Most of these sites are on or close to the forest/non-forest interface. The most common plant association type was ponderosa pine/wooly wyethia (CP-F1-11) transitional to ponderosa pine/serviceberry/Wheeler's bluegrass, and upslope ponderosa pine-white fir/snowberry/ starwort (CW-S3-13) (Hopkins 1979). Other less frequently encountered associations were ponderosa pine/bitterbrush/fescue (CP-S2-11) and ponderosa pine/bitterbrush/needle-grass (CP-S2-12). Abundant shrub/herb cover created a very competitive environment for tree establishment and growth on most diseased sites. The average collective shrub canopy cover was 32 percent (range from 2-95 percent), and the average collective herb cover was 49 percent (range was 21-80 percent). Shrubs in decreasing order of importance were squaw carpet, serviceberry, chokecherry, manzanita, Oregon grape, currant, and rose. Herbs were wooly wyethia, mountain brome, Ross' sedge, squirreltail, lupine, yarrow, ragwort, strawberry, and occasionally fescue, needlegrass, and Wheeler's bluegrass.

Prevalence of annosus-caused mortality on very dry sites near the forest edge has also been observed on the Ochoco National Forest, particularly on the Paulina District at the eastern boundary of the forest. While these sites have not been as closely scrutinized as those on the Fremont National Forest, it is believed that site characteristics are similar.

With the exception of the Panelli Seed Orchard, the sites described above have all been managed under a selective harvest system. As more and more clearcuts planted to pine are prescribed for this area, there is great concern over the role _H. annosum_ may play in these stands, particularly since many of the stumps apparently contributing inoculum that caused tree infection at Panelli Seed Orchard were smaller than the 18--inch DIB rule of thumb that seems to apply in selectively harvested stands. A survey of a 10-year-old ponderosa pine plantation created after a clearcut in the northern portion of the Bly District revealed that 57 percent of 112 ponderosa pine stumps examined were _H. annosum_-infected based on the presence of fruiting bodies.[4] Eight percent of the 248 plantation trees examined were infected. The plantation is located on a dry site on pumice soils. A similar survey of a 20-year-old plantation on a moister site revealed that although 48 percent of the stumps were

---

[3]Data on file, Forest Pest Management, Pacific Northwest Region, USDA Forest Service, Portland, Oregon 97208.

[4]Data on file, Forest Pest Management, Pacific Northwest Region, USDA Forest Service, Portland, Oregon 97208.

infected, annosus root disease had caused no mortality in the plantation. Other moist sites with younger plantations that have been stump-surveyed show similar levels of stump infection, but so far no annosus-caused mortality of the young trees.

In selectively managed stands, we believe that we now know which site characteristics and stand conditions contribute to a high risk of annosus-caused tree mortality. We speculate that _H. annosum_ kills trees that are under stress on dry sites and that more vigorous trees on moister sites, while frequently exposed to infection, either do not become infected or tolerate infection. In pine plantations created after clearcutting, however, we do not yet know the relationships between annosus mortality and site and stand characteristics. Inoculum levels are high, trees are planted close to stumps, and planted trees may be more susceptible to _H. annosum_ than naturally seeded trees. Further investigations are planned.

TRUE FIRS

Heterobasidion annosum already may be the most damaging pathogen of true firs east of the Cascade Mountains in the Pacific Northwest, and losses due to annosus root disease appear to be steadily increasing. Significant amounts of white fir (_Abies concolor_ (cord. and Glend.) Lindl.) and grand fir (_Abies grandis_ (Dougl.) Lindl.) mortality attributable to annosus root disease began to be noted in the late 1970's. Subsequently, the more we have looked for it, the more annosus root disease we have found on the true firs (Filip and Goheen 1982, Filip and Goheen 1984). It appears that the management approach of repeated selective harvests used in many of the mixed conifer stands has greatly favored the disease.

Forest Pest Management has done detailed evaluations of annosus root disease-caused losses on several eastside National Forests and has also examined the relationship between number of past selective harvest entries and disease severity (Schmitt and others 1984). Surveys have been completed on the Fremont National Forest in southern Oregon and the Ochoco National Forest in central Oregon. Results of intensive stand examinations of 98 randomly selected stands with white or grand fir components on each Forest showed the following percentages with annosus root disease affecting the fir:

Type of Stand	Percent	
	Ochoco	Fremont
Unentered Stands	0	12
Entered Once	50	40
Multiple Entries	33	100

These results show that incidence of annosus root disease is very high in entered stands on both Forests. The average percentage of the true firs infected and killed by _H. annosum_ in the three stand types were as follows:

Type of Stand	Average Percentage	
	Ochoco	Fremont
Unentered Stands	0	0.04
Entered Once	0.5	1.7
Multiple Entries	2.9	20.8

Thus, much more infection and associated mortality occurs in entered stands than unentered stands, and by far the greatest incidence of infection was found in stands that had experienced more than one entry. Within the multiple-entry stand class, stands in which the longest times had elapsed since the initial harvest exhibited the greatest amount of annosus root disease-caused mortality. For example, 69 percent of all white fir were dead due to the disease in a stand on the Lakeview Ranger District, Fremont National Forest, that was first logged in 1938.

The greater amount of annosus root disease in stands with multiple stand entries (and therefore, the largest numbers of stumps, and, in most cases, the oldest stumps) undoubtedly reflects efficient use of stumps as infection courts by _H. annosum_. Mortality caused by annosus root disease almost always occurs in firs within 20 to 40 feet of old, infected true fir stumps, and virtually all stumps that serve as infection foci are 18 inches or greater in diameter. Distances from stumps to current mortality indicate a radial spread rate across root systems of between 1 and 2 feet per year. Firs of all size classes are killed and disease centers become unstocked pockets within the stands unless other tree species are present. We have seen no evidence of disease cross-over from true firs to any other tree species.

Differences between the Ochoco and Fremont National Forests in amount of annosus root disease-caused mortality were probably due to the different harvesting histories of the two Forests. Widespread cutting of large white firs began considerably earlier on the Fremont than on other Forests in the Region.

White and grand firs are fast growers, release well, and are prolific seeders that establish themselves naturally on all but the coldest and driest sites. They are shade-tolerant, fire-intolerant species that have increased greatly on all eastside forests in the last 80 years due to fire exclusion and the preferential removal of pines, western larch, and Douglas-fir during selective harvest operations. Currently, there is a controversy concerning the best future management approach for mixed Eastside stands with major fir components in the Pacific Northwest. Some forest managers are reluctant to incur the costs associated with regeneration harvests and reestablishment of shade-intolerant tree species when naturally established true fir understories already exist. They advocate uneven-age management schemes involving continued selective removal of overstory trees and release of fir understories. There is also considerable agitation for use of uneven-age systems by public groups that oppose regeneration harvesting, especially clearcutting. On the other hand, many silviculturists believe that continued selective harvesting in mixed types is unacceptable due to the numerous existing and potential pest problems that affect the true firs. Annosus root disease may ultimately figure as a deciding factor in this debate.

REFERENCES

Buckland, D.C.; Foster, R.E.; Norden, N.J. 1949. Studies in forest pathology VII. Decay in western hemlock and fir in the Franklin River area, British Columbia. Canadian Journal of Research 27:312-331.

Filip, G.M.; Goheen, D.J. 1982. Tree mortality caused by root pathogen complex in Deschutes National Forest, Oregon. Plant Disease Reporter. 66:240-243.

Filip, G.M.; Goheen, D.J. 1984. Root diseases cause severe mortality in white and grand fir stands in the Pacific Northwest. Forest Science. 30:134-142.

Foster, R.E.; Craig, H.M.; Wallis, G.W. 1954. Studies in forest pathology XII. Decay of western hemlock in the Upper Columbia Region, British Columbia. Canadian Journal of Botany. 29:479-521.

Goheen; D.J. 1983. Forest pest survey of the proposed Bear Valley Timber Sale, Lakeview District, Bureau of Land Management. Unpublished Biological Evaluation. Forest Pest Management, Pacific Northwest Region, USDA Forest Service.

Goheen, D.J.; Filip, G.M.; Schmitt, C.L.; Gregg, T.F. 1980. Losses from decay in 40-to 120-year-old Oregon and Washington western hemlock stands. USDA Forest Service, Pacific Northwest Region. R6-FPM-045-1980. 19 p.

Hadfield, J.S.; Goheen, D.J.; Filip, G.M.; Schmitt, C.L.; Harvey, R.D. 1986. Root diseases in Oregon and Washington conifers. USDA Forest Service, Pacific Northwest Region. R6-FPM-250-86. 27 p.

Hopkins, W.E. 1979. Plant associations of the Fremont National Forest. USDA Forest Service, Pacific Northwest Region. R6-Ecol-79-004. 106 p.

Hopkins, W.E.; Goheen, D.J.; Goheen, E. Michaels; Forry, K. 1988. Evaluation of annosus root disease on ponderosa pine in the Fremont National Forest and Lakeview District, Bureau of Land Management. USDA Forest Service, Pacific Northwest Region. R6-88-04. 6 p.

Schmitt, C.L. 1982. Incidence of annosus root rot in central Oregon lodgepole pine plantations. Unpublished Impact Evaluation. Forest Pest Management, Pacific Northwest Region, USDA Forest Service.

Schmitt, C.L., Goheen, D.J.; Goheen, E. Michaels; Frankel, S.J. 1984. Effects of management activities and dominant species type on pest-caused mortality losses in true fir on the Fremont and Ochoco National Forests. Unpublished Impact Evaluation. Forest Pest Management, Pacific Northwest Region, USDA Forest Service.

Annosus Root Disease in True Firs in Northern and Central California National Forests[1]

G. W. Slaughter J. R. Parmeter, Jr.[2]

Abstract: True fir stands in California (3.5 million acres) were surveyed during 1979-1980 to estimate the prevalence of infection by Heterobasidion annosum, and to determine stand and tree characteristics associated with the occurrence of annosus root disease. Approximately 4 percent (1.46 billion board-feet) of the live true firs were estimated to be infected by H. annosum; dead firs associated with the fungus were estimated to be 25 percent (68 million board-feet) of the total dead firs during a 1.5-year period. Annosus root disease was estimated to infest 18 percent of the surveyed area (632,000 acres), indicating a high prevalence in fir stands. The fungus occurred most often in pure fir stands, red fir stands, in stands where the basal area of live true fir exceeded 20 m^2 per hectare, and in stands having patterns of chronic mortality. Larger, older trees, near stumps, had high rates of infection.

Annosus root disease, caused by Heterobasidion annosum (Fr.) Bref. (Fomes annosus [Fr.] Karst.), causes root decay and mortality in conifers throughout California (Bega and Smith 1966). In red fir (Abies magnifica A. Murr.) and white fir (Abies concolor [Gord. & Clend.] Lindl.), root decay often leads to bark beetle attack (Cobb and others 1974) or to windthrow (Smith 1978). Forest productivity can be seriously reduced by such losses.

The presence of annosus root disease in California forests has been known for decades, but an objective estimate of its prevalence is lacking. Statewide estimates of the prevalence of annosus root disease in true fir forests, the amount of tree mortality associated with infection by the fungus, and the stand and tree characteristics related to its occurrence should be useful for the evaluation of the impact of this root pathogen upon forest productivity.

In the past, root disease surveys generally focused on sites of tree mortality, rather than on entire forests. Surveys incorporating aerial photography (Hanson and Lautz 1971, Johnson and Wear 1975, Williams and Leaphart 1978, Byler and others 1979, James and others 1984) detected standing dead trees and stand openings suggestive of mortality centers. Surveys of states and regions have often incorporated data from several sources collected by different methods and with various levels of precision (Smith 1984). Ground surveys generally have involved transects through forest stands (Bloomberg and others 1980, Filip and Goheen 1984), studies of tree mortality in plantations (Hadfield 1970, Filip 1979), or scouting surveys near roads (Bega and others 1966). Hamilton (1984) discussed the need to sample both live trees and dead trees to estimate mortality rates.

The survey reported here had two objectives: to estimate the prevalence (the proportion of trees infected out of the population of both live and dead trees, at a given time) of annosus root disease in true firs on the National Forests of northern California, and to describe stand, site, and tree characteristics associated with the occurrence of annosus root disease in stands with true firs. Estimates were, therefore, necessary both for stands having evidence of root disease and also for apparently healthy stands showing no tree mortality on aerial photographs.

The methods discussed below are a compromise among the needs to survey the forest as a whole, without reference to tree mortality, to sample a sufficient number of recently dead fir trees to allow a useful count of fir mortality, and to provide sufficient opportunities to collect data at locations where annosus root disease occurs.

METHODS

Plot Selection

The Forest Pest Management staff of the U.S. Department of Agriculture, Forest Service, Region 5, conducted surveys in California during

[1] Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2] Staff Research Associate IV and Professor, respectively, Department of Plant Pathology, University of California, Berkeley, California.

1977-1979 to evaluate conifer mortality on National Forests following a major drought. Plots (each approximately 284 acres) were selected from each of five forest types: mixed conifer, red fir, ponderosa pine, eastside pine, and Douglas-fir (Smith and others 1983). This process provided 168 plots in the 12 National Forests of northern and central California (Mendocino, Six Rivers, Klamath, Shasta-Trinity, Modoc, Lassen, Plumas, Tahoe, El Dorado, Stanislaus, Sierra, and Sequoia). These plots were at least 50 percent under Forest Service control and were capable of producing commercial yields of timber and wood products on at least 50 percent of this area. The studies reported here were based on these plots. The four National Forests in southern California were omitted from this survey, since only negligible numbers of true firs are harvested there.

Normal-color, aerial photographic transparencies (high-speed Kodak Ektachrome S0-397; approximately 1:10,000 scale) were taken of each of the 168 plots in June 1979. Boundaries delineating a one-square-kilometer plot (247 acres) were drawn on the aerial photo best showing the plot. The photos were inspected stereoscopically for true firs by using characteristics similar to those discussed by Croft and others (1982) to identify tree species. Stands were designated (by photo delineation) mixed fir (10-80 percent true firs) or pure fir (more than 80 percent true firs).

For our survey, only plots with at least 20 hectares of contiguous mixed fir or pure fir stands or both within the square kilometer were considered for further study. Ninety plots had sufficient true fir to qualify, but five plots were omitted because they were in wilderness areas or other preserved areas where no timber management is contemplated. The remaining 85 plots provided the base sample universe.

Photo Interpretation and Cell Selection

The aerial photographs of each plot were interpreted for recently dead true fir trees, using methods developed for sequential imagery by Wear (1960) and Caylor and Thorley (1970). Recently dead firs (firs that were green on 1977 photos and discolored [faded] on 1979 photos) were circled, numbered, and the number of dead trees at that location (spot) were recorded.

Two separate samples from the 85-plot base were selected for ground checking, one representing all fir stands (green plots) and one representing fir stands with photo-detectable, recent fir mortality (mortality plots). The following selections were made with probability-proportional-to-size (PPS), with replacement (Cochran 1963). a. Green plots: forty green plots were selected PPS of the area within each plot supporting true fir stands (mixed + pure); several plots were picked more than once. A grid of potential cells (each representing 625 m^2 = 1/16 hectare) was overlaid upon that portion of the plot containing fir stands. Ten square cells were selected within the delineated fir stand boundaries on each of the 40 green plots. Plots and cells were randomly selected by using a PISYS desk-top calculator/plotter (DeMars 1980). PISYS produces transparent overlays that fit directly on the aerial photographs and that show the exact location of each cell. b. Tree mortality plots: thirty tree mortality plots were selected with PPS of the number of recently dead fir trees detected within the delineated fir-type boundaries on the plots. This number varied considerably, so some plots were selected several times, while some had no probability of selection (no tree mortality on the plot). Ten tree mortality spots were chosen with PPS of the number of dead trees per spot on each of the selected tree mortality plots. When less than 10 tree mortality spots occurred on a plot, all spots were visited.

Data Collection on Cells

Both green and tree mortality cells were located on the ground by examining photographs with a field stereo viewer (sun-illuminated), then walking to the correct location by using the photos as a map. A square 1/16 hectare cell (25 m by 25 m) was established at each green cell location or tree mortality spot; boundaries were marked with string. After a green cell was located, additional data were collected if at least one live cuttable fir (10-54 cm diameter at breast height [dbh]) was present. Forest Service policy did not permit the cutting of any green trees with a dbh larger than 54 cm. If there were no cuttable fir trees, the cell was recorded as zero. A tree mortality cell was acceptable if the dead tree(s) were true fir, had died within 2 years of the ground check, and were dbh 10 cm or larger. Although a tree mortality cell did not require the presence of a cuttable live fir tree, in all but two cells there was at least one cuttable live fir tree. Tree mortality cell locations were adjusted slightly on the ground so that recent tree mortality occurred in the center of the cell.

One live true fir tree on each cell was sampled by selecting at random a tree of cuttable size from all cuttable fir trees within the cell boundaries. Recently dead firs were also sampled at random. Standard sampling procedure for both green and dead trees involved felling trees with a chain saw, making a single horizontal cut across the stump top approximately 30 cm above ground, then cutting a full disk (1-2 cm thick) from the stump. The only exception to this procedure was for dead trees larger than 54 cm dbh. For these, a portion of a disk (approximately 1/4 pie-cut-shaped) was cut from the base of the standing tree. The disk (or portion) was sealed in a polyethylene bag containing a moist paper towel for 7 days, then inspected with a

Figure 1--"Laminated" decay in true fir stump, typical of annosus root disease. If such a stump occurred on a survey cell, the cell would be rated FA3, to indicate highly probable but not positively confirmed annosus root disease.

dissecting microscope (60X) for the conidial state of H. annosum. A positive reading required that the same colony appear on both sides of the disk or portion.

Data describing stand and site characteristics within cell boundaries were collected from the aerial photos or maps (geographic region in California, forest type, and stand species composition), and in the field (annosus root disease condition [fig. 1], basal area, tree mortality center pattern, slope, aspect, brush history, site potential, other tree species dying). Individual tree characteristics recorded to describe those live and dead trees felled for sampling included annosus root disease rating (+ or -, based on inspection of the cultured disk sample), species, total age, dbh, total height, crown class, crown ratio, radial growth, terminal growth, stumps within five meters, woodpecker injury, wetwood, insects, symptoms or signs of other diseases, and basal scars.

Estimation and Analysis

Relationships of annosus root disease presence to the above stand, site, and tree characteristics were evaluated by chi-square analysis. The prevalence of annosus root disease in true fir trees over the entire study area was estimated for northern and central California U.S. Department of Agriculture Forest Service land by expanding data collected during this survey. The general form of the estimation equation for numbers and volumes of live or dead fir trees with annosus root disease was derived from Cochran (1963), and is given in Smith and others (1983). The green and tree mortality plot survey data yielded two different kinds of estimates for the same variable: a green plot estimate and a mortality estimate. The green plot survey is considered to give a more accurate and useful estimation of losses, and it is the source for the following disease prevalence estimates because it:

a. accounts for tree mortality that is not detected on aerial photos (omission errors);
b. indicates the circumstances under which damage or tree mortality is rare or absent; c. indicates the distribution of disease as well as the distribution of tree mortality.

The tree mortality plot survey provided vital additional data (regarding dead fir trees) which was necessary for the chi-square analyses.

RESULTS AND DISCUSSION

During the survey, 47 square-kilometer plots were ground-checked. On these plots, 473 ground-sample cells were visited: 320 green cells and 153 tree mortality cells. A total of 694 true firs (449 live, 245 dead) was sampled on these cells.

Estimation of Annosus Root Disease Prevalence

Estimates of disease prevalence and associated losses are listed in tables 1 and 2. These estimates from the green plot survey apply to commercial forest land in the 12 National Forests of northern and central California. Numbers reported in the text are rounded to the nearest thousand.

Fir tree mortality associated with annosus root disease and occurring between fall 1977 and summer 1979 (table 1) was estimated to be 634,000 trees (25 percent of the total dead fir trees), having a volume of 319,000 m^3 (68 million board-feet). These estimates must be modified somewhat (as discussed below) to allow comparison with available (annual) statistics for California.

Most infected firs were attacked by the fir engraver beetle, Scolytus ventralis LeConte, which generally has a single, summer flight

Table 1--Numbers and timber volumes of two sizes of dead and annosus root diseased true fir trees estimated by green plot survey in National Forests in northern and central California

Tree status and size		Study period[1]				Annual losses[2]	
Status	Size(dbh)	No. trees	Std. Error	Volume[3]	Std. Error	No. trees	Volume[3]
Dead	> 9 cm	2,486,273	662,342	2,910,003	1,422,184	1,657,515	1,940,002
Diseased	> 9 cm	633,756	213,927	318,886	199,646	422,504	212,591
Dead	> 30 cm	780,007	259,377	2,653,238	1,428,346	520,005	1,768,825
Diseased	> 30 cm	97,501	68,054	213,971	196,386	65,001	142,647

[1] Study period was from late fall 1977 to spring 1979 or approximately 1.5 years.

[2] Study period loss estimates divided by 1.5 years, to give approximate annual losses.

[3] Individual tree volumes in cubic meters, derived from Wensel (1977), tables A.4, A.5. To convert cubic meters to board-feet, multiply by 211.9.

period in the survey area (Struble 1937). Trees attacked early in the 1977 season could have faded before fall 1977 photos were taken, and thus would not have been counted as part of this survey. Trees attacked late in the 1978 season might not have faded by the photo date in June 1979. Checking the 1979 survey photos against those from 1977 provided a discrete set of firs--those that died and faded during November and December 1977, all of 1978, and the winter or early spring of 1979. Since the percentages of trees fading during the seasons following attack are unknown, the estimate represents between 1 and 2 years of tree mortality. If figures in table 1 are considered to represent about 1.5 years, estimated annual losses become 1,658,000 dead fir trees, including 423,000 dead fir trees (volume 213,000 m^3) with annosus root disease. The estimates for trees over 30 cm dbh give some indication of annual losses of merchantable timber associated with annosus root disease: 13 percent of the dead trees (65,000/520,000) and 8 percent of the volume (143,000/1,769,000 m^3). We believe these percentages to be low, because the green plot survey was not designed to detect fir tree mortality specifically, but only incidentally.

The magnitude of these numbers is emphasized by comparison with the average annual harvest of true fir trees from Forest Service lands in California: approximately 4.7 million m^3 (one billion board-feet). Net annual growth of true fir growing stock on the National Forests in California was 4.1 million m^3 (876 million board-feet) for the year 1975 (Bolsinger 1980). By admittedly low green plot estimates, volume losses associated with annosus root disease were equal to about 4.5 percent of the annual cut and about 5.2 percent of the annual growth. This loss is similar to that estimated by Filip and Goheen (1984) for three root rots of fir (6 percent of annual growth) in Oregon and Washington. The annual fir tree mortality rate (total annual dead firs from table 1, divided by total live fir trees >9 cm dbh in table 2) would be 0.46 percent; for dead fir trees with annosus root disease the mortality rate would be 0.12 percent. Hamilton (1984) lists average annual tree mortality rates ranging from 0.289 percent for grand fir to 1.610 percent for western white pine in a mixed conifer forest.

Approximately 12.3 million live true fir trees were estimated to be infected with annosus root disease (3.8 percent of total, table 2). The estimated total volume of these trees was 6.9 million m^3 (1.46 billion board-feet), or nearly 150 percent of the annual harvest of true fir in California. We do not know the rate at which these infected live trees will die, how many will survive until harvest, or the extent of the yield reduction.

Problems with the Expression of Root Disease Prevalence

The total area of Forest Service lands in the study area supporting 10 percent or more true fir was estimated to be 1,427,000 hectares (3,527,000 acres). If each cell with annosus root disease is considered an infested 1/16 ha, then 18 percent (256,000 hectares; 632,000 acres) of the study area was infested.

Table 2--Numbers and volumes of live true fir trees and amount of annosus root disease infection estimated by green plot survey in National Forests in northern and central California.

Tree classes according to dbh (cm)	No. of trees	Std. Error	Volume[1]	Std. Error
Total true fir trees				
9<dbh<55	326,286,762	30,138,168	NA[2]	NA[2]
dbh>9	357,389,549	32,008,118	NA[2]	NA[2]
Diseased				
9<dbh<55	12,333,863	4,833,539	6,895,367	2,593,732

[1] Individual tree volumes in cubic meters, derived from Wensel (1977), tables A.4, A.5. To convert cubic meters to board-feet, multiply by 211.9.

[2] Not applicable - live trees were counted on each cell, but only felled live trees were measured: an insufficient sample to calculate total live true fir tree volumes.

Standardized methods to describe root disease prevalence are not available. With bark beetles, as little as 0.5 dead or dying tree per acre of timber type (1.2 trees/hectare) has been considered to be an infestation (Ciesla and Yasinski 1980). We found 0.2 dead trees per acre (0.5 trees/hectare) and 3.5 live trees per acre (8.5 trees/hectare) infected with annosus root disease. A combination of these two gives almost 4 infected trees per acre (9 trees/hectare). Thus, by the standards of Ciesla and Yasinski (1980), we could estimate that the entire survey area is one large annosus root disease infestation of about 3.5 million acres (1.4 million hectares). Viewed another way, if each 1/6-acre cell (1/16 hectare) in which annosus root disease was discovered represents a 1/6-acre infestation, there are 632,500 acres (256,000 hectares) of fir stands affected by the disease; or, if one of each six 1/6-acre cells has annosus root disease, then every acre is infested. Given this wide variation in possible infestation area estimates, we believe none of these statistics adequately describes the prevalence of annosus root disease.

Stand, Site, and Tree Factors

Chi-square analyses of data from all 473 cells (320 green and 153 tree mortality cells) were made to determine possible relationships between stand, site, or tree factors and the occurrence of annosus root disease. For all but one of the relationships listed below, the probability of the null hypothesis (no relationship) being true is $\underline{P}<0.01$.

Annosus root disease occurred more often than would be expected by chance in the following circumstances:

a. On cells with stumps, and in trees within 5 m of stumps
b. In red fir stands
c. In stands with > 80 percent fir
d. In stands where the basal area of live fir exceeded 20 m^2/hectare (87 ft^2/acre) and where the basal area for all live species exceeded 35-40 m^2 /hectare (150-175 ft^2/acre) ($\underline{P}$ < 0.05)
e. In firs older than 120 years
f. In firs larger than 30 cm dbh and 16 m tall
g. In codominant and intermediate firs
h. In the dry northeast region
i. In stands having centers with patterns of chronic mortality
j. In firs showing decreased terminal growth but increased radial growth for the last 20 years
k. In trees with wetwood at stump height.

Annosus root disease occurred less often than expected in stands where brush was, or had been present (live and/or dead brush).

There were either no significant relationships, or insufficient data, to analyze site potential, mortality of other species, dwarf mistletoe infestation and other diseases, crown ratio, or basal scars. Over 90 percent of all dead firs, in the same proportion whether infected with annosus root disease or not, were associated with damage caused by bark beetles and woodpeckers.

A few additional comments regarding these relationships:

Stumps

This is the single most important factor associated with annosus root disease in fir stands. The presence of stumps means a high likelihood of annosus root disease.

Age/Size

The chances of a stand or tree being infected with annosus root disease are cumulative over time; thus, younger trees have had less time to become infected, and smaller trees have a correspondingly smaller root system with less chance to become infected through root contact. Old-growth stands of true fir in California have generally been found to be heavily infested with annosus root disease. As these stands are converted to young growth through more intensive forest management, the importance of this size and age information may decrease from the timber management perspective, but it may increase from the management perspective for parks and preserved stands.

Tree Growth

Mean radial growth for firs with annosus root disease was 2.18 mm/year, while that for disease-free firs averaged 1.55 mm/year (significantly different $\underline{P} < 0.001$). It was thought that annosus root disease incidence would be associated with a decreasing growth rate in the individual tree (Ferrell and Smith 1976). This was confirmed by the terminal growth data but contradicted by the radial data. The tendency for increasing radial growth rates over the last 20 years to be associated with _H_. _annosum_-infected trees is probably related to the fact that some trees are dying in annosus root disease centers, allowing more growing space for the remaining live firs. These are able to put on additional radial growth, utilizing the increased growing space, but are also more likely to be infected with _H_. _annosum_, because they are growing near infected trees. Studies have shown that radial growth often responds faster to thinning or release cutting than terminal height growth (Oliver 1979; Scharpf 1979). An increased rate of radial growth in root disease centers has been recorded previously (Chavez and others 1980). An increase in vigor of uninfected trees (as measured by annual basal area increment per unit of sapwood area) in a root-diseased stand where nearby trees were dying from root rot was noted by Oren and others (1985).

Brush

The presence of brush on a site now occupied by true fir usually indicates open and sunny stand conditions that allowed brush establishment sometime in the last 25 to 75 years. These conditions are normally related to some catastrophe that removes most or all of the trees from the site (fire, windstorm, logging, etc.). Presumably, during the period of brush cover, remnants of root systems from previous stands would have decayed and inoculum of _H_. _annosum_ in the soil would have declined to the point where infection of new trees by contact with old roots would be unlikely.

Wetwood

This relationship is consistent with the hypothesis that wetwood is a host response of the tree to the occurrence of _H_. _annosum_ in heartwood (Worrall and Parmeter 1982).

FUTURE RESEARCH

The estimates of true fir losses and chi-square relationships suggest the need for additional research to develop management guidelines to reduce the impacts of annosus root disease.

1. We have presented loss estimates, but these must be converted to impact estimates to be most useful to forest managers. Methods to accomplish this are unavailable at present; these might include consideration of the size of diseased trees in relation to stand stocking levels, contribution of trees to future stand growth and yield, salvageability, utilization standards, and the timing of future stand entries.
2. The prediction of future impacts under various stand conditions and manipulations requires data on rates at which key disease processes proceed. These include the rates at which new annosus root disease centers are established, rates at which those disease centers enlarge, and the length of time that trees survive after becoming infected.
3. A thorough evaluation of thinning in fir stands is needed because many fir stands are overstocked and thinning is increasingly being done, and because reduced basal area is associated with reduced annosus root disease. On the other hand, stumps are associated with increased annosus root disease. Thinning may be setting the stage for extensive losses in "leave" trees.

ACKNOWLEDGMENTS

This study was funded in part by U.S. Department of Agriculture Forest Service (FS) and by Western Regional Research Project 110. The authors wish to thank Jim Byler (FS), Region 1, for help in establishing the need for such a survey and obtaining the necessary funding. Nancy Norick and Will Hoskins (FS), and Ken Lindahl, University of California, Berkeley (UCB), provided assistance with survey design and data analysis. C. J. DeMars (FS), Pacific

Southwest Forest and Range Experiment Station, Berkeley, provided the vital PISYS. We thank Jule Caylor and Walt Salazar (FS), formerly Region 5, Forest Pest Management, for the acquisition of the aerial photography. Many thanks to Mark Schultz (UCB), for stalwart assistance with field work, data analysis, and manuscript reviews. Ken Lindahl and Fields Cobb (UCB), and Gregg DeNitto (FS), Forest Pest Management, Region 5, provided very helpful manuscript reviews.

REFERENCES

Bega, R. V.; Dotta, D.; Miller, D. R.; Smith, R. S., Jr. 1966. Root disease survey at Boggs Mountain State Forest, California. Plant Disease Reporter 50: 439-440.

Bega, R. V.; Smith, R. S., Jr. 1966. Distribution of Fomes annosus in natural forests of California. Plant Disease Reporter 50:832-36.

Bloomberg, W. J.; Cumberbirch, P. M.; Wallis, G. W. 1980. A ground survey method for estimating loss caused by Phellinus weirii root rot. II. Survey procedures and data analysis. BC-R-4. Victoria, B.C.: Canadian Forestry Service Pacific Forest Research Centre, October, 1980; 44 p.

Bolsinger, C. L. 1980. California forests: trends, problems, and opportunities. Resource Bulletin PNW-89. Portland, OR: U.S. Department of Agriculture Forest Service; Pacific Northwest Region 6; 138 p.

Byler, J. W.; Cobb, F. W., Jr.; Rowney, D. L. 1979. An evaluation of black stain root disease on the Georgetown Divide, El Dorado County. Report No. 79-2. San Francisco, CA: U.S. Department of Agriculture Forest Service, Pacific Southwest Region 5, Forest Insect and Disease Management; 15 p.

Caylor, J. A.; Thorley, C. A. 1970. Sequential aerial photography as an aid in the evaluation of bark beetle population trends in westside Sierra forests. In: Studies on the population dynamics of the western pine beetle Dendroctonus brevicomis LeConte (Coleoptera: Scolytidae), part I, section 3. Berkeley, CA: University of California, Division of Agricultural Sciences; p. 8-32.

Chavez, T. D., Jr.; Edmonds, R. L.; Driver, C. H. 1980. Young-growth western hemlock stand infection by Heterobasidion annosum 11 years after precommercial thinning. Canadian Journal of Forest Research 10: 389-394.

Ciesla, W. M.; Yasinski, F. M. 1980. Forest Insect and Disease Information System (FIDIS) implementation plan. Report No. 80-3. Davis, CA: U.S. Department of Agriculture, Forest Service, Methods Application Group, Forest Insect and Disease Management; 6 p.

Cobb, F. W., Jr.; Parmeter, J. R., Jr.; Wood, D. L.; Stark, R. W. 1974. Root pathogens as agents predisposing ponderosa pine and white fir to bark beetles. In: Proceedings, 4th International. Conference on Fomes annosus, IUFRO, Athens, GA, September, 1973; 8-15.

Cochran, W. G. 1963. Sampling techniques. 2nd ed. New York: J. Wiley & Sons; 413 p.

Croft, F. C.; Heller, R. C.; Hamilton, D. A., Jr. 1982. How to interpret tree mortality on large-scale color aerial photographs. Gen. Tech. Rep. TNT-124. Ogden, UT: U.S. Department of Agriculture Forest Service; 13 P.

DeMars, C. J. 1980. Managing tree mortality location data with a desk-top minicomputer. In: Heller, R. C.; Ulliman, J. J.; Hall, W. B., eds. Remote sensing of natural resources; Proceedings of a Symposium; 1979, 10-15 September; Moscow, ID. University of Idaho Press; 69-77.

Ferrell, G. T.; Smith, R. S, Jr. 1976. Indicators of Fomes annosus root decay and bark beetle susceptibility in sapling white fir. Forest Science 22(3): 365-369.

Filip, G. M. 1979. Root disease in Douglas-fir plantations is associated with infected stumps. Plant Disease Reporter 63:580-583.

Filip, G. M.; Goheen, D. J. 1984. Root diseases cause severe mortality in white and grand fir stands of the Pacific Northwest. Forest Science 30(1): 138-142.

Hadfield, J. S. 1970. Color infrared photography effectively detects pines killed by Fomes annosus. In: Hodges, C.S. and others, eds. Proceedings, Third International Conference of Fomes annosus; 1968 July 29-August 3; Aarhus, Denmark. U.S. Department of Agriculture, Forest Service Washington, D.C.; 37-42.

Hamilton, D. A., Jr. 1984. Sampling and estimation of conifer mortality using large-scale color aerial photography. Forest Science 30(2): 333.342.

Hanson, J. B.; Lautz, W. 1971. Photography as an aid in estimating annosus root rot-caused tree mortality. Plant Disease Reporter 55(9): 761-763.

James, R. L.; Stewart, C. A.; Williams, R. E. 1984. Estimating root disease losses in northern Rocky Mountain national forests. Canadian Journal of Forest Research 14: 652-655.

Johnson, D. W.; Wear, J. F. 1975. Detection of Poria weirii root rot centers in the Pacific Northwest with aerial photography. Plant Disease Reporter 59: 77-81.

Oliver, W. W. 1979. Fifteen-year growth patterns after thinning a ponderosa-Jeffrey pine plantation in northeastern California. Research Paper PSW-141. San Francisco, CA: U.S. Department of Agriculture, Forest Service; 10 p.

Oren, R.; Thies, W. G.; Waring, R. H. 1985. Tree vigor and stand growth of Douglas-fir as influenced by laminated root rot. Canadian Journal of Forest Research 15: 985-988.

Scharpf, R. F. 1979. Dwarf mistletoe-infected red fir: growth after release. Research Paper PSW-143. San Francisco, CA: U.S.

Department of Agriculture, Forest Service, Pacific Southwest Region 5; 9 p.

Smith, R. S., Jr. 1978. Root diseases. In: Bega, R. V., tech. coord.; Diseases of Pacific coast conifers. U.S. Department of Agriculture Forest Service Handbook No. 521; Berkeley, CA: Pacific Southwest Forest & Range Experiment Station; 142-156.

Smith, R. S., Jr. 1984. Root disease-caused losses in the commercial coniferous forests of the western United States. Report No. 84-5. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Pest Management, Methods Application Group; 21 p.

Smith, R. S., Jr.; Byler, J.; Wood, R. E.; Caylor, J.; Hoskins, W.; Scharpnack, N. 1983. Pest damage inventory: A method for measuring pest-caused tree mortality in California. In: Forest Insect and Disease Survey Methods Manual. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Methods Application Group, Forest Pest Management; Section 3.3.1; 15 p.

Struble, G. R. 1937. The fir engraver beetle, a serious enemy of white fir and red fir. Circular No. 419. Washington, DC: U.S. Department of Agriculture; 16 p.

Wear, J. F. 1960. Interpretation methods and field use of aerial color photos. Photogrammetric Engineering 26(5): 805-808.

Wensel, L. C. 1977. Volume tables for young-growth conifers in the northern regions of California. Bull. 1883. Berkeley, CA: Division of Agricultural Sciences, University of California; 43 p.

Williams, R. E.; Leaphart, C. D. 1978. A system using aerial photography to estimate area of root disease centers in forests. Canadian Journal of Forest Research 8(2): 214-219.

Worrall, J. J.; Parmeter, J. R., Jr. 1982. Wetwood formation as a host response in white fir. European Journal of Forest Pathology 12: 432-441.

The Incidence and Impact of *Heterobasidion annosum* on Pine and Incense-Cedar in California Forests[1]

Melissa Marosy John R. Parmeter, Jr.[2]

Abstract: Approximately 12.5 percent of California commercial forest land is infested with Heterobasidion annosum, resulting in annual losses of approximately 111 million board feet. The east side of the Sierra Nevada/Cascade Crest in northeastern California is most severely affected, with about 20 percent of the land out of production because of annosus root disease. In Yosemite Valley, 158 annosus root disease centers were identified. These centers are enlarging at an average rate of 0.67 m/yr. The most important impact of annosus root disease in recreation areas appears to be hazard and the loss of vegetative cover.

Annosus root disease, which is caused by Heterobasidion annosum (Fr.) Brev., is locally a very serious problem in California forests. Its effects are particularly noticeable in pine, and the primary impact of the disease is tree mortality. Forest managers and forest pest specialists are continually aware of its presence in the forest. Evidence for this is the number of biological evaluations requested by forest managers and performed by forest pest specialists in Region Five of the National Forest System. Of 152 biological evaluations conducted during the years 1984 through 1988 at the request of forest managers, 32 percent identified H. annosum as a primary or secondary cause of tree mortality.

This paper presents our current knowledge of the incidence and impacts of annosus root disease on pine and incense-cedar trees growing on commercial forest land and in recreation areas in California.

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2]Plant Pathologist, State and Private Forestry, Pacific Southwest Region, U.S. Department of Agriculture, Forest Service, San Francisco, California, and Professor of Plant Pathology, University of California, Berkeley, California.

PINE ON COMMERCIAL FOREST LAND

Of about 16 million acres of commercial forest land in California, about 812,626 hectares (2,008,000 acres), or 12.6 percent, are infested with root disease. About 99.6 percent of this disease is annosus root disease. Approximately 566,572 hectares (1.4 million acres) of ponderosa pine (Pinus ponderosae Laws.) and Jeffrey pine (Pinus jeffreyi Grev. and Balf.) are affected; the remaining affected area (242,817 hectares [0.6 million acres]) is in true fir (Table 1) (Anonymous 1988). The area of the state where these tree species are most severely affected is northeastern California on the east side of the Sierra Nevada/Cascade crest.

Of about 826.2 million board feet (MMBF) (137.7 million cubic feet [MMCF]) of estimated annual mortality from all causes on commercial forest land in California in 1976 (Smith 1984), about 118.8 MMBF (19.8 MMCF), or 14.4 percent, is due to root disease. Of this, about 111 MMBF (18.5 MMCF), or 93.4 percent, is annosus root disease. Pine accounts for approximately 60 MMBF (10 MMCF) of annosus-caused mortality; fir accounts for 51 MMBF (8.5 MMCF) (Table 1) (Anonymous 1988). A biological evaluation conducted by Kliejunas (1986) indicated that some stands of eastside pine have up to 50 percent of stumps infected, with about 20 percent of the land out of production because of annosus root disease.

PINE AND INCENSE-CEDAR IN RECREATION AREAS

More extensive information on the incidence and impacts of annosus root disease in California recreation areas has been provided by a continuing cooperative study begun in 1970 in Yosemite National Park. Yosemite Valley is one of the most heavily used areas in the National Park system. Between 1935 and 1977, 16,000 hazardous tree situations were dealt with in the park (Anonymous 1977), including three fatalities. As it became increasingly evident that H. annosum was involved in these hazardous tree incidents, an evaluation of the root disease situation was undertaken jointly by the University of California, the U.S. Department of the Interior, Park Service, and the U.S. Department of Agriculture, Forest Service.

Objectives of the study were: 1) to determine the numbers, sizes, and locations of H. annosum infection centers within the developed sites in Yosemite Valley; 2) to estimate the rate of pathogen spread and tree mortality in infection centers and the resulting vegetation changes occurring within these centers; 3) to estimate the hazards the infected trees pose to park visitors; and 4) to develop management options aimed at reducing stand damage and hazard. Preliminary information has been published (Anonymous 1977, Felix and others 1973, Parmeter and others 1978, Parmeter and others 1979).

In 1970, developed sites of Yosemite Valley were surveyed for H. annosum by systematically traversing stands, reviewing records of hazardous tree incidents, examining aerial photographs, and observing stands of trees from the valley rim. Dead trees, and declining trees associated with stumps, windthrows, or stand openings containing stumps were investigated. Any localized area of tree mortality was considered to be an annosus center if one or more trees or stumps yielded the fungus. Centers were confirmed by finding sporophores in stumps or by isolating the fungus. A similar survey of undeveloped Yosemite Valley sites was made in 1975. Additional centers were noted by investigating windthrows, deliberately uprooted trees, and random mortality in developed sites. Most centers appeared to be single-tree centers, or to consist of at most two or three trees.

Incidence

Within the developed sites of Yosemite Valley, 102 annosus root disease centers including both ponderosa pine and incense-cedar (Calocedrus decurrens) were identified, representing about 140-150 loci of infection. An additional 56 centers of infection were confirmed in undeveloped sites.

To estimate the rate of center enlargement, historical maps of areas where annosus root disease centers have since been identified were examined. Measurements on ten mapped plots coincident with older vegetation maps gave an average annual radial enlargement of 0.67 m (2.2 ft) (Table 2). At this rate, centers could be expected to reach 0.20 hectares (0.5 acre) in about 38 years and 0.40 hectares (1 acre) by 54 years. It appears that continued monitoring for perhaps another 20 years will be necessary to develop needed refinement of spread rate estimates.

Impact

Potential impacts to recreation areas caused by annosus root disease include growth loss, mortality, loss of vegetative cover, and hazard. To estimate annosus root disease-caused growth loss, growth for the past 20 years was measured on 44 pines which had been uprooted and examined for disease. No correlation was found between growth patterns and root disease (Table 3).

Estimates of mortality caused by annosus root disease were made from 67 disease centers mapped in 1971 and monitored from 1972 through 1980. Annual losses of both pine and cedar during this period averaged about 78 trees. This mortality varied greatly by year. For example, high mortality occurred during 1978 and 1979, coincident with a period of drought and epidemic bark beetle activity. Extrapolation from these figures, and from DBH and volume records for recent timber salvage sales in the valley, indicates that over 1-1/3 MMBF of timber have been lost on 85 mapped centers, or about 16 thousand board feet (MBF) per center.

In addition to losses of timber volume, recreational areas are impacted by a loss of vegetative cover and the creation of large openings. Large areas (up to 0.2 hectare [1/2 acre]) have been virtually denuded within 30-40 years by single loci of infection. Since most

Table 1--Annual mortality caused by Heterobasidion annosum in pine and fir trees in California

Host	Area infested	Losses to mortality	Value of dead timber
	hectares	MBF	dollars
Pine	566,572	60	$7,838,500
Fir	242,817	51	$1,804,124
Total	809,389	111	$9,642,624

Table 2--Enlargement calculations for tree disease centers caused by <u>Heterobasidion</u> <u>annosum</u> coincident with areas in Yosemite Valley for which there are old vegetation maps

Center	Early map	Recent map[1]	Years	Infection Center Enlargement
	<u>year</u>	<u>year</u>	<u>no.</u>	<u>avg. m/yr</u>
UR 9	1937	1983	46	0.64
UR Oak	1937	1971	34	0.70
UR Oak	1937	1983	46	0.73
Juniper	1948	1971	23	0.70
Juniper	1948	1977	29	0.76
Juniper	1948	1980	32	0.73
Tent	1948	1964	16	0.79
6-4	1950	1971	21	0.43
6-4	1950	1978	28	0.61
6-5	1950	1978	28	0.52
6-2	1950	1983	33	0.55
LP-41	1950	1976	26	0.91
LP-6	1966	1983	17	0.35
LP-17	1966	1976	10	<u>0.64</u>
			Average =	0.67

[1]Date of recent map depends on the years in which significant center enlargement occurred.

Table 3--Radial growth of pines infected with <u>Heterobasidion</u> <u>annosum</u>

Root disease	Average growth 1958-1978	Trees examined
<u>pct</u>	<u>centimeters</u>	<u>no.</u>
0	2.41 ± 0.39	10
1 - 25	1.33 ± 1.19	8
26 - 50	0.70 ± 0.57	7
51 - 75	1.07 ± 0.53	5
76 - 100	1.24 ± 0.67	14

annosus root disease centers are small, losses in the future will probably accelerate. If most of the 140-150 loci reach 0.20 hectares in the next 30 years, many of the existing camping and housing developments will be without forest cover. If the estimate of 140-150 loci is far too low, then most of the cabin and campground cover in the valley will be lost within the next 20-40 years. Attempts to revegetate large openings in campgrounds with native hardwoods in southern California have cost the Forest Service $24,710/hectare ($10,000/acre) and up. Treatment of fresh stumps with borax is required in Forest Service public recreational areas, at a cost of about $65.00/100 MBF removed[3]. Region 5 spent about $9,000 in 1987 for stump treatment.

Equal in importance to the loss of vegetative cover in recreation areas is the hazard (due to falling of trees whose roots are weakened by annosus root disease) to recreationists and facilities. Although pines are usually killed by annosus root disease before the root systems are extensively decayed, incense-cedar usually has extensive decay of the roots and butt before the tree dies; therefore, it is likely to fail while still living. Annosus root disease centers open up the stand; this reduces the protection from wind afforded by surrounding trees, and thereby further increases the chances of windthrow. The manager of the forest recreation area is legally responsible for the reasonable safety of visitors, and he must have the means to reduce hazard in root disease-infested stands. Otherwise, removal either of the forest or the people and facilities must be considered. How this dilemma is being addressed in Yosemite National Park is discussed by West (1989).

[3]Unpublished data available at the Big Bear Ranger District of the San Bernardino National Forest, Fawnskin, California.

REFERENCES

Anonymous. 1977. Natural resources management plan and environmental assessment. U.S. Department of the Interior, Park Service, Yosemite National Park, California; 118 pp.

Anonymous. 1988. Forest Pest Conditions in California - 1987. California Forest Pest Council, Sacramento; 26 pp.

Felix, L.S.; Parmeter, J.R. Jr.; Uhrenhodt, B. 1974. Fomes annosus as a factor in the management of recreational forests. In: Proceedings of the 4th International Conference on F. annosus, Athens, GA, September 1973. Washington, DC: U.S. Department of Agriculture, Forest Service; 2-7.

Kliejunas, J. 1986. Incidence of Fomes annosus stump infection on the Doublehead and Devil's Garden Ranger Districts, Modoc National Forest. Forest Pest Management Report 86-21. San Francisco, California: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region; 4 pp.

Parmeter, J.R., Jr.; MacGregor, N.J.; Smith, R.S., Jr. 1978. An evaluation of Fomes annosus in Yosemite National Park. Forest Insect and Disease Management Report 78-2. San Francisco, California: U.S. Department of Agriculture, Forest Serivce [sic], Pacific Southwest Region; 11 pp.

Parmeter, J.R., Jr.; Srago, M.; MacGregor, N.J.; Cobb, F.W., Jr. 1979. Root disease, hazard, and protection in Yosemite Valley. Proceeedings [sic] of the First Scientific conference on Research in National Parks. U.S. Department of the Interior, Park Service, Transactions and Proceedings Series 5:1097-1100.

Smith, R.S. 1984. Root disease-caused losses in the commercial coniferous forests of the western United States. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Report No. 84-5; 21 pp.

West, L. 1989. Management of annosus root disease caused by Heterobasidion annosum in coniferous trees in Yosemite National Park. 1989 [These proceedings].

Factors Affecting Loss and Impact

Impact of Precommercial Thinning on Development of *Heterobasidion annosum* in Western Hemlock[1]

Robert L. Edmonds David C. Shaw Tom Hsiang Charles H. Driver[2]

Abstract: The impact of precommercial thinning of western hemlock (Tsuga heterophylla) on the development of Annosus root and butt rot (caused by Heterobasidion annosum) in coastal Washington has been followed for more than 20 years. Infection of stumps and wounds was high following thinning and there was a high probability of residual tree infection. Eleven years after precommercial thinning tree infection was high, but after 20 years levels of infection were low in both thinned and unthinned stands (averaging <5 percent). Volume losses were even lower (<1 percent). Host tree defense mechanisms, including wetwood, appear to be effective in minimizing losses due to H. annosum. Precommercial thinning did not appreciably increase the incidence of H. annosum in the current rotation but problems could occur in future rotations. Borax treatment of precommercially thinned stumps was not effective in reducing the incidence of H. annosum.

Heterobasidion annosum (Fr.) Bref. causes root and butt rot of western hemlock (Tsuga heterophylla (Raf.) Sarg.) in coastal Oregon, Washington, British Columbia, and Alaska (Wallis and Reynolds 1970; Goheen and others 1980; Shaw 1981). This fungus, which is dispersed via airborne spores, colonizes freshly cut stump surfaces (Edmonds 1968; Russell and others 1973) or wounds created during thinning operations (Hunt and Krueger 1962; Wallis and Morrison 1975). In addition, mycelium spreads to adjacent trees through root contacts (Chavez and others 1980).

Because young western hemlock stands are generally overstocked, forest managers wish to thin them early, often precommercially. Will precommercial thinning of western hemlock increase the incidence of infection by H. annosum? Hadfield and others (1986) suggested that the benefits of precommercial thinning will be considerably greater than any disease losses. Chavez and others (1980), Morrison and Johnson (1978), and Wallis and Reynolds (1970) raised concern that impacts from H. annosum would be greatly increased by precommercial thinnings in western hemlock.

The objectives of this paper are to discuss current knowledge of the biology of H. annosum in western hemlock based on our work over the last 23 years and to determine whether precommercial thinning really creates a problem in current and future rotations. The sites involved in our studies are shown in figure 1 and the discussion that follows is in the context of six questions.

1. Is the inoculum of H. annosum increased in precommercially thinned stands vs. unthinned stands in Washington?
2. Is stump treatment with borax desirable?
3. How long does it take for advanced decay to develop, and what are the volume losses in precommercially thinned stands?
4. How do incipient and advanced decay affect wood quality, pulp yields and paper properties?
5. How much variability is there in virulence among isolates of H. annosum?
6. Will H. annosum be a problem in future rotations?

INCREASE IN INOCULUM IN PRECOMMERCIALLY THINNED STANDS

Spore production and release

Heterobasidion annosum produces both basidiospores and conidia which differ morphologically (Shaw and Florance 1979). Hunt and others (1976) suggested that conidia may be important as airborne inoculum in west coast forests in the United States. Leslie (1983) found that as many as 18 percent of the spores of H. annosum trapped in Washington were conidia, and Hsiang and others (in press) suggested that the aerial spore load of H. annosum may be one-third to one-half conidia. Florance and Shaw (1988), however, trapped only basidiospores in Oregon. We still do not fully understand the role of conidia in the Annosus root disease cycle, although it could be a very important one.

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2]Professor and Graduate Research Assistant, College of Forest Resources, University of Washington, Seattle, Washington, Research Associate, Western Washington Research and Extension Center, Washington State University, Puyallup, Washington, and Professor Emeritus, College of Forest Resources, University of Washington, Seattle, Washington.

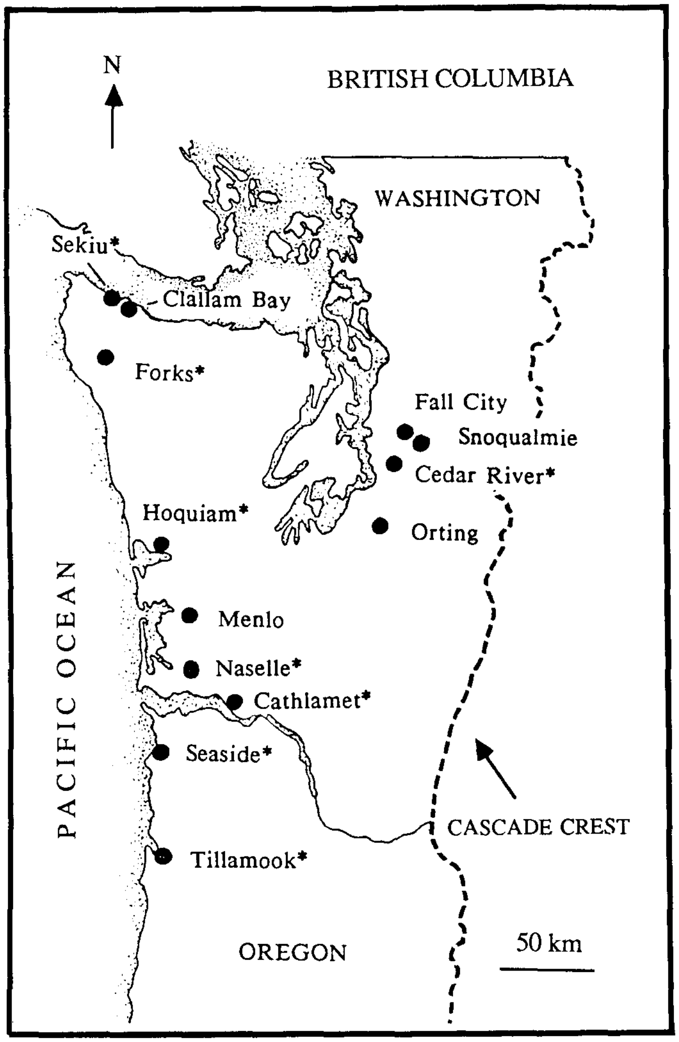


Figure 1--Study site locations in western Oregon and Washington used for research on Heterobasidion annosum in western hemlock.

*spore deposition studied at these sites.

Diurnal patterns of spore release have been observed in western Washington; maximum release is at night although this was not always consistent (Leslie 1983). Other workers have found that wood rotting basidiomycetes tend to have maximum spore release at night. Rockett and Kramer (1974) and Schmidt and Wood (1972) found this to be true for H. annosum in the eastern United States. Spores of H. annosum disperse rapidly at night even at extremely low wind speeds (Edmonds 1971; Edmonds and Driver 1974a; Fritschen and Edmonds 1976).

Seasonal patterns of spore release also have been observed. The highest rates at Hoquiam, Washington, occurred in the fall and the lowest rates occurred in the winter (Leslie 1983). Schmidt and Wood (1972) found that spore release patterns were related to microclimate. At Hoquiam, spore release was inversely related to temperature but not closely related to relative humidity (Leslie 1983). Spore release ceased in August when daytime temperatures exceed 38°C (100°F) (Edmonds and Leslie 1983). Reynolds and Wallis (1966) found that spore production ceased whenever temperatures fell below freezing.

Spore deposition

The range of spore deposition rates in precommercially thinned stands in Washington and Oregon is from 1700 - 20,000 spores $m^{-2} \cdot hr^{-1}$) (Edmonds and others 1984b). Much lower rates (3-70 spores $m^{-2} \cdot hr^{-1}$) were observed in an unthinned stand in Washington, although no sporophores were observed (Edmonds and Driver 1974a). Spore deposit on was higher (maximum rate - 2,100 spores $m^{-2} \cdot hr^{-1}$) in an unthinned stand of western hemlock and Douglas-fir in British Columbia with sporophores nearby (Reynolds and Wallis 1966). Lower spore concentrations were obtained when sporophores were not observed. The presence or absence of fruiting bodies is obviously important in determining spore deposition rates. Precipitation also appears to reduce spore deposition rates (Shaw 1981; Morrison and others 1986). Thus, it is not clear whether precommercial thinning changes spore deposition loads; this question needs further investigation. Precommercially thinned stands, however, appear to have higher spore deposition rates than commercially thinned stands (Edmonds and others 1984b).

Diurnal patterns of spore deposition occur in western Washington with highest rates at night and lowest during the day (Edmonds and Driver 1974a; Edmonds and others 1984a). Seasonal patterns of spore deposition also occurred. The lowest rates were in the summer and the higher rates were in the fall, winter and spring (Reynolds and Wallis 1966; Leslie 1983; Edmonds and others 1984b).

Stump and wound infection

Thinning creates fresh stump surfaces that are infection courts for airborne spores of H. annosum. Because of the high spore deposition rates in Washington, Oregon and British Columbia, natural stump infection is generally high, but it ranges from 0 to 100 percent. Stump infection is lower in Alaska (Shaw 1981; 1985) although spore deposition can be high (Shaw 1981). The incidence of stump infection declined with time in a British Columbia study; 5 years after thinning only 3-13 percent of stumps were infected compared to initial levels of 9-87 percent (Morrison and Johnson 1978). This decline was attributed to loss of viability and competition from other basidiomycetes, particularly Armillaria spp.

Stump infection in Washington occurs in all months of the year, but the highest rates occur in spring and summer (Edmonds 1968; Driver and Edmonds 1970; and Russell and others 1973). Interestingly, the lowest rates at both the coastal and Cascade sites occurred in the fall when spore deposition rates were high. All sizes of stumps are infected and the fungus seems to move faster in smaller stumps at least in the summer when temperatures are warmer, but it moves slower in the winter (Edmonds 1968; Edmonds and Driver 1974b).

High stump temperatures are known to inhibit stump infection (Driver and Ginns 1969). However, stump temperatures in Washington are rarely high enough to inhibit stump infection (Edmonds 1968; Edmonds and Driver 1974b), and they may even favor stump infection in the summer. Temperatures are generally not low enough to inhibit stump infection in the winter in the maritime northwest United States. Although fungal competitors such as *Trichoderma* spp. and *Leptographium* spp. are commonly observed on stump surfaces, they are not effective competitors on hemlock stumps (Edmonds 1968). Temperatures are rarely warm enough to favor high-temperature fungi like *Trichoderma* spp. which are effective inhibitors of *H. annosum* in the southeastern United States (Driver and Ginns 1969).

Tree infection

Once stumps are infected, the fungus moves downward into the root system and through root grafts into the stems of healthy trees. The majority of the tree infection in the study by Chavez and others (1980) at Clallam Bay, Washington, was through thinning stumps, but animal damage to roots by mountain beaver (*Aplodontia rufa*) and other wounding were important. Logging wounds also increase the amount of infection in a stand (Hunt and Krueger 1962; Wallis and Morrison 1975; Goheen and others 1980).

Chavez and others (1980) noted that tree infection was most common through residual stumps that were either close or grafted to the remaining crop tree. They estimated fungal growth rates in the trees remaining after thinning to range from 23 to 128 $cm \cdot yr^{-1}$ with an average of 75 $cm \cdot yr^{-1}$. Wallis and Reynolds (1970) reported that *H. annosum* could grow in wood at a similar rate.

Second-growth unthinned western hemlock stands in Oregon, Washington and British Columbia show a range of infection from 3 to 38 percent of total trees sampled (table 1). One stand in the study of Schmitt (1979) was 67 percent infected. Thus, infection levels can be high even in unthinned stands. The source of most of the tree infection probably is root contacts with infected old-growth stumps (Wallis and Morrison, 1975).

Although precommercial thinning results in stump infection, is tree infection really any higher in thinned than unthinned stands? At Clallam Bay, tree infection was 90 percent, 11 years after precommercial thinning at age 15 (table 2). However, 20 years after thinning, tree infection was only 5 percent. In similar precommercially thinned stands at Menlo and Naselle, Washington, infection rates were also low (0 and 4 percent infection, respectively, 15-20 years after thinning) (table 2). This is a very low rate of infection, and at Clallam Bay the amount of tree infection appears to have decreased from year 11 to year 20. How could this occur? We found that 92 percent of the trees in the thinned stand had wetwood in the base. Wetwood is "a type of heartwood in standing trees which has been internally infused with water" (Ward and Pong 1980). Wetwood in western hemlock also has high extractives content and reduced permeability (Schroeder and Kozlik 1972). Properties of wetwood have been shown to form an effective defense against *H. annosum* in *Abies concolor* (Worrall and Parmeter 1983) and in *A. grandis* (Coutts and Rishbeth 1977). We suspect that wetwood in western hemlock is antagonistic to *H. annosum*, holding it in check.

BORAX STUMP TREATMENT

One way of reducing the impact of *H. annosum* in precommercially thinned western hemlock stands is through chemical stump treatment. Many chemicals have been tested including borax (Edmonds 1968; Edmonds and others 1969; Russell and others 1973), sugar borax, sodium nitrate and urea (Edmonds 1968), zinc chloride (Morrison and Johnson 1975), monolaurin (Nelson and Lu 1980), benlate, captan, and wood preservatives (ACA and CCA) (Hu 1984). Borax is probably the easiest to apply and can be effective if applied carefully (Edmonds and others 1969; Russell and others 1973). It is difficult to apply in precommercial thinnings because of the stump density, and it tends to wash off if stumps are not cut horizontally. Twenty-eight percent of the borax treated stumps at Clallam Bay were infected compared to 76 percent of untreated stumps (Edmonds 1968). In addition, we know that the fungus can enter the stand through wounds caused by thinning and animal damage. Thus it is expected that *H. annosum* cannot be totally excluded by stump treatment alone.

Evaluation of borax stump treatment 20 years after precommercial thinning does not reveal that infection levels can be reduced compared to untreated stands (figure 2). *Heterobasidion annosum* infections averaged 4.7 percent for thinned, no-borax plots, 11.2 percent for thinned-boraxed plots, and 2.9 percent for unthinned plots. Differences are not significant between thinned-borax and thinned, no-borax treatments. Operational use of borax in forest stands probably will not provide protection from stand infection.

DEVELOPMENT OF INCIPIENT AND ADVANCED DECAY

Eleven years after precommercial thinning at Clallam Bay, Washington, incipient decay caused by *H. annosum* had extended an average of 4.1 m in height and as far as 11 m in one tree (Chavez and others 1980). No advanced decay was noted in the boles, and infected trees had no external symptoms, although height growth was slightly impaired. Although 90 percent of the trees were

Table 1--Percent infection by Heterobasidion annosum in unthinned western hemlock stands in western Oregon, Washington, and British Columbia

Average infection	Stand age (years)	Location	Reference
8	15	Clallam Bay	Edmonds 1968
17	20-60	Coastal Range and Cascade Mountains, Washington	Driver and Wood 1968
38	22-50	Coastal Oregon, Coastal Range and Cascade Mountains, Washington	Schmitt 1979
3	35	Clallam Bay	Shaw and Edmonds unpublished[1]
6	37	Menlo	Shaw and Edmonds unpublished[1]
22	50-60	British Columbia	Blair and Driver 1977
13	40-125	Washington and Oregon	Goheen and others 1980
10	Unknown[2]	British Columbia	Wallis and Morrison 1975

[1]Unpublished data on file, College of Forest Resources, University of Washington, Seattle, Washington.

[2]Tree age range data not available.

Table 2--Percent infection by Heterobasidion annosum in precommercially thinned stands of western hemlock in Washington

Average percent infection	Years after thinning	Location	References
90	11	Clallam Bay	Chavez and others 1980
5	20	Clallam Bay	Shaw and Edmonds unpublished[1]
0	15	Menlo	Shaw and Edmonds unpublished[1]
4	20	Naselle	Shaw and Edmonds unpublished[1]

[1]Unpublished data on file at College of Forest Resources, University of Washington, Seattle, Washington.

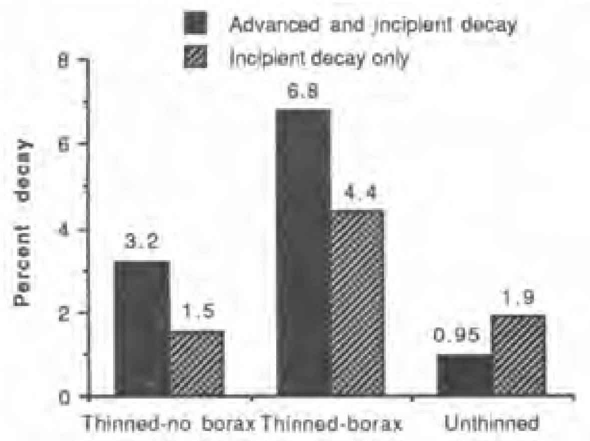


Figure 2--Percent of western hemlock trees with incipient decay only and advanced and incipient decay due to Heterobasidion annosum in precommercially thinned no-borax treatment, precommercially thinned-borax treated, and unthinned stands at Clallam Bay, Washington.

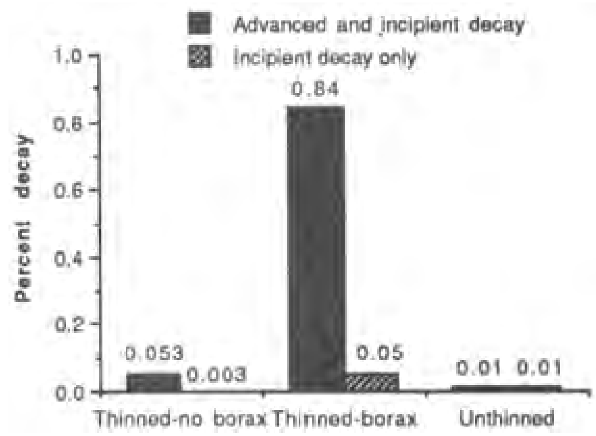


Figure 3--Percent volume loss to Heterobasidion annosum in western hemlock trees with incipient decay only and with advanced and incipient decay in precommercially thinned no-borax, precommercially thinned-borax treated, and unthinned stands at Clallam Bay, Washington.

infected, very little merchantable volume (to a 10-cm diameter top) was associated with the incipient decay stain.

The stands at Clallam Bay were revisited 20 years after precommercial thinning to determine whether advanced decay had developed and what losses had occurred. We sampled three 0.04-ha plots each in thinned, no-borax; thinned-borax; and unthinned treatments (see Shaw and others in press for method description). Advanced decay caused by H. annosum occurred in each treatment; 3.7 percent of the trees in thinned, no-borax, 6.8 percent in thinned-borax and 1.0 percent in the unthinned trees (figure 2).

The average height of H. annosum decay was 1.5, 1.0 and 1.3 m in thinned, no-borax; thinned-borax; and unthinned treatments, respectively. The highest decay column extended 3.7 m above ground level.

Volume losses, in terms of percent of volume to a 10-cm (4-in) top in combined advanced and incipient decay, averaged under 0.1 percent for all treatments except thinned-borax, which averaged 0.9 percent (figure 3). In coastal Washington at harvest, western hemlock with basal decay may be long-butted (cut high off the ground to avoid decay). Percent volume losses with long-butted logs are shown in figure 4. Losses are still minimal (less than 1 percent for thinned no-borax and unthinned treatments, whereas the thinned-borax treatment averaged 3 percent).

Volume losses due to advanced decay caused by H. annosum are just becoming realized 20 years after precommercial thinning. The suggestion by Hadfield and others (1986) that losses due to H. annosum will be minimal compared to benefits of thinning appears to be correct.

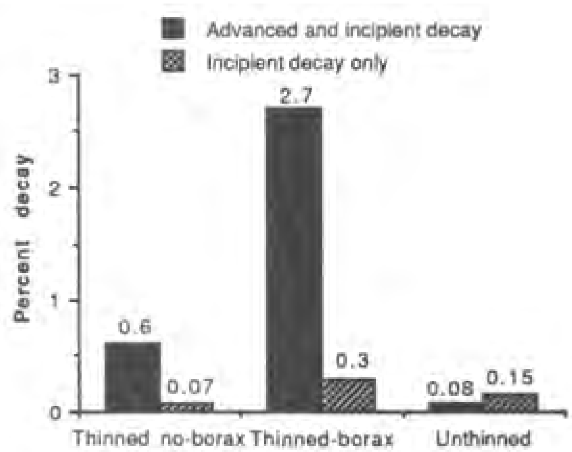


Figure 4--Percent volume loss to Heterobasidion annosum in western hemlock if decayed base is long-butted, for trees with incipient decay only and advanced and incipient decay in precommercially thinned no-borax, precommercially thinned-borax treated, and unthinned stands at Clallam Bay, Washington.

IMPACT OF HETEROBASIDION ANNOSUM ON WOOD QUALITY AND PULP YIELDS AND PAPER PROPERTIES

We have little information on the effects of H. annosum on western hemlock wood quality. There is no current degrade for stain in the domestic market. However, long-butting of export logs with stain is commonly conducted to make them acceptable. Not all of the stain in western hemlock is incipient decay stain, however. Much of it is wetwood. Wetwood may cause differential shrinkage in kiln-dried lumber, and it is associated with ringshake. This is an important area for investigation, and we need more information about the effects of stain to determine its economic impacts on wood quality.

We have conducted preliminary tests on the physical properties of western hemlock wood with incipient and advanced decay caused by H. annosum. Wood with incipient decay did not have reduced strength. However, as expected, wood with advanced decay had significantly lower modulus of rupture (P = 0.01) and modulus of elasticity (P = 0.05).

We do know, however, that pulp yields from incipiently decayed wood are reduced an average of 2-3 percent, and from wood with advanced decay, as much as 8 percent (Driver and others 1984). These reductions in yield could be economically important since a 1 percent change in yield can result in economic loss (W. McKean, University of Washington, Seattle, Washington, personal communication, 6 June, 1985).

Paper properties are also affected by H. annosum decay in pulp wood. Paper apparent density is increased about 6 and 15 percent using wood with incipient and advanced decay, respectively. Tear index (a major index of paper strength) showed the most dramatic change: 20 percent and 40 percent reduction from wood with incipient and advanced decay, respectively. Fiber lengths were shorter and fiber coarseness was lower in wood with advanced decayed. The decrease in fiber coarseness occurs because infection by H. annosum results in thinner cell walls, and this in combination with smaller fiber length explains the dramatic drop in tear strength in paper made from wood with advanced decayed. Thus, H. annosum is likely to increase the amount of culling loss with wood used for manufacturing fiber products.

VARIABILITY IN VIRULENCE OF ISOLATES OF HETEROBASIDION ANNOSUM

Table 1 shows the considerable variation in disease incidence among stands. There is also variation in infection within a stand. For example, Chavez and others (1980) found that the mean growth rate of H. annosum within trees varied from 23 to 128 $cm \cdot yr^{-1}$. Environmental factors such as variation in temperature and moisture, the presence or absence of competing organisms, stand factors (age and diameter of trees, size of wounds), and wood properties can account for some of this variability. Edmonds (1974) attempted to determine whether edaphic factors were related to disease development. Results from a preliminary study suggested that A horizon soil in the vicinity of infected trees is lower in organic matter, has lower pH, and has fewer fungal propagules than similar soil near healthy trees. There was no clear relationship between disease development and percent sand, silt, and clay. Habitat type may also influence disease development. Relationships between environment and disease development, however, need further investigation.

Environmental and substrate quality differences cannot, however, explain all of the observed variation. Some of it is no doubt due to differences in fungal pathogen virulence. Hsiang (1988) reported that isolates of H. annosum from western hemlock trees belong to the S-group (*sensu* Korhonen), and that these isolates were extremely variable with respect to growth and virulence. The largest component of variation in growth occurred within fungal populations. Electrophoresis and cross-plating techniques were used to delimit clones of H. annosum in western hemlock stands. Individual clones were found to be very limited in size and were confined to single trees or even just parts of trees. This indicated the greater importance of aboveground infections caused by basidiospores or conidia over belowground mycelial infections in the spreading of this fungus.

Heterobasidion annosum is physiologically specialized for host trees of different or even the same species based on the production of conidia on branch disks (Hsiang and Edmonds in press). However, there are no full barriers to infections of different host species in populations of H. annosum from western hemlock. There is tremendous variation in the resistance of western hemlock toward H. annosum, but the level of resistance of individual trees is not equal against all isolates.

Considerable variability in H. annosum also exists in culture. Growth rates vary for both linear extension and biomass production. In culture, the linear growth of H. annosum from different geographic locations and even from the same stand varies considerably although the maximum growth rate was always at 25°C (Edmonds 1968). While testing isolates from Alaska to California, Hsiang (1988) did not find adaptation to local temperatures by H. annosum.

Wood decay tests also indicate considerable variability in weight loss between and within sites (table 3). According to the American Society for Testing and Materials (1969), a 12-week incubation test with 11-24 percent weight loss indicates resistance. Thus, the 11-20 percent weight loss recorded by Frankel (1983) on wood blocks from 25-yr-old trees suggests that western hemlock is resistant to H. annosum. Perhaps this explains the relatively low losses to advanced decay in the field. Heartwood extractives from 40-year-old western hemlock, however, were not strongly inhibitory to H. annosum in culture (Edmonds 1976).

Interestingly, isolates from trees experiencing the most damage in the field had the highest weight loss in the soil block test (technique described in American Society for Testing and Materials 1969), i.e., isolates from windthrown trees caused the greatest weight loss (table 3). Lowest weight loss was associated with isolates from incipiently decayed trees. This seems to indicate that differences in pathogen virulence is responsible for some of the observed differences in disease development.

Table 3--Average percent weight loss for western hemlock wood decayed by each of nine isolates of Heterobasidion annosum after 12 weeks in a standard soil-block test (from Frankel 1983)

Isolate number	Isolate location (Washington)	Average percent weight loss (Standard deviation)[1]	Stand condition
1	Orting	20.2 (1.5)[a]	Windthrown[2]
2	Orting	17.1 (1.0)[b]	Windthrown[2]
3	Orting	15.4 (0.8)[c,d]	Windthrown[2]
4	Snoqualmie	11.6 (.5)[f]	Windthrown[2]
5	Fall City	17.7 (0.7)[b]	Windthrown[2]
6	Forks	11.0 (1.4)[f]	Standing[3]
7	Forks	13.2 (0.7)[e]	Standing[3]
8	Forks	14.4 (0.7)[d]	Standing[3]
9	Forks	15.7 (0.9)[c]	Standing[3]

[1]Associated letters indicate Duncan's multiple range test subsets. Numbers with different letters are significantly different (P - 0.05).

[2]Infection with advanced and incipient decay.

[3]1nfection with incipient decay only.

WILL HETEROBASIDION ANNOSUM BE A PROBLEM IN WESTERN HEMLOCK MANAGEMENT DURING FUTURE ROTATIONS?

The inoculum potential of H. annosum is extremely high. Forests in western Washington, Oregon and British Columbia seem to be bathed continuously in spores and only rarely does the temperature become hot or cold enough to inhibit spore release. Year-round, infection rates are high in stumps and wounds created by precommercial thinning. Infection rates in stumps are high in the summer months despite the lower spore release and deposition rates at that time of year. The environmental factors that control stump infection in other regions such as the southeastern United States (high temperatures and microbial competition) and Scandinavia (too cold) rarely operate in low elevation coastal forests in western North America, except perhaps in Alaska where cold temperatures and anaerobic conditions in stumps may inhibit fungus development (Terry Shaw, USDA Forest Service, Juneau, Alaska, personal communication, 9 September, 1986).

Heterobasidion annosum moves quickly from stumps to retaining crop trees at an average rate of 75 $cm \cdot yr^{-1}$ and it causes incipient decay in the majority of trees (in 90 percent of trees 11 years after thinning at Clallam Bay). It also causes incipient decay in unthinned second-growth western hemlock stands, but infection rates appear to be lower than those in precommercially thinned stands (figure 2). Thus, 11 years after precommercial thinning the situation did not look very good. We thought that when we examined the stands at Clallam Bay 20 years after thinning, we would see strong development of advanced decay and considerable volume and economic loss. This did not happen. There was very little advanced decay and volume loss, and in fact it appears that the amount of total tree infection was reduced.

We now believe that regulating factors in western hemlock trees inhibit the development of H. annosum; the wetwood environment which develops in most trees may be too antagonistic for the fungus to exist, or it may be that other microorganisms involved with wetwood outcompete H. annosum.

There is tremendous variability in virulence of H. annosum. The situation at Clallam Bay involved strains that only appear to cause butt rot. Some strains of H. annosum isolated from western hemlock appear to be more virulent than Clallam Bay isolates, for example, those at Orting, Washington, which cause root-rot, blow-down, and butt rot (table 3). In these stands, increased tree infection by precommercial thinning could be a much bigger problem.

What about future rotations? Most thinning stumps are infected and they could serve as a source of inoculum for residual trees. Precommercial thinning stumps are small in diameter, and H. annosum seems to be easily replaced in them by Armillaria spp. and other basidiomycetes. We do not know as yet what species of Armillaria is involved at Clallam Bay, but this will be determined, since it is not desirable to increase the incidence of Armillaria in hemlock stands. Morrison and others (1986), however, classified the Armillaria on western hemlock stumps in British Columbia to be in Group V which is not pathogenic to conifers. Thus, the next rotation does not seem to be particularly at risk from H. annosum existing in precommercial thinning stumps. The larger stumps remaining after clearcut harvesting at the end of the rotation, however, may prove to be a greater risk for inoculum increase.

There is considerable virulence among strains of H. annosum and we know that highly virulent strains exist like the one at Orting, Washington. We also know that strains can show specificity toward particular host individuals (Hsiang and Edmonds in press). Can such virulent and specialized strains spread more widely? To answer this, we need to know more about the role of conidia in the spread of H. annosum. Conidia can retain highly virulent gene combinations, but basidiospores lose those combinations, thus, enhancing variability.

CONCLUSIONS

The direct effect of precommercial thinning of western hemlock stands on infection by H. annosum is to create fresh infection courts, both stump surfaces and tree wounds, for spores to colonize. Once these surfaces are colonized, H. annosum must contend with host tree defenses and competition from other organisms in thinned stumps. It appears that these mechanisms are effective in minimizing losses due to H. annosum within 20 years after thinning. Thinned western hemlock stands do not have significantly more infections than unthinned stands at Clallam Bay.

Our ideas on the effects of precommercial thinning in western hemlock stands have evolved considerably over the last 23 years. Based on experience in Europe and the southeastern United States, we expected that precommercial thinning could dramatically increase H. annosum and that rotation lengths would be "pathological rotations" determined by the amount of butt rot developing in relation to time after thinning. Environmental conditions in Oregon and Washington appeared to be ideal for development of the fungus. Our current evaluation, based on considerable knowledge of the biology of H. annosum, is that the present situation is not as serious as it first appeared to be over a decade ago. Heterobasidion annosum has tremendous capacity to spread. However, it is apparently being held in check at this time by "natural" biological control mechanisms involving wetwood and microbial competitors.

Borax does not appear to be effective for operational use in coastal Washington, although it may be effective if applied very carefully to stumps, particularly those close to the remaining trees. Morrison and others (1986) believe that borax stump treatment should be considered in parts of British Columbia.

The book is not yet closed on H. annosum in western hemlock and the ultimate effect of precommercial thinning on the development of H. annosum remains to be determined. There are still many questions which need to be answered, such as:

- What will be the extent of H. annosum development in stands at rotation age?
- What is the optimum rotation age for western hemlock stands being utilized for lumber or fiber products relative to development of H. annosum decay?
- Will large stumps remaining after clearcut harvesting increase the inoculum potential of a site?
- Can H. annosum produce hypervirulent strains capable of rapid spread in western hemlock forests?
- What is the relationship between wetwood and the development of H. annosum?
- Will wetwood result in product degrade and economic impact?
- What is the relationship between H. annosum and other pathogens such as Armillaria spp. in both thinned and unthinned stands?

ACKNOWLEDGMENTS

This research was supported mostly by grants from the Washington Forest Protection Association, Olympia, Washington and the U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

REFERENCES

American Society for Testing And Materials. 1969. Standard method for accelerated laboratory test of natural decay resistance of wood. Philadelphia: ASTM Designation, D2017-63, 1969 Book of ASTM Standards, Part 16; 711-718.

Blair, H.A.; Driver, C.H. 1977. A portable power drill - an aid in the detection of tree root and butt rot pathogens. Plant Disease Reporter 61: 481-483.

Chavez, T.D., Jr.; Edmonds, R.L.; Driver, C.H. 1980. Young-growth western hemlock stand infection by Heterobasidion annosum 11 years after precommercial thinning. Canadian Journal of Forest Research 10: 389-394.

Coutts, M.P.; Rishbeth, J. 1977. The formation of wetwood in grand fir. European Journal Forest Pathology 7: 13-22.

Driver, C.H.; Ginns, J.H. 1969. Ecology of slash pine stumps: Fungal colonization and infection by Fomes annosus. Forest Science 15: 1-10.

Driver, C.H.; Wood, R.E. 1968. Occurrence of Fomes annosus in intensively managed young-growth western hemlock stands. Plant Disease Reporter 52: 370-372.

Driver, C.H.; Edmonds, R.L. 1970. Fomes annosus in young-growth western hemlock. Contribution No. 9, Seattle, Washington: Institute of Forest Resources, College of Forest Resources, University of Washington; 12 p.

Driver, C.H.; Jordan, T.B.; Edmonds, R.L. 1984. The impact of Heterobasidion annosum decay on pulping and paper properties of western hemlock. In: Kile, G.A., editor, Proceedings 6th International Conference on Root and Butt Rots of Forest Trees; August 25-31, 1983, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia. Melbourne: CSIRO; 351-358.

Edmonds, R.L. 1968. Natural occurrence and control of Fomes annosus in precommercially thinned stands of western hemlock. Seattle: University of Washington; 144 p. M.S. thesis.

Edmonds, R.L. 1971. Dispersion and deposition of spores of Fomes annosus and fluorescent particles into and within a forest canopy. Seattle: University of Washington; 170 p. Ph.D. Dissertation.

Edmonds, R.L. 1974. Soil properties and fungal populations in a young-growth western hemlock stand infected with Fomes annosus. Plant Disease Reporter 58: 1077-1079.

Edmonds, R.L. 1976. Effects of cold and warm water extractives from decayed western hemlock heartwood on the growth of Fomes annosus. Canadian Journal of Forest Research 6: 1-5.

Edmonds, R.L.; Driver, C.H. 1974a. Dispersion and deposition of spores of Fomes annosus and fluorescent particles. Phytopathology 64: 1313-1321.

Edmonds, R.L.; Driver, C.H. 1974b. Effect of temperature on growth rate and survival of Fomes annosus in western hemlock stumps. In: E.G. Kuhlman, ed. Proceedings Fourth International Conference on Fomes annosus. IUFRO Section 24: Forest Protection, U.S. Department of Agriculture, Forest Service, Washington, D.C.; 192-213.

Edmonds, R.L.; Driver, C.H.; Russell, K. W. 1969. Borax and control of stump infection by Fomes annosus in western hemlock. Plant Disease Reporter 53: 216-219.

Edmonds, R. L.; Leslie, K. 1983. Deposition and release of spores of Fomes annosus in relation to meteorological conditions. In: Proceedings Sixth Conference on Biometeorology and Aerobiology, April 25, 1983, Ft. Collins, Colorado. Boston: American Meteorological Society; 33-34.

Edmonds, R.L.; Hinshaw, R.W.; Leslie, K. 1984a. A 24-hour deposition sampler for spores of Heterobasidion annosum. Phytopathology 74: 1032-1034.

Edmonds, R.L.; Leslie, K.B.; Driver, C.H. 1984b. Spore deposition of Heterobasidion annosum in thinned coastal western hemlock stands in Oregon and Washington. Plant Disease 68: 713-715.

Florance, E.R.; Shaw, C.G., III. 1988. Surface morphology of basidiospores from decay fungi that are common in Pacific Northwest forests. Northwest Science 62: 233-241.

Frankel, S.J. 1983. Decay capacity of Heterobasidion annosum isolates from individual western hemlock trees within and between stands exhibiting a range of decay rates. Seattle: University of Washington; 90 p. M.S. thesis.

Fritschen, L.J.; Edmonds, R. L. 1976. Dispersion of fluorescent particles into and within a Douglas-fir forest. In: Engelmann, R. J.; Sehmel, G.A. eds. Proceedings Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants. ERDA Symposium Series-38. NTIS CONF-74-0921; Oak Ridge, Tennessee: ERDA Technical Information Center; 280-301 p.

Goheen, D.J.; Filip, G.M.; Schmitt, C.L.; Gregg, T.F. 1980. Losses from decay in 40- to 120-year old Oregon and Washington western hemlock stands. R6-FPM-045-1980. Portland, OR: U.S.Department of Agriculture Forest Service; 19 p.

Hadfield, J.S.; Goheen, D.J.; Filip, G.M.; Schmitt, C.L.; Harvey, R. D. 1986. Root diseases in Oregon and Washington conifers. R6-FPM-250-86. Portland OR: U.S. Department of Agriculture Forest Service; 27 p.

Hsiang, T. 1988. Variability in growth, population structure, and virulence of Heterobasidion annosum. Seattle: University of Washington; 204 p. Ph.D. Dissertation.

Hsiang, T.; Edmonds, R.L. Physiological specialization of Heterobasidion annosum on its conifer hosts. Canadian Journal of Botany

[In press].

Hsiang, T.; Edmonds, R.L.; Driver, C.H. Conidia of Heterobasidion annosum from Tsuga heterophylla forests in western Washington. Canadian Journal of Botany [In press].

Hu, R.L.F. 1984. Chemical and biological control of Heterobasidion annosum on western hemlock. Seattle: University of Washington; 55 p. M.S. thesis.

Hunt, J.H.; Krueger, K.W. 1962. Decay associated with thinning wounds in young-growth western hemlock and Douglas-fir. Journal of Forestry 60: 336-340.

Hunt, R.S.; Cobb, F.W., Jr.; Parmeter, J.R., Jr. 1976. Fomes annosus stump colonization and fungus development in the California mixed-conifer type. Canadian Journal of Forest Research 6: 159-165.

Leslie, K.B. 1983. Diurnal seasonal patterns of Heterobasidion annosum spore release and deposition in western hemlock stands of the Pacific Northwest. Seattle: University of Washington; 152 p. M.S. thesis.

Morrison, D.J.; Johnson, A.L.S. 1975. Zinc chloride effectively controls Fomes annosus stump infection. Environment Canada, Forest Service BiMonthly Research Notes 31: 5-6.

Morrison, D.J.; Johnson, A.L.S. 1978. Stump colonization and spread of Fomes annosus 5 years after thinning. Canadian Journal of Forest Research 8: 177-180.

Morrison, D.J.; Larock, M.D.; Waters, A.J. 1986. Stump infection by Fomes annosus in spaced stands in the Prince Rupert Forest region of British Columbia. BC-X-285. Victoria, B.C.: Canadian Forest Service, Pacific Forest Centre; 12 p.

Nelson, E.E.; Lu, C.Y. 1980. Preliminary test of two stump surface protectants against Fomes annosus. Res. Note PNW-363. Portland, Oregon: Pacific Northwest Forest and Range Experimental Station; 6 p.

Reynolds, G.; Wallis, G.W. 1966. Seasonal variation in spore deposition of Fomes annosus in coastal forests of British Columbia. Department of Forestry Canada, BiMonthly Research Notes 22: 6-7.

Rockett, T.R.; Kramer, C. L. 1974. Periodicity and total spore production by lignicolous basidiomycetes. Mycologia 66: 817-829.

Russell, K.W.; Thompson, J.H.; Steward, J.L.; Driver, C.H. 1973. Evaluation of chemicals to control infection of stumps by Fomes annosus in precommercially thinned western hemlock stands. DNR Rep. 33. Olympia: Washington State Department of Natural Resources. 16 p.

Schmidt, R.A.; Wood, F.A. 1972. Interpretation of microclimate data in relation to basidiospore release by Fomes annosus. Phytopathology 62: 319-321.

Schmitt, C.L. 1979. Detection and incidence of Fomitopsis annosa in unthinned western hemlock in Washington and Oregon. Seattle: University of Washington; 43 p. MFR, Professional Paper.

Schroeder, H.A.; Kozlik, C. T. 1972. The characterization of wetwood in western hemlock. Wood Science and Technology 6: 85-94.

Shaw, D.C.; Edmonds, R.L.; Driver, C.H.; Russell, K.W.; Littke, W.R. Annosus root disease in western hemlock 20 years after treating stumps with borax during precommercial thinning. In: Proceedings, Western International Forest Disease Work Conference, Park City, Utah. September, 1988 [In press].

Shaw, C.G., III. 1981. Infection of western hemlock and Sitka spruce thinning stumps by Fomes annosus and Armillaria mellea in southeast Alaska. Plant Disease 65: 967-971.

Shaw, C.G., III. 1985. Colonization of conifer thinning stumps by root disease fungi in southeast Alaska. Phytopathology 75: 1294.

Shaw, C.G., III; Florance, E.R. 1979. Scanning electron microscopy reveals differences in surface morphology between basidiospores and conidia of Heterobasidion annosum. European Journal of Forest Pathology 9: 249-254.

Wallis, G.W.; Reynolds, G. 1970. Fomes annosus root and butt rot: A threat to managed stands in coastal British Columbia. Forestry Chronicle 51: 202-207.

Wallis, G.W.; Morrison, D.J. 1975. Root rot and stem decay following commercial thinning in western hemlock and guidelines for reducing losses. Forestry Chronicle 51: 203-207.

Ward, J.C.; Pong, W.Y. 1980. Wetwood in trees: A timber resource problem. Gen. Tech. Rep. PNW-112. Portland, OR: Pacific Northwest Forest and Range Experimental Station. U.S. Department of Agriculture, Forest Service. 56 P.

Worrall, J.J.; Parmeter, J.R., Jr. 1983. Inhibition of wood-decay fungi by wetwood in white fir. Phytopathology 73: 1140-1145.

Factors Affecting Infection of Precommercial Thinning Stumps by *Heterobasidion annosum* in Coastal British Columbia[1]

D. J. Morrison[2]

Abstract: Stumps of Douglas-fir, western hemlock, Sitka spruce, and amabilis fir were sampled in precommercially thinned stands to determine the percentage of stump surface area colonized by Heterobasidion annosum. There were significant differences among species in the percentage of stumps colonized. Seasonal patterns were evident for each species; however, differences were not significant. Both the percent incidence of infection and the percentage of surface area colonized increased with increasing stump diameter. The results indicate that stump treatment to prevent infection is not necessary for Douglas-fir, but it should be considered for the most susceptible species, Sitka spruce and amabilis fir.

Coastal British Columbia (B.C.) includes Vancouver Island, the Queen Charlotte Islands and the mainland west of the Coast Mountains. The region extends from 48° 20′ to about 55° N latitude. It is mountainous and contains several major river valleys and numerous fjords which extend the maritime climatic influence into the Coast Mountains.

The forest land classification of the region is based on climate, soil and vegetation (Krajina 1965, Klinka and others 1984). Annual precipitation ranges from 600 mm in the rain shadow of the Vancouver Island mountains to 4500 mm at locations on the outer coast. Commercial forests occur within the coastal Douglas-fir zone (CDF), which is located on southeastern Vancouver Island, and the coastal western hemlock zone (CWH). The commercial coniferous tree species in those zones are Douglas-fir [Pseudotsuga menziesii (Mirb.) France], western hemlock [Tsuga heterophylla (Raf.) Sarg.], amabilis fir [Abies amabilis Dougl. ex Forbes], Sitka spruce [Picea sitchensis (Bong.) Carr.] and western red cedar [Thuja plicate. Donn]. Second-growth stands are established either by planting, primarily of Douglas-fir, or by natural regeneration; most of these stands require precommercial thinning at between 12 and 20 years of age to achieve optimum stocking.

Heterobasidion annosum (Fr.) Bref. occurs throughout coastal B.C., except in the driest parts of the CDF zone. Sporophores of H. annosum are common on diseased old-growth stumps and logging residue, although often they are difficult to locate. Spores of H. annosum are present in the air spora throughout the year, although their numbers are lowest during summer and winter and are reduced by precipitation (Reynolds and Wallis 1966). Except for western red cedar, fresh stumps of the commercial species are susceptible to infection by airborne spores of the fungus (Morrison and Johnson 1970, Wallis and Reynolds 1970). The stump and its roots may be colonized by the fungus, which spreads to adjacent residual trees at root contacts (Morrison and Johnson 1978). In most stands, particularly those which are naturally regenerated (unburned and not planted), precommercial thinning creates large numbers of susceptible stumps. If even a small percentage of these stumps are colonized by H. annosum, the amount of inoculum on the site increases markedly (Morrison and Johnson 1978).

A study in the Prince Rupert Forest Region (Morrison and others 1986) showed that tree species, stump diameter, and season of thinning influence the number of stumps that are colonized. The purpose of the work described here was to evaluate the effect of these factors on stump infection by H. annosum throughout the coastal B.C. region in order to determine hazard from annosus root disease.

[1] Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2] Forest Pathologist, Forestry Canada, Pacific Forestry Centre, Victoria, B.C. Canada.

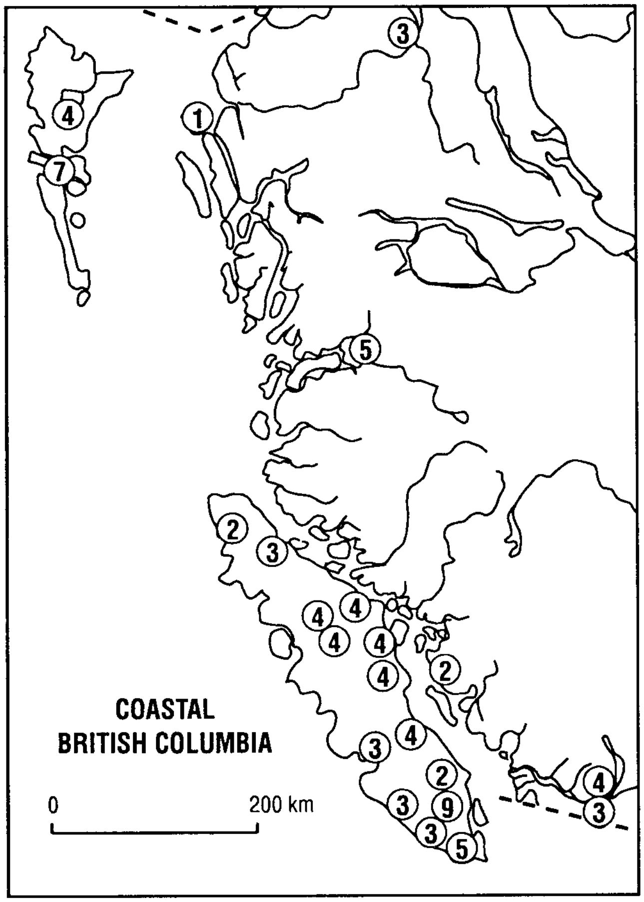


Figure 1--Location of precommercially thinned conifer forest stands in which stumps were sampled for Heterobasidion annosum in coastal British Columbia. The number in each circle indicates the number of stands sampled at each location.

METHODS

Stumps were sampled in 83 precommercially thinned stands in the coastal B.C. region (Fig. 1). Other studies show that the proportion of stumps colonized by H. annosum declines for a few years after thinning (Dimitri and others 1971, Morrison and Johnson 1978); hence, only stands thinned 3-5 years previously were sampled. For each tree species, 25 stumps in each 5-cm diameter class (2.5-7.4, 7.5-12.4, etc.) were sampled along random transects through each stand. After 5 to 15 cm was trimmed from the top of the stump and discarded, depending on the number of years since thinning, a disk 2-4 cm thick was cut from each stump. These disks were incubated between layers of moist newspaper for about 5 days, then the areas showing the conidial stage of H. annosum were marked on each disk. The areas colonized by H. annosum on each disk were traced on transparent plastic and were measured with a planimeter. The diameter-inside-bark of all disks and the heartwood diameter for Douglas-fir disks were measured. The season of thinning was noted from stand management records.

The data were analyzed as follows: plots and regressions of standard deviations against the means were examined, and the dependent variables were transformed to reduce associations between their means and variances. The values for percent infection of the susceptible stump area were arcsine-transformed. Colonized area values were logarithmically transformed by taking the base-10 logarithm of one plus the value. Disease incidence, a binary variable with values 0 (uninfected) or 1 (infected) for each stump, was converted into the infected proportion of the stumps found within each cell (stand by species by diameter-class subgroup), and was then arcsine-transformed.

These transformed variables were subjected to analysis of covariance by the method of least squares, using the General Linear Model procedure of SAS (SAS Institute 1985), to better enable attribution of dependent-variable variation to classification and continuous independent variables in spite of missing cells and unequal numbers of stumps per cell.

Disease incidence, untransformed, was also subjected to categorical analysis by logistic regression, using the CATMOD procedure of SAS (SAS Institute 1985).

RESULTS

Douglas-fir stumps occurred in 38 of the 83 stands sampled, western hemlock stumps in 75, amabilis fir stumps in 25, and Sitka spruce stumps in 11. The only stands that contained a sufficient number of Sitka spruce stumps to make a sample were on the Queen Charlotte Islands. For each species, a majority of the stands sampled had stumps in the 5, 10, and 15 cm diameter classes, about 40 percent of stands contained 20 cm diameter stumps and only two or three stands had 25 cm diameter stumps. The number of stands available for sampling varied for each species, stump diameter class and season of thinning. Consequently, unequal numbers of stands were sampled. For example, the number of stands precommercially thinned in each season varied due to operational constraints

Table 1. Infection of precommercial thinning stumps by _Heterobasidion annosum_ in coniferous forest stands in coastal British Columbia.

Species	Stands	Stumps Colonized	Stumps ≥ 10% Area Colonized	Area Colonized All Stumps	Area Colonized Inf. Stumps
	No.	Pct	Pct	Pct	Pct
Douglas-fir	38	5.9a+	2.7	1.6	16.0a+
Hemlock	75	9.8b	7.0	4.3	27.7b
Sitka spruce	11	16.8c	12.7	11.4	32.3b
Amabilis fir	25	21.3d	15.8	8.6	32.7b

+ Means within the column followed by a different letter are significantly different ($P < 0.01$) according to Duncan's multiple range test.

such as snow depth in the winter and spring (particularly in high elevation western hemlock-amabilis fir stands) and fire hazard during the summer.

The entire surface of stumps of western hemlock, amabilis fir and Sitka spruce was susceptible to infection by airborne spores, whereas only the sapwood of Douglas-fir stumps, which comprised about 69 percent of the surface area, could be infected by airborne spores. _Heterobasidion annosum_ was not found in any stumps from nine of the 83 stands sampled; two stands contained only Douglas-fir stumps and seven stands contained Douglas-fir and western hemlock stumps. Four of the nine stands were thinned in the spring, one in the summer, three in the autumn and one in the winter.

Species Susceptibility

Species susceptibility as indicated by percent stumps infected and percent surface area colonized on infected stumps was (in increasing order) Douglas-fir, western hemlock, Sitka spruce, and amabilis fir (Table 1). Disease incidence values for the species differed significantly ($P<0.01$) from each other, and values for percent stump surface area colonized for hemlock, Sitka spruce, and amabilis fir differed significantly (P(0.01) from that for Douglas-fir. Species susceptibility differences also are apparent from the distribution of mean disease incidence and mean percent surface area colonized for stands containing each species (Figs. 2 and 3). Most notably, the percentage of stands lacking or with low incidence of diseased stumps and low stump surface area colonized is high for Douglas-fir and low for amabilis fir and Sitka spruce.

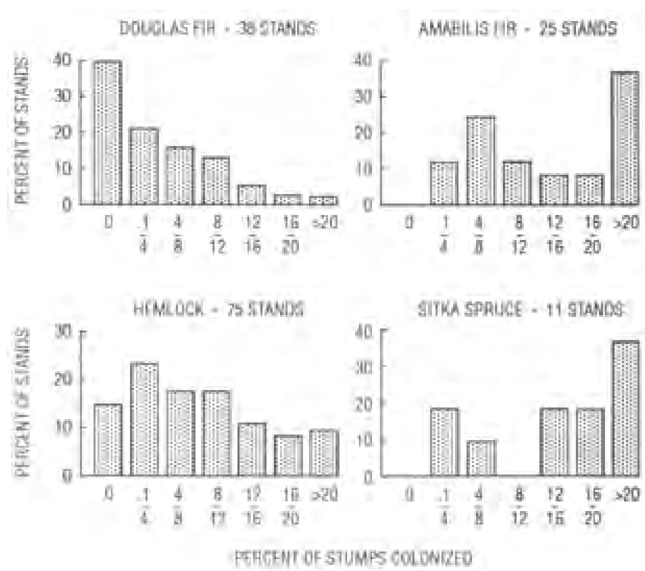


Figure 2--Percentage of conifer forest stands containing Douglas-fir, western hemlock, Sitka spruce, and amabilis fir within categories of percent stumps colonized by _Heterobasidion annosum_ in coastal British Columbia.

Stump Diameter

For stumps in the 5-20 cm diameter classes of each species, the percentage colonized by _H. annosum_ increased with increasing stump diameter. Percent stumps colonized plotted against stump susceptible area is essentially linear (Fig.4). Percent surface area colonized also increased with increasing diameter for 5-20 cm stumps (Fig.5). Except for Sitka spruce, surface area colonized was lower for 25 cm diameter stumps than for 20 cm diameter stumps.

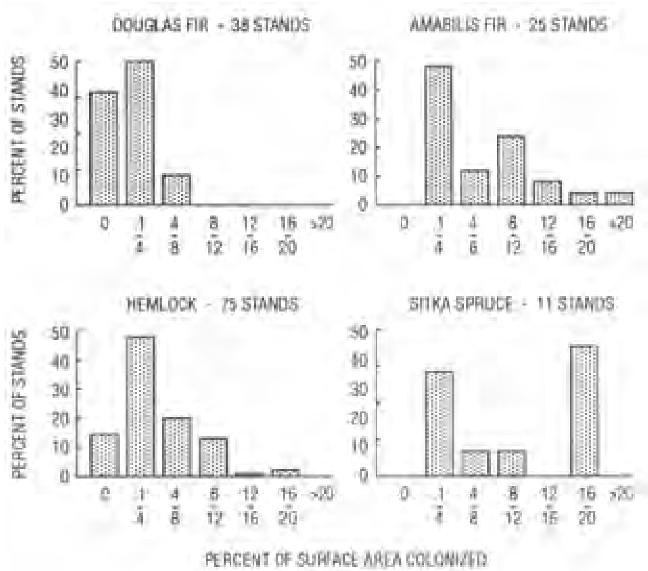


Figure 3--Percentage of conifer forest stands containing Douglas-fir, western hemlock, Sitka spruce, and amabilis fir within categories of percent surface area colonized by Heterobasidion annosum in coastal British Columbia.

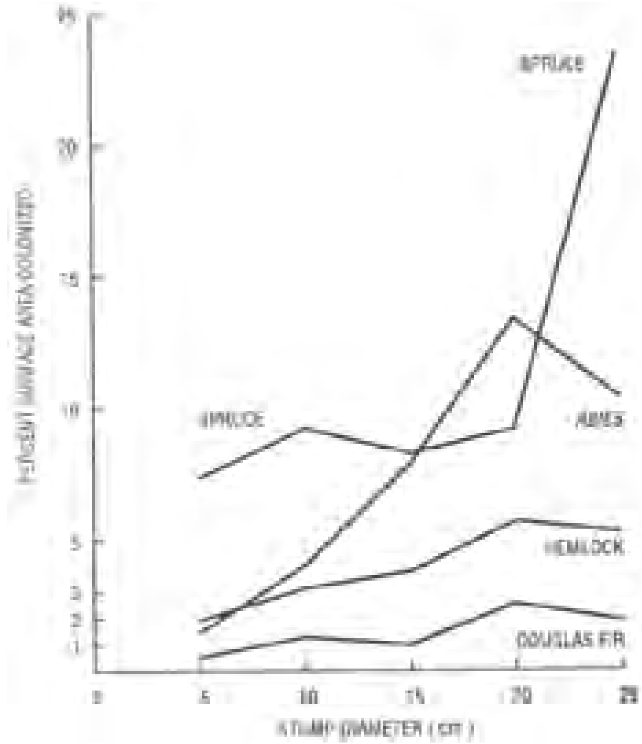


Figure 5--Percentage of stump surface area colonized by Heterobasidion annosum for stumps 5-25 cm in diameter from coniferous forest stands in coastal British Columbia.

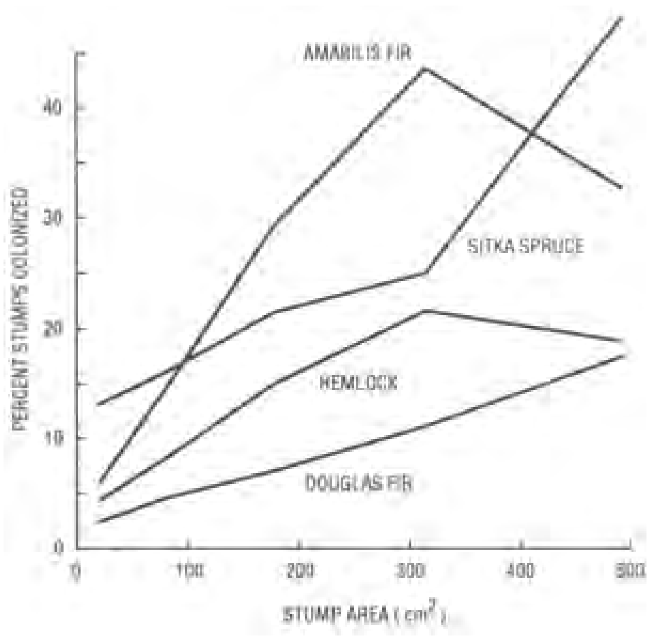


Figure 4--Percentage of stumps colonized by Heterobasidion annosum plotted against area of 5-25 cm diameter stumps from coniferous forest stands in coastal British Columbia.

Season of Thinning

Data for stumps of each species show a season-of-thinning pattern for percent stumps colonized and percent stump surface area colonized (Table 2). For each species, the pattern was identical for both parameters. Variation due to season of thinning when compared to the residual variation among stands was non significant. The maximum value of each of those parameters occurred in the summer for Douglas-fir, western hemlock, and Sitka spruce and in the autumn for amabilis fir. The minimum values for each of those parameters occurred in the spring for Douglas-fir and amabilis fir, in the winter for Sitka spruce, and in the autumn and winter for western hemlock. There was little difference among values for two or three seasons for Douglas-fir, western hemlock, and Sitka spruce. Amabilis fir showed the most seasonal variation and Douglas-fir the least.

Table 2. Effect of season-of-thinning on the percentage of thinning stumps colonized and the percentage of susceptible area colonized by Heterobasidion annosum in coniferous forest stands in coastal British Columbia.

Season	Douglas-Fir		Hemlock		Amabilis Fir		Sitka Spruce	
	Colon. Pct	Area Pct	Colon. Pct	Area Pct	Colon. Pct	Area Pct	Colon. Pct	Area Pct
Mar-May	3.0	0.6	10.8	4.2	4.0	1.1	18.0	9.1
Jun-Aug	7.8	3.1	13.1	5.6	12.9	3.6	24.3	14.7
Sep-Nov	6.4	1.4	8.1	3.4	30.4	12.4	18.8	13.0
Dec-Feb	5.8	1.4	9.1	3.4	16.2	10.1	15.1	5.4

DISCUSSION

The amount of airborne inoculum of H. annosum at the time of stand thinning is the most important factor determining the incidence of infection and percentage of stump surface area colonized (Rishbeth 1957, Meredith 1959, Yde-Andersen 1962). A retrospective, quantitative measure of inoculum in each stand was not possible; however, the occurrence of stumps colonized by H. Annosum in 74 of 83 stands confirms previous reports (Reynolds and Wallis 1966, Morrison and Johnson 1970) of the geographical and temporal distribution of the fungus. The nine Douglas-fir or Douglas-fir-hemlock stands in which H. annosum-colonized stumps were not found lacked a common characteristic. The absence of colonized stumps may be related to species composition of the previous stand, in that stands lacking a hemlock component in the old growth are less likely to contain H. annosum inoculum.

The increasing order of susceptibility of the four species was identical to that reported for the Prince Rupert Forest Region (Morrison and others 1986). In the 1986 study, the percentage of Douglas-fir stumps colonised was about one-half that in this study, and for the other species it was 20-30 percent lower in this study. These differences may be attributed to a larger number of stands representing a wider range of geographical location, stump diameter and season of thinning. The average percentages of stumps infected for uninoculated hemlock and Sitka spruce in southeastern Alaska (Shaw 1981) were 3 percent and 12 percent, respectively, which are somewhat lower than for those species on the Queen Charlotte Islands. The difference in incidence between those locations is difficult to explain. The tree species and climate are identical; however, sporophores are common on old-growth hemlock stumps on the Queen Charlotte Islands whereas they appear to be rare in southeastern Alaska (Shaw 1981). The incidence of H. annosum in stumps of both species 6-15 months after inoculation with conidia and mycelial fragments of H. annosum (Shaw 1981) was similar to the natural incidence observed in this study, suggesting that lower spore populations in Alaska may account for the difference in natural incidence of colonized stumps.

Predictably, target size (stump diameter) is an important determinant of disease incidence, particularly when inoculum levels are low. With abundant inoculum, the lines in Figure 3 could be expected to be parallel to the x-axis. In addition, if inoculum is limiting, the percent surface area colonized would be directly related to stump diameter. In each stand sampled, the age when cut of stumps of all diameters were within 2-3 years of the mean for the stand. If inoculum is not limiting, the increase in percentage of surface area colonized with increasing stump diameter suggests that larger diameter stumps with wider growth rings are more readily colonized than are smaller diameter stumps.

The marked seasonal variation in the incidence of stump colonization by H. annosum observed in Norway spruce by Yde-Andersen (1962) and in pines by Rishbeth (1957) and Meredith (1959) was attributed to weather and fungal competitors. The clear seasonal patterns evident for uninoculated hemlock and Douglas-fir stumps 0.5 year after thinning were much less pronounced and somewhat altered 5 yr after thinning (Morrison and Johnson 1978). In this study, competition from other primary colonizers did not appear to limit the incidence of H. annosum. In most stands, a number of the stumps sampled were free from Basidiomycete colonizers, except for _Armillaria sinapina_ Bérubé & Dessureault which spread from the roots and invaded the sapwood. Redfern (1989) showed that high moisture content resulting from high rainfall is likely to reduce stump infection by _H. annosum_ in Sitka spruce. His results undoubtedly apply to other tree species and may explain the lower incidence of _H. annosum_ in stumps cut from late autumn to early spring in coastal B.C.

At the beginning of this study, the questions were: Can species, stump diameter, and season of thinning be hazard-rated for stump colonization by _H. annosum_, and if so, is the hazard low enough in any category to make stump treatment unnecessary and conversely, where should stump treatment be recommended. The proportion of stands (0.4) in which no Douglas-fir stumps were colonized, and the low incidence and low percentage of surface area colonized in most of the other stands indicate that the hazard for Douglas-fir is low. In contrast, the high values of these parameters for amabilis fir and Sitka spruce suggest that the hazard for these species is high, and that treatment of stumps of these species should be considered.

ACKNOWLEDGMENTS

I thank Alan Johnson for technical assistance and Clarence Simmons for statistical analyses.

REFERENCES

Dimitri, L.; Zycha, H.; Kliefoth, R. 1971. Untersuchungen über die Bedeutung der Stubbeninfektion durch _Fomes annosus_ für die Ausbreitung der rotfäule der Fichte. Forstwissenschaftliches Centralblatt 90:104-117.

Klinka, K.; Green, R.N.; Courtin, P.J.; Nuszdorfer, F.C. 1984. Site diagnosis, tree species selection, and slash burning guidelines for the Vancouver Forest Region. Land Management Report 25, British Columbia Ministry of Forests, Victoria.

Krajina, V.J. 1965. Biogeoclimatic zones and classification of British Columbia. In: V.J. Krajina, ed. Ecology of Western North America 1:1-17. Botany Department, University of British Columbia

Meredith, D.S. 1959. Infection of pine stumps by _Fomes annosus_ and other fungi. Annals of Botany, New Series 23:455-476.

Morrison, D.J.; Johnson, A.L.S. 1970. Seasonal variation of stump infection by _Fomes annosus_ in coastal British Columbia. Forestry Chronicle 46:200-202.

Morrison, D.J.; Johnson, A.L.S. 1978. Stump colonization and spread of _Fomes annosus_ 5 years after thinning. Canadian Journal of Forest Research 8:177-180.

Morrison, D.J.; Larock, M.D.; Waters, A.J. 1986. Stump infection by _Fomes annosus_ in spaced stands in the Prince Rupert Forest Region of British Columbia. Report BC-X-285. Canadian Forestry Service, Pacific Forestry Centre, Victoria B.C.; 12 pp.

SAS Institute Inc. 1985. User's Guide: Statistics, Version 5 Edition. Cary, NC: SAS Institute Inc.; 956pp.

Redfern, D.B. 1989. Factors affecting infection of Sitka spruce stumps by _Heterobasidion annosum_ and the implications for disease development. pages 297-307 In: D.J. Morrison, ed. Proceedings of the Seventh International Conference on Root and Butt Rots. Forestry Canada, Pacific Forestry Centre, Victoria, B.C.; 680 pp.

Reynolds, G.; Wallis, G.W. 1966. Seasonal variation in spore deposition of _Fomes annosus,_ in coastal forests of British Columbia. Canadian Forestry Service Bi-monthly Research Notes 22:6-7.

Rishbeth, J. 1957. Some further observations on _Fomes annosus_ Fr. Forestry 30:69-89.

Shaw, C.G. III. 1981. Infection of western hemlock and Sitka spruce thinning stumps by _Fomes annosus_ and _Armillaria mellea_ in southeast Alaska. Plant Disease 65:967-971.

Wallis, G.W.; Reynolds, G. 1970. _Fomes annosus_ root and butt rot: A threat in coastal British Columbia. Forestry Chronicle 46:221-224.

Yde-Andersen, A. 1962. Seasonal incidence of stump infection in Norway spruce by air-borne _Fomes annosus_ spores. Forest Science 8:98-103.

Is *Heterobasidion annosum* Poorly Adapted to Incite Disease in Cool, Wet Environments?[1]

Charles G. Shaw, III[2]

Abstract: An argument is advanced to suggest that infection and damage caused in coniferous forests by Heterobasidion annosum are markedly less severe, and survival of the fungus less common, under cool, wet conditions than in other climates. This premise is supported by the author's incisive insights, experience in southeastern Alaska, and data from this area and from other sources. In general, frequent rains reduce the population of airborne spores and wash many of them from stump surfaces. Cool temperatures reduce evaporation of water which helps to maintain a high moisture content in stumps that hinders development of H. annosum. This cool, wet condition also lowers overall metabolic rates and reduces the availability of oxygen, which further inhibits infection by, and survival of, H. annosum in stumps. In contrast, primarily saprophytic Armillaria spp. survive under these same conditions and, through rather rapid colonization of stumps and roots, limit the opportunity for whatever colonies of H. annosum do become established to spread and incite disease in surrounding trees.

Heterobasidion annosum (Fr.) Karst. damages numerous coniferous tree species growing under various, primarily temperate, environmental conditions in many localities around the world (Pegler and Waterston 1968). It is the purposely provocative premise of this paper, however, that damage from this organism is markedly less in cool, wet environments than in those characterized by either warm and wet (the southeastern United States), warm and dry (the east side of the Sierra Nevada mountains and south-central Oregon), or cool and dry climates (interior Scandinavia).

I developed this hypothesis of limited impact from annosus root disease in cool, wet environments after years of often being cold and sopping-wet while doing fieldwork in southeastern Alaska. That work revealed limited infection by, and survival of, H. annosum in stumps of Sitka spruce (Picea stichensis (Bong.) Carr.) and western hemlock (Tsuga heterophylla (Raf.) Sarg.)--and no damage caused in standing trees (Shaw 1981a, 1989). Additional data to support the hypothesis were selectively obtained from other sources.

THE SITUATION IN SOUTHEASTERN ALASKA

Over 160,000 ha of old-growth Sitka spruce/ western hemlock forest have been clearcut harvested on the mainland and islands of southeastern Alaska (W. Farr, 1989, Research Mensurationist, Juneau Alaska, Personal Communication). Young stands of these species have regenerated naturally into the clearcut areas, generally with adequate stocking and vigorous growth (Harris 1974). At age 15-20 years, many of these stands are precommercially thinned--an operation that creates numerous stumps that may serve as infection courts for root disease fungi.

Spores of H. annosum and Armillaria spp. are relatively common in these young stands, even though basidiocarps of H. annosum are rare (Shaw 1981a,b), as are infections of large and small stumps of both of those tree species (Shaw 1981a, 1985, 1989, Tait and others 1985). In contrast, stumps frequently are colonized by Armillaria spp. (Shaw 1981a, 1985, 1989, Tait and others 1985), probably by contact of their roots with rhizomorphs or infected roots rather than by spores (Wargo and Shaw 1985). Nevertheless, few surrounding trees die.

Butt and stem decay are common in old-growth trees in the area. In old, affected stands, gross timber volumes have often been reduced by one-third or more (Farr and others 1976) by rot caused primarily by hymenomycetes--H. annosum, Armillaria spp., and Phaeolus schweinitzii (Fr.) Pat (Kimmey 1956). Even in these old-growth forests, however, sporophores of H. annosum are rare--as noted by Kimmey on an herbarium collection form filed at the Forestry Sciences Laboratory in Juneau, Alaska. In addition, T. Laurent (1981, forest pathologist, Juneau Alaska; personal communication) found no basidiocarps of H. annosum, although decay caused by it was common, during the dissection of 1776 trees to measure cull volumes at 67 locations in southeastern Alaska (Farr and others 1976). Several basidiocarps previously collected in southeastern Alaska and identified as those of H. annosum (Cooke 1955, Cooke and Shaw 1952) have been reexamined and found to be

[1] Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, CA.

[2] Research Plant Pathologist and Project Leader, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

those of Fomitopsis pinicola (Swartz: Fr.) Karst (R. Gilbertson, 1981, mycologist, University of Arizona; personal communication). During 9 years of collecting in southeastern Alaska, I gathered basidiocarps of H. annosum only once (Shaw and Florance 1979) and, even with a monetary bounty inducement, all students except one found none. Thus, the source of the airborne spore inoculum that does exist remains an enigma (Shaw 1981a, b). Perhaps conidia are involved (Florance and Shaw 1988, Shaw and Florance 1979).

As indicated, the results of several studies in southeastern Alaska showed limited stump colonization by H. annosum--an event which is considered to be a necessary precursor to development of damaging levels of disease caused by H. annosum in managed, young stands of Sitka spruce and western hemlock. Because of this situation, I have concluded (Shaw 1989) that, in southeastern Alaska, there is little likelihood that H. annosum will damage young, managed stands of Sitka spruce and western hemlock within the planned 90- to 120-year rotation. The question, however, still remains--Why not?

ENVIRONMENTAL CONDITION OF STUMPS

My data (Shaw 1981a, 1985, 1989) and those of Morrison (1976, Morrison and others 1986) indicate that H. annosum becomes a less common inhabitant of thinning stumps with movement northward along the west coast of North America. With movement north, lower temperatures (Farr and Harris 1979) and higher precipitation (Farr and Hard 1987) probably reduce the aerial spore population of H. annosum (Reynolds and Wallis 1966). The frequent and often heavy rains also are likely to wash many spores from stump surfaces. In Scotland, near the latitude of southeastern Alaska, Redfern (1982) suggests that infection of Sitka spruce stumps may be limited by high rainfall, and that on sites with high rainfall, H. annosum is absent from stumps with a high moisture content. These results resemble those found in southeastern Alaska where rain is common on any date (Farr and Hard 1987) and where the moisture contents (on a percent dry weight basis) of Sitka spruce and western hemlock stumps are often well over 100 percent (Shaw 1989).

Perhaps the high moisture content of these stumps reduces the availability of 0_2 to a level that inhibits growth of H. annosum--a reason suggested for the lack of growth by H. annosum in white fir wetwood (Worrall and Parmeter 1983). The low temperatures common in southeastern Alaska could further affect fungal utilization of the limited 0_2 available because they would lower overall metabolic rates of the pathogen and inhibit the evaporation of water from stump surfaces.

In vitro studies indicate that H. annosum (Worrall and Parmeter 1983), Armillaria spp. (Smith and Griffin 1971, Worrall and others 1986), and an array of other wood-decaying fungi (Jensen 1967, Scheffer 1986, Worrall and Parmeter 1983) can grow at extremely low levels of available 0_2. Extrapolation of these in vitro results to decay of stumps in situ may not, however, be appropriate. Availability of 0_2 in woody substrates is complicated by the patterns of water and air distribution in cell walls and pores, and how this distribution is affected by decay, moisture content, temperature, and other microenvironmental factors (Boddy 1983).

The moisture content of wood at which no air spaces would remain can be calculated if the specific gravity (SG) of the species in question and that of solid wood substance are known. I made such theoretical calculations, using 1.5 for the SC of solid wood substance, a value that is rather constant regardless of tree species (Wangaard 1950), and a range of values between 0.34 and 0.44 for the SC of wood from young Sitka spruce and western hemlock trees in southeastern Alaska (Farr 1973). These calculations indicate that, at a moisture content between 161 percent and 227 percent (depending on SG), all pore spaces in these woods would be water-filled and thus unavailable for air. Many stumps in southeastern Alaska have moisture contents that high (Shaw 1989).

The results of in vitro studies indicate that decay by certain fungi is inhibited in Sitka spruce wood at moisture contents around 150 percent and that decay stops near 190 percent (Boyce 1961)--a value within the theoretical range (as calculated above) for all available wood pore spaces to be water-filled. Redfern (1989) suggests that at moisture saturation levels somewhere between 70 and 80 percent, Sitka spruce wood is unsuitable for growth of H. annosum. Using a SG of 0.36, this 70 percent saturation level corresponds to a moisture content of 147 percent, a value that is exceeded in many of the stumps in southeastern Alaska, particularly Sitka spruce (Shaw 1989). Even though in southeastern Alaska, H. annosum frequently failed to colonize stumps with a moisture content below that necessary for total occupancy of the pore spaces by water, these calculations appear to support the contention that the reduced availability of 0_2 may limit colonization of wet, cool stumps by H. annosum.

Growth of Armillaria spp. also may be reduced at extremely low levels of available 0_2 (Smith and Griffin 1971, Worrall and others 1986). However, three features of stump colonization by this fungus, in contrast to that by H. annosum, could allow Armillaria spp. to survive in 0_2-poor stump wood:

1) Typically, H. annosum initially colonizes the more interior portions of stumps, while Armillaria initiates colonization between the bark and wood where more air is likely to be present.

2) Rhizomorphs of Armillaria spp., which

are common on interior surfaces of bark on these stumps and in the surrounding soil, can absorb O_2 at their growing tips (Smith and Griffin 1971). Although it is unclear how far back along the rhizomorph such absorbed O_2 might be transported and utilized, certain ions can be transported basipetally within rhizomorphs (Granlund and others 1985, Morrison 1975). Morrison (1976) also suggested that, when Armillaria grows from buried wood blocks with a high moisture content (170 percent), which thus have a limited supply of O_2 available in the food base, the O_2 requirement for fungal growth may be met by absorption from the soil atmosphere. Depending on the effective distance of O_2 transport along the rhizomorph, this mechanism may allow for growth of mycelium that is located in an O_2-poor, wood environment.

3) Growth of Armillaria may be stimulated, even at low levels of O_2 (Worrall and others 1986), by ethanol (Weingold and Garroway 1966), which can be a by-product of metabolism in Armillaria spp. (Tarry 1968) and other common soil microorganisms often associated with Armillaria spp.

The frequent occurrence of Armillaria spp. in stumps from southeastern Alaska (Shaw 1989, Tait and others 1985) agrees with data from northern British Columbia (Morrison and others 1986) where 32 percent of the non-pine stumps were infected with an Armillaria sp. identified as North American Biological Species (NABS) V (Anderson and Ullrich 1979). The NABS of Armillaria spp. in stumps from southeastern Alaska are poorly understood, but NABS V and IX are common in the region (Shaw and Loopstra 1988). Because these two species have limited pathogenic capabilities on coastal species and sites (Morrison and others 1985, Shaw and Loopstra 1988, Wargo and Shaw 1985), their common occupancy of stump wood may deter spread of the limited H. annosum that does inhabit stumps, rather than act as an incitant of disease (Greig 1962, Morrison and Johnson 1978, Shaw 1981a, 1989).

WHAT DOES IT ALL MEAN?

Some might consider these ramblings to be rash, data-free analysis. I challenge those active in research on H. annosum, however, to critically evaluate the following scenarios, to find the researchable topics, and go at it! Heterobasidion annosum is markedly less able to incite disease in managed, young stands growing under cool, wet conditions than in other climates. This situation develops because in a cool, wet environment the airborne population of spores is reduced and many of those that are deposited on stump surfaces are washed away. In addition, low temperatures reduce evaporation of water which helps to maintain a high moisture content in stumps. This condition reduces the availability of O_2, thereby inhibiting infection by, and survival of, H. annosum in stumps. Low temperatures also reduce the ability of H. annosum to utilize the limited O_2 that is available by lowering overall metabolic rates. In contrast, the primarily saprophytic Armillaria spp. survive under those conditions and, through rather rapid colonization of stump and root wood, limit the opportunity for whatever H. annosum does become established to spread and incite disease in surrounding trees.

An alternate scenario is that H. annosum becomes established in aboveground wounds on standing, live trees rather than through contact with roots of infected stumps (Pawsey and Gladman 1965). Such aboveground wounds may offer a dryer, more hospitable infection court than water-logged stumps. They are likely the sites where H. annosum became established decades ago in old-growth trees in southeastern Alaska that now contain extensive decay columns caused by H. annosum. Even though substantial levels of stump infection are generally considered a prerequisite to development of damaging disease levels in managed, young stands, a preponderance of stem wounds, if infected with H. annosum, could be important in disease development. The importance of aboveground wound infection increases when there is an extended time period between thinning and final harvest (that is, 50 or more years), as is anticipated for managed, young stands in southeastern Alaska. Thus, this possibility also needs investigation.

REFERENCES

Anderson, J.B.; Ullrich, R.C. 1979. Biological species of Armillaria mellea in North America. Mycologia 71:402-414.

Boddy, L. 1983. Microclimate and moisture dynamics of wood decomposing in terrestrial ecosystems. Soil Biology and Biochemistry 15:149-157.

Boyce, J.S. 1961. Forest Pathology. New York: McGraw-Hill. 572 p.

Cooke, W.B. 1955. Some fungi from Alaska. Northwest Science 29:127-138.

Cooke, W.B.; Shaw, C.G. 1952. Notes on Alaskan fungi. Washington State College Research Studies 20:15-20.

Farr, W.A. 1973. Specific gravity of western hemlock and Sitka spruce in southeast Alaska. Wood Science 6:9-13.

Farr, W.A.; Hard, J.S. 1987. Multivariate analysis of climate along the southern coast of Alaska--some forestry implications. Res. Paper PNW-372. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 38 p.

Farr, W.A.; Harris, A.S. 1979. Site index of Sitka spruce along the Pacific coast related to latitude and temperatures. Forest Science 25:145-153.

Farr, W.A.; Labau, V.J.; Laurent, T.H. 1976. Estimation of decay in old-growth western hemlock and Sitka spruce in southeast

Alaska. Res. Paper PNW-204. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 24 p.

Florance, E.R.; Shaw, C.G., III. 1988. Surface morphology of basidiospores from decay fungi that are common in Pacific Northwest forests. Northwest Science 62:233-241.

Granlund, H.I.; Jennings, O.H.; Thompson, W. 1985. Translocation of solutes along rhizomorphs of Armillaria mellea. Transactions of the British Mycological Society 84:111-119.

Greig, B.J.W. 1962. Fomes annosus (Fr.) Cke. and other root-rotting fungi in conifers on ex-hardwood sites. Forestry 35:164-182.

Harris, A.S. 1974. Clearcutting, reforestation and stand development on Alaska's Tongass National Forest. Journal of Forestry 72:330-337.

Jensen, K.F. 1967. Oxygen and carbon dioxide affect the growth of wood-decaying fungi. Forest Science 13:384-389.

Kimmey, J.W. 1956. Cull factors for Sitka spruce, western hemlock and western redcedar in southeast Alaska. Sta. Paper No. 6, Juneau, AK: Alaska Forest Research Center, Forest Service, U.S. Department of Agriculture; 31 p.

Morrison, D.J. 1975. Ion uptake by rhizomorphs of Armillaria mellea. Canadian Journal of Botany 53:48-51.

Morrison, D.J. 1976. Vertical distribution of Armillaria mellea rhizomorphs in soil. Transactions of the British Mycological Society 66:393-399.

Morrison, D.J.; Chu, D.; Johnson, A.L.S. 1985. Species of Armillaria in British Columbia. Canadian Journal of Plant Pathology 7:242-246.

Morrison, D.J.; Johnson, A.L.S. 1978. Stump colonization and spread of Fomes annosus 5 years after thinning. Canadian Journal of Forest Research 8:177-180.

Morrison, D.J.; Larock, M.D.; Waters, A.J. 1986. Stump infection by Fomes annosus in spaced stands in the Prince Rupert forest region of British Columbia. Inf. Rep. BC-X-285. Victoria, BC: Pacific Forest Research Centre, Canadian Forest Service. 12 p.

Pawsey, R.G.; Gladman, R.J. 1965. Decay in standing conifers developing from extraction damage. H.M.S.O. London: Forestry Commission Forest Record No. 54. 25 p.

Pegler, D.N.; Waterston, J.M. 1968. Heterobasidion annosum. Descriptions of Pathogenic Fungi and Bacteria, Set 20, No. 192. London: Commonwealth Mycological Institute. 2 p.

Redfern, D.B. 1982. Infection of Picea sitchensis and Pinus contorta stumps by basidiospores of Heterobasidion annosum. European Journal of Forest Pathology 12:11-25.

Redfern, D.B. 1989. Factors affecting infection of Sitka spruce stumps by Heterobasidion annosum and the implications for disease development. Pages 297-307 in: D.J. Morrison, ed. Proceedings of the 7th IUFRO Conference Root and Butt Rot in Forest Trees; 1988 August; Vernon and Victoria, BC: Pacific Forest Research Centre. 680 p.

Reynolds, G.; Wallis, G.W. 1966. Seasonal variation in spore deposition of Fomes annosus in coastal forests of British Columbia. Canadian Forest Service Bi-monthly Research Notes 22(4):6-7.

Scheffer, T.C. 1986. 0_2 requirements for growth and survival of wood-decaying and sapwood-staining fungi. Canadian Journal of Botany 64:1957-1963.

Shaw, C.G., III. 1981a. Infection of western hemlock and Sitka spruce thinning stumps by Fomes annosus and Armillaria mellea in southeast Alaska. Plant Disease 65:967-971.

Shaw, C.G., III. 1981b. Basidiospores of Armillaria mellea survive an Alaskan winter on tree bark. Plant Disease 65:972-974.

Shaw, C.G., III. 1985. Colonization of conifer thinning stumps by root disease fungi in SE Alaska. Phytopathology 75:1294 (Abstract).

Shaw, C.G., III. 1989. Root disease threat minimal in young stands of western hemlock and Sitka spruce in southeast Alaska. Plant Disease 73:573-577.

Shaw, C.G., III; Florance, E.R. 1979. Scanning electron microscopy reveals differences in surface morphology between basidiospores and conidia of Heterobasidion annosum. European Journal of Forest Pathology 9:249-254.

Shaw, C.G., III; Loopstra, E. 1988. Identification and pathogenicity of some Alaskan isolates of Armillaria. Phytopathology 78:971-974.

Smith, A.M.; Griffin, D.M. 1971. Oxygen and the ecology of Armillaria elegans Heim. Australian Journal of Biological Sciences 24:231-262.

Tait, S.M.; Shaw, C.G., III; Eglitis, A. 1985. Occurrence of insect and disease pests on young-growth Sitka spruce and western hemlock in southeastern Alaska. Res. Note PNW-433. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Dept. of Agriculture; 16 p.

Tarry, J.C. 1968. The dieback of Ceanothus with emphasis on some of the physiological aspects of Armillaria mellea. Pullman, WA: Washington State University. Ph.D. thesis. 102 p.

Wangaard, F.F. 1950. The mechanical properties of wood. New York: John Wiley & Sons. 377 p.

Wargo, P.M.; Shaw, C.G., III. 1985. Armillaria root rot--the puzzle is being solved. Plant Disease 69:826-832.

Weinhold, A.R.; Garroway, M.O. 1966. Nitrogen and carbon nutrition of Armillaria mellea in relation to growth promoting effects of ethanol. Phytopathology 56:108-112.

Worrall, J.J.; Chet, I.; Huttermann, A. 1986. Association of rhizomorph formation with laccase activity in Armillaria spp. Journal of General Microbiology 132:2527-2533.

Worrall, J.J.; Parmeter, J.R., Jr. 1983. Inhibition of wood-decay fungi by wetwood of white fir. Phytopathology 73:1140-1145.

Interactions of Root Disease and Bark Beetles[1]

George T. Ferrell **J. Richard Parmeter, Jr.**[2]

Abstract: Associations between root diseases and bark beetles (Scolytidae) constitute some of the most serious pest complexes affecting forests in North America and elsewhere. The interactive functioning of these pests derives from the following relationships: 1) root diseases predispose trees to bark beetle infestation by lowering resistance, and perhaps increasing attractiveness, of trees to the attacking beetles; 2) bark beetles may be vectors of root disease fungi or may create infection courts for them.

Symbioses between bark beetles and fungi are common in nature, and previous reviewers (e.g., Graham 1967) have identified several types of these symbiotic relationships, some of which appear to be beneficial to both (mutualism), and others which apparently benefit only one (competition, predation, parasitism). These relationships will be discussed in relation to interactions between root diseases and bark beetles. Others, which benefit neither (i.e., commensalism or cohabitation), are not considered to be true interactions as defined here, and will not be further mentioned.

VECTORING

Virtually all bark beetles vector fungi to host trees, inoculating the phloem and xylem as they mine in the cambial region. Much studied are the pathogenic blue- and brown-staining fungi, vectored by stem- and twig-infesting beetles. These fungi largely infect above-ground host tissues and thus are not true root pathogens. Bark beetles can also carry propagules of saprot fungi (Castello and others 1976; Harrington 1980), which may explain the rapid decay of sapwood following tree-killing by bark beetles. Despite much research, vectoring of root disease fungi by stem-infesting bark beetles has not yet been firmly established, but they have been implicated as vectors of Peniophora gigantea (Fr.) Jul., a fungal antagonist of Heterobasidion annosum (Hunt and Cobb 1982). Recently, however, a species of root-colonizing bark beetle in the genus Hylastes and root-colonizing species of the weevil genera Steremnius and Pissodes have been implicated in vectoring Leptographium (Verticicladiella) wageneri (Kendr.) Wingf., the fungus causing black-stain root disease in Douglas-fir (Harrington and others 1985, Witcosky and others 1986a). As these vectors readily breed in roots of recently cut stumps, their populations evidently increase in stands after thinning (Harrington and others 1985; Witcosky and others 1986b). Previously, another root-colonizing species of Hylastes had been implicated as a vector of this fungus in ponderosa pine (Goheen and Cobb 1978). As other root-colonizing beetles are studied, more species will probably be implicated as vectors of root disease fungi.

Vectoring of H. annosum by bark beetles has not been confirmed. Nuorteva and Laine (1968) and Hodges (1969) reviewed literature on the possibility of insect vectoring. Nuorteva and Laine showed that various beetles could become contaminated with conidia by walking across agar cultures of H. annosum. Hunt and others (1976, 1982) discussed the possibility of insect vectoring of H. annosum in western North America. They concluded that even though conidia and basidiospores are produced on stumps, it is unlikely that insects play a major role in dissemination of H. annosum. However, circumstantial evidence and the observations that annosus root disease can appear in stands with no history of cutting suggest that the possibility of at least occasional spread of H. annosum by insect vectors cannot yet be excluded. Because the initiation of new centers of annosus-caused mortality in western timber stands appears to be a relatively rare event, even infrequent insect vectoring could be important. The initiation of one or two such centers per acre over an 80-year rotation could have serious impacts.

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2]Research Entomologist, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif., and Professor of Plant Pathology, University of California, Berkeley, Calif.

PREDISPOSITION

The role of root diseases in predisposing trees to bark beetles was largely ignored in early studies of bark beetle population dynamics and control. More recent studies (Partridge and Miller 1972, Cobb and others 1974, Lane and Goheen 1979, Alexander and others 1980) have revealed that, where bark beetle populations are not in outbreak phase, a high proportion of trees killed by bark beetles also are root-diseased. However, Cobb and others (1974) found that, where bark beetle outbreaks are in progress, the proportion of killed trees that also are root-diseased tends to be lower, suggesting that root-diseased trees act as foci from which bark beetle outbreaks can spread during droughts or other widespread tree stress.

Physiologically, the predisposition of root-diseased trees to bark beetle attack has been shown to involve such indications of subnormal physiology as increased moisture stress and reduced resin exudation pressure, both of which are known to signify reduced tree resistance to bark beetle attack (Stark and Cobb 1969, Ferrell and Smith 1976). There is also some evidence that ponderosa pines with black-stain root disease are attractive to certain species of _Dendroctonus_ bark beetles before they initiate mines and concomitantly produce attractants (Goheen and others 1985). Similarly, in Douglas-fir, segments of roots with black-stain root disease were more attractive to the _Hylastes_ and _Steremnius_ vectors of the black-stain fungus than were segments of uninfected roots (Witcosky and others 1987).

Other than the vectoring of pathogenic fungi to trees, there is presently little evidence supporting the idea that bark beetles predispose their host trees to root diseases. However, even if root-colonizing beetles are not vectoring fungal pathogens, their feeding wounds in roots may create infection courts for pathogenic fungi present in soil or other, infected, roots. For example, in precommercially thinned Douglas-fir stands, Harrington and others (1985) found numerous feeding wounds of _Hylastes_ beetles in roots of residual trees. None of these wounds was observed to be infected by black-stain disease, but field observations have long implicated lesions in the root cortex as infection courts for _H. annosum_ (see review by Nuorteva and Laine 1968). Hendrix and Kuhlman (1964) found that pine roots could be infected by _H. annosum_ through root wounds, including wounds made by insects. It is therefore likely that insect wounds in roots are important infection courts for _H. annosum_.

COMPETITION

Compared to mutualistic relationships, competitive or other antagonistic interactions between bark beetles and root disease fungi have not been widely reported. But in stumps or at the base of trees, in galleries of stem-infesting beetles invaded by _H. annosum_, the beetles are sometimes observed to be dead and enveloped by mycelium of the fungus (Stark and Borden 1965, Hunt and Cobb 1982). However, root disease infections rarely spread far upward in stems. Thus, on a tree-wide basis, beetle survival would likely not be much reduced by this mortality except for a species like _Dendroctonus valens_ LeConte which seldom attacks its host pines more than two meters above ground.

Competitive or other antagonistic interactions may also occur between the fungal symbionts of stem-infesting bark beetles and root disease fungi. Such interactions could be particularly important in reducing stump colonization by _H. annosum_ in trees felled for bark beetle control. Hunt and Cobb (1982) observed that fungal symbionts of bark beetles frequently co-occur with _H. annosum_ in pine stumps in California. They concluded that although these fungi may reduce the amount of _H. annosum_ colonization somewhat, they had not colonized enough stump surface or volume to reduce _H. annosum_ colonization in pine stumps to a level acceptable to forest managers.

Other interactions may be envisioned. For example, root systems of trees killed by bark beetles might deteriorate too rapidly to provide suitable substrate for root disease fungi. If so, it is possible that early killing of infected trees or their healthy neighbors by bark beetles might reduce the rate of enlargement of root disease centers.

CONCLUSION

Our understanding of the various ways in which bark beetles and root diseases interact remains limited. Interactions in addition to those discussed above may also be important. For example, whether insectan natural enemies of bark beetles might vector root disease fungi has not been widely assessed, but it may be important to do so because of their potential introduction into new environments as biological control agents for bark beetles. With the increased recognition of the importance of interactions between bark beetles and root diseases, it is likely that this field of research will receive increased attention.

Additional research on insect/annosus interactions could greatly benefit forest managers. If spread of _H. annosum_ by insects to roots of trees or stumps is common in some tree species, reduction of insect activity could be an effective adjunct to treatment of stump surfaces to prevent infection by the fungus. Conversely, frequent spread by insects could compromise the effectiveness of stump treatment to prevent colonization. Since H. annosum sporulates mainly in and on stumps, burning or removal of stumps could minimize the opportunities for insects to encounter and disseminate spores. Burning is known to reduce the incidence of annosus root disease (Kallio 1965, Froelich and Dell 1967), but the mechanism of reduction is unknown.

If the maintenance of endemic beetle populations rests in large part on the availability of trees weakened by root disease, early recognition and removal of live trees that are infected or that have a high probability of infection might reduce or delay epidemic build-up of beetles.

The importance of information on these insect/annosus interactions and the opportunity to exploit such information in forest management are almost entirely speculative at present. The potential benefits from the development and use of such information certainly justify additional research effort.

REFERENCES

Alexander, S. A.; Skelly, J. M.; Webb, R. S.; Bardinelli, T. R.; and B.Bradford, 1980. Association of Heterobasidion annosum and the southern pine beetle on loblolly pine. Phytopathology 70: 510-513.

Castello, J. D.; Shaw, C. G.; and M. M. Furniss, 1976. Isolation of Cryptoporus volvatus and Fomes pinicola from Dendroctonus pseudotsugae. Phytopathology 66: 1431-1434.

Cobb, F. W., Jr.; Parmeter, J. R.,Jr.; Wood, D. L.; and R. W. Stark, 1974. Root pathogens as agents predisposing ponderosa pine and white fir to bark beetles. Proceedings of I.U.F.R.O. working party on Fomes annosus; 1973 September 17-21; Athens, GA. New York: Plenum; p. 1-8.

Ferrell. G. T. ; and R. S. Smith, Jr., 1976. Indicators of Fomes annosus root decay and bark beetle susceptibility in sapling white fir. Forest Science 22: 365-369.

Froelich, R. C.; and T. R. Dell, 1967. Prescribed fire as a possible control for Fomes annosus. Phytopathlogy 57: 811. Abstract.

Goheen, D. J.; and F. W. Cobb, Jr.,'1978. Occurrence of Verticicladiella wagenerii and its perfect state Ceratocystis wageneri in insect galleries. Phytopathology 68: 1192-1195.

Goheen, D. J.; Cobb, F. W., Jr.; Wood, D. L.; and D. L. Rowney, 1985. Visitation frequencies of some insect species on Ceratocystis wageneri infected and apparently healthy ponderosa pines. Canadian Entomologist 117: 1535-1543.

Graham, K., 1967. Fungal-insect mutualism in trees and timber. Annual Review of Entomology 12: 105-126.

Harrington, T. C., 1980. Cultural characteristics, bark beetle relationships, and dissemination of Cryptoporus volvatus. Pullman: Washington State University, 75 p. M. S. thesis.

Harrington, T. C.; Cobb, F. W., Jr.; and J. W. Lownsberry, 1985. Activity of Hylastes nigrinus, a vector of Verticicladiella wageneri, in thinned stands of Douglas-fir. Canadian Journal of Forest Research 15: 519-523.

Hendrix, F. F.; and E. G. Kuhlman, 1964. Root infection of Pinus Elliotii by Fomes annosus. Nature 201: 55-56.

Hodges, C. S., 1969. Modes of infection and spread of Fomes annosus. Annual Review of Phytopathology 7: 247-266.

Hunt, R. S.; Cobb, F. W., Jr.; and J. R. Parmeter, Jr., 1976. Fomes annosus stump colonization and fungus development in the California mixed-conifer type. Canadian Journal of Forest Research 6: 159-165.

Hunt, R. S.; and F. W. Cobb, Jr., 1982. Potential arthropod vectors and competing fungi of Fomes annosus in pine stumps. Canadian Journal of Plant Pathology 4: 247-253.

Kallio, T., 1965. Tutkimuskia Maanousemasienen leviamisbiologiasta ja torjuntamahdollisuuksista suomessa. Acta Forestale Fennici 78:1-21.

Lane, B. B.; and D. J. Goheen, 1979. Incidence of root disease in bark beetle-infested eastern Oregon and Washington true firs. Plant Disease Reporter 63: 262-266.

Nuorteva, M.; and L. Laine, 1968. On the possibility of insects as carriers of root fungus (Fomes annosus (Fr.) Cooke). Annales Entomologici Fennici 34: 113-135.

Partridge, A. D.; and D. L. Miller, 1972. Bark beetles and root rots related in Idaho conifers. Plant Disease Reporter 56: 498-500.

Stark, R. W.; and J. H. Borden, 1965. Observations on mortality factors of the fir engraver beetle, Scolytus ventralis (Coleoptera: Scolytidae). Journal of Economic Entomology 58: 1162-1163.

Stark, R. W.; and F. W. Cobb, Jr., 1969. Smog injury, root diseases and bark beetle damage in ponderosa pine. California Agriculture 23: 13-15.

Witcosky, J. J.; Schowalter, T. D.; and E. M. Hansen, 1986a. Hylastes nigrinus(Coleoptera: Scolytidae), Pissodes fasciatus, and Steremnius carinatus (Coleoptera: Curculionidae) as vectors of black-stain root disease of Douglas-fir. Environmental Entomology 15: 1090-1095.

Witcosky, J. J.; Schowalter, T. D.; and E. M. Hansen, 1986b. The influence of time of precommercial thinning on the colonization of Douglas-fir by three species of root-colonizing insects. Canadian Journal of Forest Research 16: 745-749.

Witcosky, J. J.; T. D., Schowalter; and E. M. Hansen, 1987. Host-derived attractants for the beetles Hylastes nigrinus (Coleoptera: Scolytidae) and Steremnius carinatus (Coleoptera: Curculionidae). Environmental Entomology 16: 1310-1313.

Management Strategies—Survey, Detection, and Control

Annosus Root Disease Hazard Rating, Detection, and Management Strategies in the Southeastern United States[1]

S. A. Alexander[2]

Abstract: Annosus root disease (ARD), is the major root disease of pines in the southeastern United States where severely affected trees exhibit growth loss. Assessing the potential damage of ARD is essential for making effective disease control and management decisions. A soil hazard rating system developed to identify potential for tree mortality is described. The Annosus Sampling Procedure accurately estimates the severity of ARD within a stand. The GY-ANNOSUS computer program estimates growth loss caused by ARD. ARD management strategies are discussed.

Annosus root disease (ARD), which is the major root disease of pines in the southeastern United States, is most severe in thinned plantations and stands. Thinning creates fresh stump surfaces and root wounds which are points of entry for *Heterobasidion annosum* Bref., the fungus that causes ARD. Severely affected trees grow at a slower rate and are more susceptible to bark beetle attack. Tree mortality tends to occur in localized areas, although the disease may occur throughout severely affected stands. ARD tends to be most severe on well-drained soils. Determining the amount of ARD present in a stand is essential for making effective disease control and management decisions.

In the southeastern United States, symptoms of ARD are for the most part similar to those for any stressed pine tree. Severely affected trees may have thin, light green to yellow crowns, with tufted branches and short needles. Windthrown trees may be present in affected stands, especially on deep, sandy soils. Most infected trees show no detectable symptoms. Signs of ARD are basidiocarps (often called conks) of the pathogen produced at the base of infected trees or stumps. Conks may be small and difficult to locate unless the duff layer is removed from around the tree or stump. Most infected trees, however, do not produce conks, which are the source of the airborne spores that infect freshly cut stump surfaces. After spore germination, the fungus grows down through the stump and roots, and infects standing trees through root contacts. Wounded roots close to the soil surface also may be infected by spores in the soil. Infected roots initially become resin-soaked and brownish-red. Later, these infected roots become a white, stringy mass of decayed tissue.

The most critical factor in estimating disease incidence and severity within populations of plants is the accuracy of the survey and effectiveness of the detection methods. This is particularly true when working with a root disease of forest trees, because areas are extensive and samples are often large and difficult to collect.

A cursory method of determining the incidence of *H. annosum* in pine stands was used in several major surveys to measure the incidence of infection by *H. annosum* (Powers and Verrall 1962; Powers and Hodges 1963). This method, based upon the observation of basidiocarps of the fungus at the base of infected trees, found that 2.8 percent of the loblolly pines examined within 120 plots from Virginia to Texas were found to be infected (Powers and Verrall 1962). A more direct sampling method was used by Ginns and Gillespie (1962) and later was tested extensively by Cordell and Stambaugh (1966). They used an increment borer to remove four core samples from the root collar of suspect trees and plated out the cores on culture media. This method was used for the determination of disease incidence in

[1] Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2] Associate Professor of Plant Pathology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

living trees in 12 plots ranging in size from 0.10 to 0.20 acres (0.04 to 0.08 hectare). A total of 392 trees were sampled of which 254 were white pine *(Pinus strobus L.),* 54 were loblolly pine *(P. taeda* L.), and 15 were red pine (*P. resinosa* Ait.). The increment core method of sampling indicated approximately an 11 percent increase in recovery of *H. annosum* over the use of pathogen signs alone.

A similar study on 71-year-old Norway spruce (*Picea abies* (L.) Karst.) (Dimitri 1970) compared the isolation efficiency from core samples removed by the increment borer method to samples taken from trunk disks. All samples were taken at the 50 centimeter height on the stems of spruce. The disks were removed after felling. Results showed that where increment core sampling procedures indicated only 40 percent of the trees were infected, isolations from trunk disks showed that 85 percent of the 256 trees sampled were infected.

Results of another study that involved the sampling of borax- or urea-treated stumps showed that culture plating of chips removed from individual roots did not significantly change the percent recovery of *H. annosum* over results obtained with the increment core technique (Artman and others 1969). However, isolation of the pathogen from the roots of check (untreated) stumps demonstrated a nearly threefold higher detection of the pathogen by the root chip isolation method than by the increment core isolation method. Alexander and Skelly (1973) compared the methods used for surveying the incidence of ARD in loblolly pine stands. A total of 79 trees were evaluated. The methods compared were: 1) to count conks, 2) to extract and culture increment core samples (two per tree) from the root collar zone, and 3) to remove 18 in. sections of two primary roots and make isolations from the samples. The results were, respectively, 2.5, 10.1, and 31.6 percent trees infected. In other studies, that involved the excavation and sampling of root systems, the average incidence of ARD was 80 percent. Assuming the 80 percent number to represent the actual level of infection, the lower percentages detected by the other methods show how little of the actual ARD was detected. Without doubt, the current estimates of the impact of ARD on pine forests in the southeastern United States are low.

Tree mortality is the most visible result of annosus root disease, and for many years it was considered to be the only impact of ARD on southeastern pine forests. Morris (1970), for instance, described timber volume losses caused by this disease on several sites by measuring only dead trees. Growth losses sustained by infected living trees were not considered. Alexander and Skelly (1973) provided the first evidence of the potential impact of ARD on the radial growth of loblolly pine. Alexander and others (1975) demonstrated that loblolly pines infected by *H. annosum* produced 19 percent less radial growth during the preceding 5 years in thinned, coastal plain plantations. Alexander and others (1981) later reported that loblolly pines in southern pine beetle (SPB)-infested plots, with an average ARD incidence of 65 percent and an average ARD severity (percentage of roots colonized by *H. annosum*) of 23 percent, produced 6 percent less radial growth during the preceding 10 years than control plots with an average ARD incidence of 73 percent and an average ARD severity of 11 percent. Between SPB-infested trees (54 percent ARD severity) and SPB-uninfested trees (11 percent ARD severity), the SPB-infested trees grew 20 percent less for the preceding 10 yrs than the SPB-uninfested trees. Trees infected by *H. annosum,* regardless of SPB presence, produced 36 percent less radial growth than noninfected (healthy) trees during the preceding 10 years. Bradford and others (1978) excavated the root systems of 25 loblolly pine trees in 14 thinned plantations and measured their infection by *H. annosum.* The average ARD incidence was 85 percent and the average ARD severity was 30 percent. The majority of the trees showed no above-ground symptoms or signs. Trees infected by *H. annosum* produced 19 percent less radial growth (the same as reported by Alexander and others 1975) during the preceding 5 yrs than noninfected (healthy) trees. Three plots were on intermediate ARD hazard soils; the average ARD incidence level was 70 percent with a severity level of 33 percent. Froelich and others (1977) evaluated 65 slash pines for ARD in one thinned plantation and found a 20 percent reduction in radial growth of trees with greater than 50 percent of their root system colonized by *H. annosum* and a 40 percent reduction in height growth 6 years after thinning.

SOIL HAZARD RATING SYSTEM

Morris and Frazier (1966) developed a field hazard evaluation system based on soil characteristics which identified soils associated with high mortality caused by ARD. Froelich and others (1966) identified the characteristics of healthy and high ARD plantations. In an examination of high- and low-hazard disease sites Alexander and others (1975) measured 14 soil parameters at depths of 10 to 20 centimeters. Sand, porosity, organic matter, and field capacity had the highest correlation when compared with disease incidence. Because of the simplicity and ease of use, the soil ARD hazard system has been extensively used, and misused, in the southeast. Many have assumed that ARD is a problem only on high ARD hazard soils. This belief is unfounded because most southern pines can be significantly infected and show no outward sign of the disease. We now know that ARD can reduce growth without causing any outward signs of infection.

Tree mortality and to some extent high disease incidence are associated with: (1) high sand content, (2) high percentage of noncapillary pores, (3) high soil bulk density, (4) low organic matter, (5) a deep A-horizon, (6) a low water table, and (7) dense grass or similar vegetation cover. The most important independent variables are sand content, organic matter, and water table depth (Alexander and others 1975).

Low ARD caused mortality is related to (1) high clay content, (2) high percentage of capillary pores, (3) high organic matter, (4) ground cover, (5) a high water table.

<u>ARD Hazard Rating</u>

Low	-	clay and clay loams
Intermediate	-	loams and silt loams
High	-	sandy loams, loamy sands, and sands

Soil Saturation--If the soil is saturated for 2 months, or if the soil shows indications of poor drainage at 18 inches (46 centimeters) or less, the soil is low hazard, regardless of texture.

Clay Content--If field examination shows that clay is detectable at 10 inches (25 centimeters) or less, the soil ARD hazard rating is intermediate to low for ARD.

Soil ARD hazard rating was developed and utilized only to identify the potential for tree mortality. It should be used only as a general guide to the potential impact of ARD in thinned pine stands. For example, in an evaluation of Forest Inventory and Analysis plots in the southern piedmont area, a low ARD hazard soil type, an estimated 30 percent of the trees had ARD (Alexander, unpublished data)[3].

ANNOSUS SAMPLING PROCEDURE

The Annosus Sampling Procedure (ASP) provides an objective approach to estimating ARD severity in a stand of trees (Alexander and Anderson 1985). The ASP was developed from data collected in Virginia, Alabama and Mississippi. The percent severity from the ASP plots were compared, in the same plantations, with two or three systematically placed 1/20th acre (0.02 hectare), circular plots in which all the plot trees were excavated and their root systems were measured for infection. The ASP estimates ARD severity to within 10 percent of the baseline estimate at P = 0.05.

Two methods may be used for the ASP: the 20-plot method and the variable-plot method. With the 20-plot method, 20 sample plots are systematically distributed within the stand and sampled. With the variable-plot method, 10 plots are systematically distributed within the stand, the data are collected, and the degree of variation is calculated. Once the variation between the 10 plots is known, the number of plots needed to support the probability level required for any particular operation can be calculated. The advantage of the variable-plot method is that usually fewer plots are required to obtain the necessary level of probability. With the 20-plot method, however, only one pass is required.

Once a plot center has been located, the actual sampling point is moved to a position that maximizes the number of tree root systems sampled. Sampling begins with the removal of the duff layer over an area 12 inches (30.5 centimeters) square. A 1 cubic foot (0.028 cubic meters) sample of soil is removed for evaluation. All pine root segments 1/8 inch (0.317 centimeters) in diameter or larger are separated, counted and examined for typical symptoms of ARD: resin soaking and a stringy white rot. Roots with other symptoms, or which are symptomless, are classed as noninfected.

[3] S.A. Alexander. Associate Professor of Plant Pathology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

The sampling process is repeated at each of the plots, and the results are averaged to provide an estimate of the severity of ARD in the stand.

Outline of ASP

1. Determine stand size.

2. Decide on plot location (establish a systematic grid distribution to represent the entire stand).

3. At each plot location, adjust sample location to obtain roots from the maximum number of trees (try to include three or four dominant or codominant trees each within 15 feet (4.6 meters) of plot center).

4. Remove 1 cubic foot (0.028 cubic meters) sample of soil and roots with a shovel.

5. Separate the pine root segments from the soil and examine them for symptoms of ARD.

6. Record the total number of root segments and the number of segments with symptoms of ARD.

7. If the GY-ANNOSUS growth and yield model is selected, collect additional data on (a) site index (base age 25 years) (b) current stand age, and (c) pine basal area.

8. Repeat steps 1-7 for all 20 plots.

9. Sum the infected and noninfected root segments from all plots and calculate the mean annosus root disease severity percentage for the plantation.

It may be advantageous to conduct a timber cruise as part of the ASP. By so doing, only one pass through the stand is necessary; standard cruise data can be collected along with such things as mortality, the presence of other diseases and insects, e.g. fusiform rust and the southern pine bark beetle; and increment cores for determining the rate of radial growth may also be taken at this time.

The GY-ANNOSUS PROGRAM (Fanelli and others 1984) (a computer program for the Apple II series) allows the manager to project the growth of the thinned pine stand. Program outputs compare year-by-year yields of diseased and disease-free stands. If values cannot be determined for cubic-foot yields, the percent reductions can be applied to your own timber merchandising table or tree diameter distribution model.

The decision whether to thin a commercially managed timber stand is based on the expectation of a predicted improvement in yields resulting from an improved yield of merchantable volume and early returns on reforestation investment. The model allows a forest manager to estimate the shortfall of these predicted yields and to adjust the management strategy for the infected stand accordingly. Further, the model can be used to simulate the potential investment impact of not treating stumps to prevent infection. Thus, management guidelines can be developed to account for both the biological conditions and the economic factors affecting a particular loblolly pine stand.

MANAGEMENT RECOMMENDATIONS

Treatments

Chemical and biological controls have been used effectively in preventing the spread of ARD (Kuhlman and others 1976).

Chemical--granular borax applied to stumps immediately after cutting is effective in preventing infection through stump surfaces. Borax offers no below-ground protection. Treated stumps may still become infected through root contacts with infected untreated stumps. Borax treatment is not effective in stands severely infected with ARD.

Biological Control--*Phlebia gigantea* is a vigorous fungal competitor of *H. annosum* and has been used effectively as a biological control on infected stands when applied in a spore suspension spray.

Regeneration Areas

High Hazard Sites

Use wide spacing to delay the thinning date. Consider longleaf pine, which is somewhat less susceptible. Site can be regenerated immediately after harvest.

Low Hazard Sites

Use normal management practices.

Existing Stands

Plantation or Natural Stands

High ARD Hazard Sites

a) > 30 percent ARD - Do not thin; either harvest now or when practical.
b) 10 - 30 percent ARD - Treat new stumps with *Phlebia gigantea*.
c) < 10 percent ARD - Use borax on all new stump surfaces.

Low ARD Hazard Sites

ARD-Related Tree Mortality Present--
a) > 30 percent ARD - Do not thin; either harvest now or when practical.
b) < 30 percent ARD - Treat new stumps with *P. gigantea.*

No ARD-Related Tree Mortality Present--
a) Normal management.

Seed Orchards

High ARD Hazard Sites

Remove stumps and treat remaining roots with *P. gigantea*. Minimize traffic in orchard. Use herbicides within row to reduce mowing damage.

Low ARD Hazard Sites

Always treat fresh stumps with borax.

Recreation and Other High Value Areas

> 10% ARD - Treat new stumps with *P. gigantea.*
< 10% ARD - Always treat new stumps with borax.

SUMMARY

Losses in southern pines to ARD include both the obvious tree mortality and the more insidious growth loss. Present management practices risk serious errors by not treating the stumps from thinning on high ARD hazard sites to prevent the disease. Costs of prevention are offset by increased growth and reduced mortality. The use of microcomputer software facilitates the analysis by forest managers and consultants by allowing the financial and biological assumptions for each situation to be evaluated.

Several points should be noted concerning ARD in pines in the southeastern United States. It has been almost 30 years since the only extensive survey for and evaluation of ARD was made. The techniques used in that survey, although considered to be the best available at the time, have since been found to be insufficient for accurately estimating ARD infection levels. Since that survey, we have found that ARD can cause reduced growth without producing any signs or symptoms of infection, and that, in many circumstances, bark beetle damage increased significantly in the presence of ARD. ARD stresses trees in a way that often makes the primary cause of the disorder appear to be bark beetles, air pollution, drought, or poor site conditions. All of these factors make it even more important that accurate and effective techniques and procedures be used for estimating the severity and impact of ARD in pine stands in the southeastern United States. A forest manager who can not accurately measure whether root disease is present often concludes that he has no problem.

ACKNOWLEDGEMENTS

I would like to thank Dr. Rick Hokans for his contribution and Moss Baldwin for her help in preparing this manuscript.

REFERENCES

Alexander, S.A.; Anderson, R.L. 1985. How to: identify and control annosus root rot in the south. Forestry Bull. R8-FB/P 19. U.S. Department of Agriculture, Forest Service, Southern Region.

Alexander, S.A.; Skelly, J.M. 1973. The effect of *Fomes annosus* infection on diameter growth of *Pinus taeda* L.: An initial report. In: Proceedings IV Conference on *Fomes annosus*. Southeast. Forest Experiment Station, U.S. Department of Agriculture; September 17-22, 1973. Asheville, NC. pp. 30-40.

Alexander, S.A.; Skelly, J.M.; Morris, C.L. 1975. Edaphic factors associated with the incidence and severity of disease caused by *Fomes annosus* in loblolly pine plantations in Virginia. Phytopathology 65: 585-591.

Alexander, S.A.; Skelly, J.M.; Webb, R.S. 1981. Effects of *Heterobasidion annosum* on radial growth in southern pine beetle-infested loblolly pine. Phytopathology 71: 479-481.

Artman, J.D.; Frazier, D.H.; Morris, C.L. 1969. *Fumes annosus* and chemical stump treatment in Virginia---A three year study. Plant Disease Reporter. 53:108-110.

Bradford, B.; Skelly, J.M.; Alexander, S.A. 1978. Incidence and severity of annosus root rot in loblolly pine plantations in Virginia. European Journal of Forest Pathology 8: 135-145.

Cordell, C.E.; Stambaugh, W.J. 1966. Increment core sampling reveals more *Fomes annosus.* Plant Disease Reporter 50: 589-592.

Dimitri, L. 1970. Valuation of butt rot of spruce by boring cores. In: C.S. Hodges and others, eds. Proceedings of the 111 International Conference on *Fomes annosus.* Aarhuis, Denmark. Ashville, N.C. Southeastern Forest Experiment Station, U.S. Department of Agriculture. pp. 13-15.

Fanelli, E.S.; Hokans, R.H.; Alexander, S.A. 1984. Cubic-Foot Volume Projection for Thinned Loblolly Pine Plantations on High Annosus Hazard Sites (GY-ANNOSUS) version 1.0. School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University. Blacksburg, Virginia.

Froelich, R.C.; Dell, T.R.; Walkinshaw, C.H. 1966. Soil factors associated with *Fomes annosus* in the Gulf States. Forest Science 12(3): 356-361.

Froelich, R.C.; Cowling, E.B.; Collicott, L.V. ; Dell, T.R. 1977 *Fomes annosus* causes substantial loss in growth of planted slash pine. Forest Science 23: 299-306.

Ginns, J.A.; Gillespie, W.H. 1962. Fomes root rot found in five thinned native white pine stands in West Virginia. Plant Disease Reporter 46: 734.

Kuhlman, E.G.; Hodges, C.S. Jr.; Froelich, R.C. 1976. Minimizing losses to *Fomes annosus* in the Southern United States. Forest Service Research Paper SE-151. U.S. Department of Agriculture Southeastern Forest Experimental Station. Asheville, North Carolina.

Morris, C.L. 1970. Volume losses from *Fomes annosus* in loblolly pine in Virginia. Journal of Forestry 68: 283-284.

Morris, C.L.; Frazier, D.H. 1966. Development of a hazard rating for *Fomes annosus* in Virginia. Plant Disease Reporter 50: 510-511.

Powers, H.R., Jr.; Verrall, A.F. 1962. A closer look at *Fomes annosus.* Forest Farmer 21: 8-9; 16-17.

Powers, H. R., Jr.; Hodges, C. S. 1963. Annosus root rot in eastern pines. Forest Pest Control Leaflet 76: 7p. U.S. Department of Agriculture.

The Lack of a Long-Term Growth Effect of Annosus Control in Southeastern United States[1]

F. H. Tainter J. G. Williams N. J. Hess S. W. Oak D. A. Starkey[2]

Abstract: An evaluation of basal area increment was made in 1988 of six pine plantations located across the southeastern United States. These plantations had been thinned in 1969-1970 and stumps treated with borax to measure long-term efficacy of annosus root rot control. In the present study, no long-term growth effects were identified. There were neither negative growth effects of residual infection in surviving trees nor were there positive growth effects in trees which were released as a result of tree mortality. These results suggest that effects of inoculation and control treatments may have been limited only to those trees which died as a result of infection center development following thinning.

Annosus root rot, which is caused by Heterobasidion annosum (Fr.) Bref., is potentially destructive on southern pines growing on high-risk sites. Root contacts and grafts are abundant among closely spaced plantation trees. When these trees are thinned, stumps are colonized by H. annosum, which continues to colonize the root systems of the thinned trees and eventually the roots of adjacent living trees. Affected trees may either be killed after several years or suffer growth loss (Alexander and others, 1981).

An important control measure recommended for plantations on high risk sites at the first thinning is to treat the freshly cut stump surfaces with borax. The boron ion is toxic to germinating spores of many fungi, including H. annosum. As the toxic effects of the boron gradually leach away, soil-borne saprophytic fungi quickly invade the stump and H. annosum is unable to compete. The beneficial effects of borax in southern pine plantations were first observed by Driver (1963) and subsequently shown by Hodges (1970) to reduce stump colonization by H. annosum up to 18 months after treatment.

In 1969, a southwide pilot project was begun to compare the effectiveness of four promising treatments to prevent annosus root rot in thinned southern pine plantations (Phelps and others, 1970). Stump treatments included application of borax, sodium nitrite, Peniophora gigantea, summer thinning, and a check. In addition, the effects of heavy disease pressure were explored by artificially inoculating H. annosum on some plots. The project was a cooperative effort among state forestry agencies, private landowners, and the USDA Forest Service Southeastern Forest Experiment Station, and Southeastern Area Forest Insect and Disease Management.

A summary of results obtained for the period 1969 through 1977 indicated that, although positive effects were not always evident at some locations, borax provided the most effective and consistent protection against stump surface colonization, residual tree infection, and tree mortality (Weiss and others, 1978). No attempt was made at that time to translate residual tree infection and mortality into growth or volume losses.

In 1988, we reevaluated the study and discussed the possibility of taking a final look at the plots before they were lost. Several plots had already been lost, either to natural calamities or to harvesting, and the remainder were approaching final harvest age. Owing to limited survey resources, we decided to examine only the effects of borax treatments in combination with inoculations of H. annosum, which were basically the worst case and best case scenarios. Our objective was to determine if radial growth patterns showed that root disease depressed growth in surviving trees, and if borax stump treatment ameliorated these possible negative growth effects.

MATERIALS AND METHODS

Plots were reexamined at six locations (fig. 1). Plot locations and tree species were: Del Rio, Tenn., and Marion, Va., eastern white pine (Pinus strobus L.); Shelby, N.C., Mineral Springs, Ark., and Lexington, Tenn., loblolly pine (P. taeda L.); and Jasper, Tex., slash pine (P. elliottii Engelm.). The treatments compared were:

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-24, 1989, Monterey, California.

[2]Professor and Lecturer/Statistician, respectively, Department of Forestry, Clemson University, Clemson, SC 29634-1003; and Plant Pathologists, respectively, Forest Pest Management, USDA Forest Service, Southern Region, Atlanta, GA 30367.

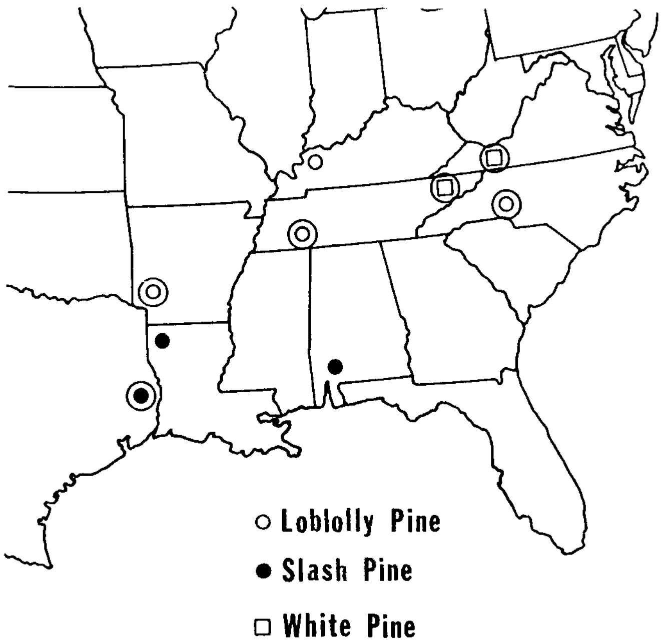


Figure 1--Location of plantations used in the annosus root rot stump treatment pilot project. Circled locations were selected for the present study.

Code Designation	Treatment
A-U	Borax, not inoculated with H. annosum
A-I	Borax, inoculated with H. annosum
E-U	Check, not inoculated with H. annosum
E-I	Check, inoculated with H. annosum

The two available replicate plots for each treatment for each location were sampled. When originally established in 1969-1970, plots were 93.4 ft (28.5 m) square with a 15-ft (4.6-m) wide buffer on each side. Steel rods marked the corners of the buffer zones. Maps were made of each plot, showing the compass bearings of the sides, and plot trees were identified with aluminum tags fixed with aluminum nails about 8.2 ft (2.5 m) above ground. Each plot center was reestablished 87 ft (26.5 m) from a corner rod on a bearing that bisected the corner angle. If rods could not be located, the plot center was estimated by measuring 66 ft (20.1 m) on the same bearing from the tagged tree closest to the true corner location.

All pines and hardwoods with diameter at breast height (DBH) 2 5 in (12.7 cm) and within a 33-ft (10.1-m) radius of plot center were counted to determine the number of trees per acre. This radius ensured that all plot trees were within the original plot without encroaching on the buffer zone. About 40 percent of the original plot area was used to calculate volume and stocking. Basal area was calculated by measuring the stem diameters of those trees. Heights were measured for all pines within the 33-ft (10.1-m) radius and were to be used in volume calculations.

The 10 pines closest to the plot center and within a 40-ft (12.2-m) radius of the plot center were sampled for radial growth analyses. In cases in which a road went through a plot, trees with crowns bordering the road were not sampled. If fewer than 10 eligible trees were found inside the 40-ft (12.2-m) radius, extra trees were sampled on the treatment plot's replicate. For example, if only 6 trees could be sampled on plot E-I-1, then at least 14 trees were sampled on plot E-I-2.

Increment cores to the pith were removed at 4.5 ft (1.4 m) from ground level on the north and south faces of each of the 10 sampled trees. After being dried, the cores were glued into grooves in wood blocks, and a flat surface was sanded on each to prepare a transverse face suitable for measurement of annual ring widths. After cores were cross-dated, width of each annual ring was measured to 0.01 mm with a Bannister increment-measuring machine. The raw annual increment data were then converted to annual basal area increments (BAI) for each tree which were then averaged for each plot for the pretreatment period (prior to 1969) and the posttreatment period (1970-1979). These plot averages were then analyzed by using analysis of variance, and the means were subjected to Tukey's means separation technique. Contrasts were also constructed in which data from the borax treatment plots were compared to those from the check treatment plots, and data from plots inoculated with H. annosum were compared to those from plots that had not been inoculated. The variables of interest were the average BAI of pretreatment, the average BAI of posttreatment, and the average change in BAI between the pretreatment and posttreatment measurements. Because each location also represented a different tree species and stand age, the analyses were done separately for each location and location data were not combined for a pooled analysis.

RESULTS

Basal area increment curves of each of the six locations are shown in figure 2. Stand establishment was generally in the early- to mid-1950's except for white pine at Va., which was established in the early 1940's. Growth at all locations markedly increased during the first 5 years or so of stand life, then settled into a period of several decades of stable growth with rather wide fluctuations. Growth curves of trees from plots with each of the four treatments at each location tended to be relatively synchronous except for white pine at Va. During the last decade (1980's), BAI growth has declined at all the locations except for slash pine at Tex. Growth at all

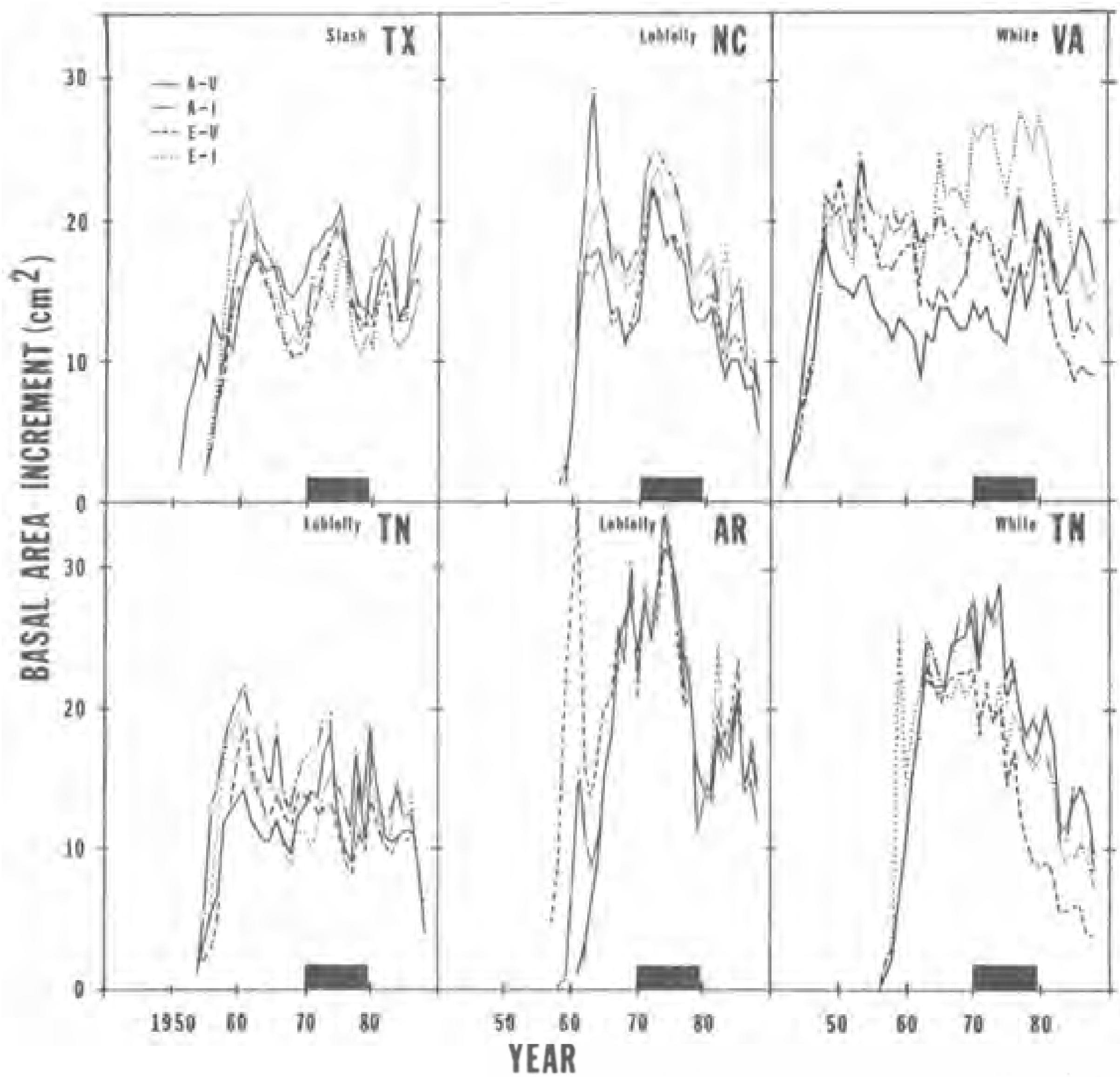


Figure 2--Annual basal area increment growth curves of residual trees, by treatment, for the six locations sampled in the present study. The first thinning and treatments were performed in 1969-70. Growth prior to this period is pre-treatment growth. The broad horizontal bar represents the posttreatment growth period (1970-79) examined for treatment effects. Treatments were: A = Borax; E = Check, not treated with borax; I = Inoculated with H. annosum; and U = Check, not inoculated with H. annosum.

locations except for white pine at Va. exhibited a growth depression just prior to the first thinning in 1969-1970. This was followed by at least some recovery and then a growth decline as the canopy closed.

The first thinning and treatments, performed in 1969-1970, resulted in increased average BAI on most plots at all locations (table 1). Loblolly pine at Ark. showed the greatest positive effect in BAI. Loblolly pine at Tenn. was the only location with a significant effect, with 3 of the treatments having a negative growth in BAI. When pretreatment BAI was subtracted from posttreatment BAI, treatment effects were no longer significant.

Contrast means (table 2) show that borax treatment increased BAI at 4 of 6 locations and that inoculated plots (maximum disease pressure) had lower BAI than uninoculated plots at 4 of 6 locations. These differences, however, are not statistically significant, largely because of the

Table 1--Average pretreatment, posttreatment and change in basal area increment (BAI) (cm^2) for the four treatments and the six location-species combinations. Treatments were: A = Borax; E = Check, not treated with borax; I = Inoculated with _H_. _annosum;_ and U = Check, not inoculated with _H_. _annosum._

Treatment	Average BAI (cm^2) Pretreatment						Average BAI (cm^2) Posttreatment					
	Slash Tex.	Lob. Tenn.	Lob. N.C.	Lob. Ark.	White Va.	White Tenn.	Slash Tex.	Lob. Tenn.	Lob. N.C.	Lob. Ark.	White Va.	White Tenn.
AI	15.27a[1]	16.51a	17.81a	18.26a	18.43a	18.84a	16.46a	15.96a	21.58a	26.99a	18.89a	24.28a
AU	14.85a	10.84a	13.70a	18.28a	12.93a	18.03a	17.06a	13.50a	17.83a	27.80a	13.52a	24.18a
EI	14.98a	13.20a	16.03a	18.29a	18.08a	19.32a	13.75a	11.57a	20.80a	28.19a	25.68a	19.82a
EU	13.35a	13.09a	12.66a	19.31a	16.33a	17.11a	15.10a	10.57a	18.39a	25.80a	17.66a	18.55a

Treatment	Change in Average BAI (cm^2) Posttreatment minus Pretreatment					
	Slash Tex.	Lob. Tenn.	Lob. N.C.	Lob. Ark.	White Va.	White Tenn.
AI	1.18a	-0.55a	3.78a	8.68a	0.45a	5.44a
AU	2.21a	2.67a	4.13a	0.60a	0.60a	6.78a
EI	-1.23a	1.63a	4.77a	7.60a	7.60a	0.50a
EU	1.75a.	1.41a	5.73a	1.13a	1.13a	1.44a

[1]Treatment means followed by same lowercase letter in each vertical column of data are not significantly different, P = 0.05, according to Tukey's means separation technique.

large variances present in the data. Although loblolly pine at Tenn. was the only location which showed significant posttreatment growth differences following the A-I treatment (table 1), there were no significant differences between contrasts of borax-treated plots and untreated check plots. There were, likewise, no differences between inoculated plots and uninoculated check plots.

DISCUSSION

From 1969 through 1977, stump surface colonization and subsequent residual tree infection and mortality in loblolly pine plantations were least on borax-treated plots (Weis and others, 1978). In slash pine plantations, stump surface colonization was approximately the same for all treatments, but residual tree infection and mortality were least on artificially inoculated borax plots. In white pine plantations, stump surface colonization was least on borax plots and residual tree mortality did not occur.

The general lack of significant differences in BAI between treatments in the present study suggests that stump colonization and residual mortality effects were limited to trees which died before the 1977 survey and that those happenings had very little effect on growth of surviving trees. Residual trees sampled in 1988 showed no negative growth effects of low-level infection or positive effects from release.

This is, perhaps, not entirely unexpected. Froelich and others (1977) found that slash pine growth was significantly reduced only in trees with more than half of their roots infected by _H_. _annosum_. Height growth was reduced by 40 percent and basal area growth by 20 to 32 percent, depending on crown symptoms. A similar result for reduced basal area growth was shown for loblolly pine (Bradford and others, 1978).

Infected trees which did not die within the normal 7-year progression of a disease infection center following thinning (Kuhlman and others,

Table 2--Contrasts in average pretreatment, posttreatment, and change in basal area increment (BAI) (cm^2) for the four treatments and the six location-species combinations.

Contrasts	Average BAI (cm^2) Pretreatment						Average BAI (cm^2) Posttreatment					
	Slash Tex.	Lob. Tenn.	Lob. N.C.	Lob. Ark.	White Va.	White Tenn.	slash Tex.	Lob. Tenn.	Lob. N.C.	Lob. Ark.	White Va.	White Tenn.
Borax Treated (all A's)	15.06	13.68	15.76	18.27	15.68	18.44	16.76	14.73	19.70	27.37	16.20	24.54
	ns[1]	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	ns
No Borax (all E's)	14.16	13.14	14.34	18.80	17.20	18.22	14.42	11.62	19.60	27.00	21.67	19.18
Inoculated (all I's)	15.12	14.85	16.92	18.28	18.26	19.08	15.10	13.76	21.19	27.56	22.28	22.05
	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Not Inoculated (all U's)	14.10	11.96	13.18	18.80	14.63	16.08	16.08	12.58	18.11	26.80	15.59	21.68

Contrasts	Change in average BAI (cm^2) (Posttreatment minus pretreatment)					
Borax Treated (all A's)	1.70	1.05	3.96	9.10	0.52	6.11
	ns	ns	ns	ns	ns	ns
No Borax (all E's)	0.26	-1.52	5.25	8.20	4.47	0.99
Inoculated (all I's)	-0.02	-1.09	4.28	9.90	4.02	2.97
	ns	ns	ns	ns	ns	ns
Not Inoculated (all U's)	1.98	0.62	4.93	8.00	0.96	4.11

[1]ns = not significant, P = 0.05.

** Significant differences, P = 0.01.

1976) may have suffered a growth loss during that time, but those trees either did not survive or were not included in the present survey. Those trees would have been at high risk to attack by other pests such as the southern pine beetle (Dendroctonus frontalis Zimm.) (Alexander and others, 1981). There is little evidence, however, that the surviving trees compensated for this loss by an increase in basal area growth. It is possible that surviving trees, regardless of location and treatment status, may have suffered similar natural low level root infections by H. annosum which prevented significant growth response to treatment (Bradford and others, 1978).

ACKNOWLEDGMENTS

We thank H. Daniel Brown, USDA Forest Service, for the idea to carry out this research.

REFERENCES

Alexander, S.A.; Skelly, J.M.; Webb, R.S. 1981. Effects of Heterobasidion annosum on radial growth in southern pine beetle-infested loblolly pine. Phytopathology 71: 479-481.

Bradford, B.; Alexander, S.A.; Skelly, J.M. 1978. Determination of growth loss of Pinus taeda L. caused by Heterobasidion annosus (Fr.) Bref. European Journal of Forest Pathology 8: 129-134.

Driver, C.H. 1963. Effect of certain chemical treatment on colonization of slash pine stumps by Fomes annosus. Plant Disease Reporter 47: 569-571.

Froelich, R.C.; Cowling, E.B.; Collicott, L.V.; Dell, T.R. 1977. Fomes annosus causes substantial loss in growth of planted slash pine. Forest Science 23: 299-306.

Hodges, C.S. 1970. Evaluation of stump treatment chemicals for control of Forces annosus. In: C.S. Hodges, J. Rishbeth and A. Yde-Andersen, editors, Proceedings, third international conference on Fomes Annosus. Aarhus, Denmark: 1968. July 29-August 3; unnumbered report. Asheville, NC: Southeastern Experiment Station, U.S. Department of Agriculture, Forest Service; 208 p.

Kuhlman, E.G.; Hodges, C.S.; Froelich, R.C. 1976. Minimizing losses to Fomes annosus in the southern United States. U.S. Department of Agriculture, Forest Service, Research Paper SE-151. 16 p.

Phelps, W.R.; Wolfe, R.D.; Laird, P.P. 1970. Evaluation of stump treatments for control of Fomes annosus: An interim report of a pilot project. Atlanta, Ga. U.S. Department of Agriculture, Forest Service, SE (unnumbered). 13 p.

Weiss, M.J.; Peacher, P.H.; Knighten, J.L.; Affeltranger, C.E. 1978. Annosa root rot stump treatment: a pilot project. Forestry Report SA-FR1. Atlanta, Ga. U.S. Department of Agriculture, Forest Service; 21 p.

A Model for Estimating Current and Future Timber Volume Loss from Stem Decay Caused by *Heterobasidion annosum* and Other Fungi in Stands of True Fir[1]

Gregory M. Filip[2]

Abstract: In 1979, an equation was developed to estimate the percentage of current and future timber volume loss due to stem decay caused by Heterobasidion annosum and other fungi in advance regeneration stands of grand and white fir in eastern Oregon and Washington. Methods for using and testing the equation are presented. Extensive testing in 1988 showed the equation to be valid for estimating volumes of timber loss due to stem decay in grand fir stands in northern Idaho, in white fir stands in southern Oregon and northern California, in red fir stands in northern California, and in western hemlock stands in western Oregon and Washington. Intensive testing of these and other species in western North America and in other geographical areas should be done to verify the utility of the fir decay model.

In western North America, the true firs (Abies spp.) attain maximum economic and ecological importance. Fir timber volumes in Oregon and Washington are 17.2 billion cubic feet (0.5 cubic meters) distributed among several species: noble fir (Abies procera Rehd.), Pacific silver fir (A. amabilis (Dougl.) Forbes), subalpine fir (A. lasiocarpa (Hook.) Nutt.), California red fir (A. magnifica A. Murr.), white fir (A. concolor (Gord. & Glend.) Lindl.:Hildebr.), and grand fir (A. grandis (Dougl.:D. Don) Lindl.). These true fir species are an important timber resource. Stands of fir also protect watershed, hold mountain snowpacks, and provide cover and thermal protection for wildlife. They are also valuable as aesthetic components of recreational landscapes, and for specialty products such as Christmas trees and decorative greenery (Franklin 1981).

Annual stem decay losses in true firs in Oregon and Washington have been estimated at 25 million cubic feet (0.7 million cubic meters) (Childs and Shea 1967). Over 20 percent of the decay in advance grand and white fir regeneration is caused by Heterobasidion annosum (Fr.) Bref. in eastern Oregon and Washington (Aho and others 1987). Other fungi that cause appreciable stem decay in true firs are Echinodontium tinctorium (Ell. & Ev.), Hericium Abietis (Weir:Huber) K. Harrison, Pholiota limonella (Pk.) Sacc., and Stereum sanguinolentum (Alb. & Schw.:Fr.) Fr.

Stem decay losses in noble fir, Pacific silver fir, California red fir, and subalpine fir are less serious than in white fir and grand fir. Consequently, there are few reports of stem decay damage in these species in Oregon and Washington. Although studies (Morrison and others 1986) show stumps of Pacific silver fir to be highly susceptible to infection by H. annosum, the incidence of infection or decay in young trees has not been reported. Stem decay fungi most commonly found in advance regeneration stands of Pacific silver fir and subalpine fir include S. sanguinolentum and E. tinctorium (Smith and Craig 1970, Herring and Etheridge 1976). The fungi most commonly associated with stem decay in young-growth California red fir include H. annosum, P. limonella, and Y. tinctorium (Aho and others 1983). Noble fir is probably the most decay-resistant species among the true firs, but occasionally & tinctorium causes significant losses in mature timber (Filip, G.M., unpublished)[3]. Incidence of stem decay fungi in advance regeneration stands of noble fir has not been reported.

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, Calif.

[2]Research Plant Pathologist, Pacific Northwest Research Station, USDA Forest Service, La Grande, Oreg.

[3]Unpublished data on file, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, La Grande, Oreg.

DEVELOPMENT OF THE FIR DECAY EQUATION

Methods

In the field in 1979, 24 stands of advance regeneration of grand fir and white fir in eight National Forests in eastern Oregon and Washington were sampled to determine the incidence of fungal infection and stem decay (Filip and others 1983). A variety of stand and tree characteristics were recorded to relate these to amounts of stem decay. A total of 464 living stems averaging 5.9 inches (15.0 cm) in diameter at breast height (DBH) and 77 years of age were sampled systematically in all stands (approximately 20 trees per stand). Only potential crop trees were sampled because it was assumed that noncrop trees would be destroyed during stand improvement. Each tree was felled and measured to determine total cubic volume and volume of stem discoloration and decay. Each tree was dissected into 1- to 2-foot (0.3 to 0.6 m) bolts to just above the lowest whorl of live branches, and these bolts were returned to the laboratory.

In the laboratory, a total of 21,249 isolations were attempted by aseptically splitting each bolt to expose wounds and stem and twig piths (Aho and others 1987). Isolations were attempted from stem and twig piths, heartwood, sapwood, wetwood, ingrown tissue, fir engraver beetle (Scolytus ventralis LeConte) galleries, discolored wood, and decayed wood.

Results

Decay Fungi and Wounding Incidence

Of 655 isolations of decay fungi from 247 of 464 trees, E. tinctorium was recovered most frequently, followed by H. annosum and P. limonella (fig. 1). A total of 141 of 464 trees had discoloration and decay which accounted for 2.2 percent of the total merchantable stand volume. Most (55 percent) of the discoloration and decay was caused by E. tinctorium, H. annosum, and P. limonella (fig. 2). A total of 334 wounds on 248 trees were classified and dissected. At least 45 percent of all trees with wounds had decay fungi present. Decay fungi most frequently isolated from wounded trees were E. tinctorium, P. limonella, and H. annosum (fig. 3). Most of the isolations of H. annosum were from discolored or decayed wood, whereas most of the isolations of E. tinctorium were from clearwood (fig. 4). These data support the hypothesis that fungi such as H. annosum invade wounds and initiate the decay process almost immediately, whereas other fungi such as E. tinctorium enter hosts via minute branchlet stubs, become dormant after branchlet stubs occlude, and are activated by wounds in the vicinity of dormant infections (Aho and others 1987).

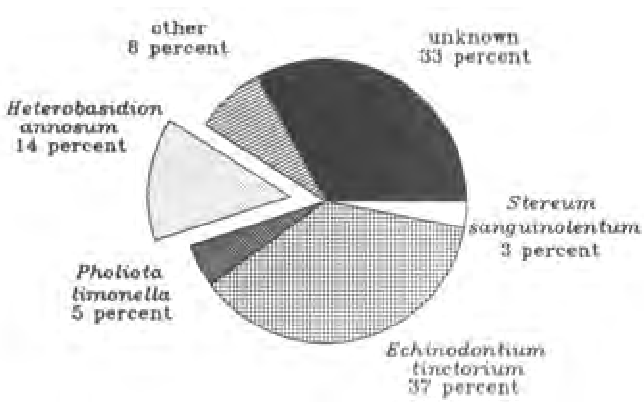


Figure 1--Frequency of isolation of wood decaying fungi from clear, discolored, and decayed wood in 247 of 464 white fir and grand fir trees in eastern Oregon and Washington.

Fir Decay Equation

An equation was developed from the above data to estimate the percentage of total crop tree volume affected by both incipient and advanced decay caused by all species of fungi (Filip and others 1983):

$$\mathrm{LogN}\ (DV\%) = 1.8\ \mathrm{LogN}\ (AG) + 0.8\ \mathrm{LogN}\ (WD\%) - 0.4(AS) - 10.4$$

where DV% = Percentage of total crop tree volume with incipient and advanced decay
AG = Mean crop tree total age (years)
WD% = Percentage of crop trees with one or more wounds

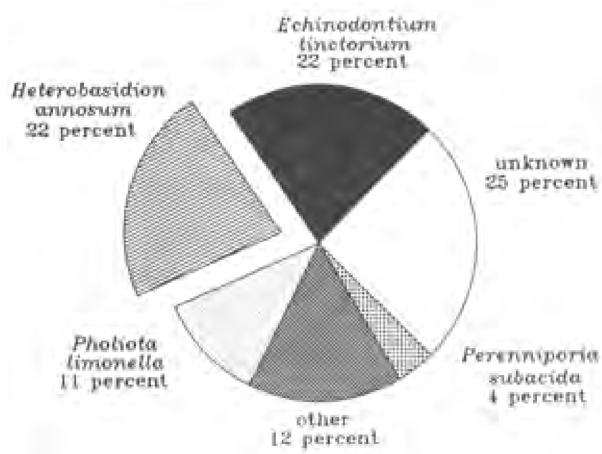


Figure 2--Frequency of isolation of wood decaying fungi from decayed wood in 141 white fir and grand fir trees in eastern Oregon and Washington.

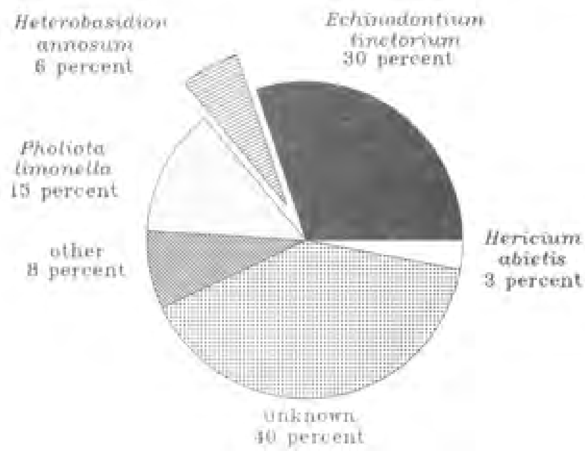


Figure 3--Frequency of isolation of wood decaying fungi from 112 wounded and infected white fir and grand fir trees in eastern Oregon and Washington.

AS = Stand aspect (0 = N, NW, NE, W, flat; 1 = S, SE, SW, E)
LogN = Natural logarithm
(R^2 = 0.70, SE = 0.79)

This equation can be programmed on hand-held calculators or data recorders. It can be used to predict percentage of decay at any preharvest time in the future because "mean crop tree total age" is a variable in the equation. Also, the "percentage of crop trees with one or more wounds" can be increased, especially if future stand entries are planned. Board-foot (Scribner) defect percentages can be calculated for stands •11 inches (30 cm) DBH by multiplying cubic decay percentages by a factor of 2.7 (Aho 1977). Managers of true fir stands in eastern Oregon and Washington routinely use this equation to predict current and future amount of stem decay.

TESTING OF THE FIR DECAY EQUATION

In 1988, data from four different areas were used to test the fir decay equation that was developed in Oregon and Washington. Only the comparisons in southern Oregon stands were done with data that were collected within the geographic range and with the species used to develop the equation. The other three tests were done with data from other species or from areas beyond the range of model development. Methods of stand sampling and data collection for all four areas were similar to those used to originally develop the fir decay equation.

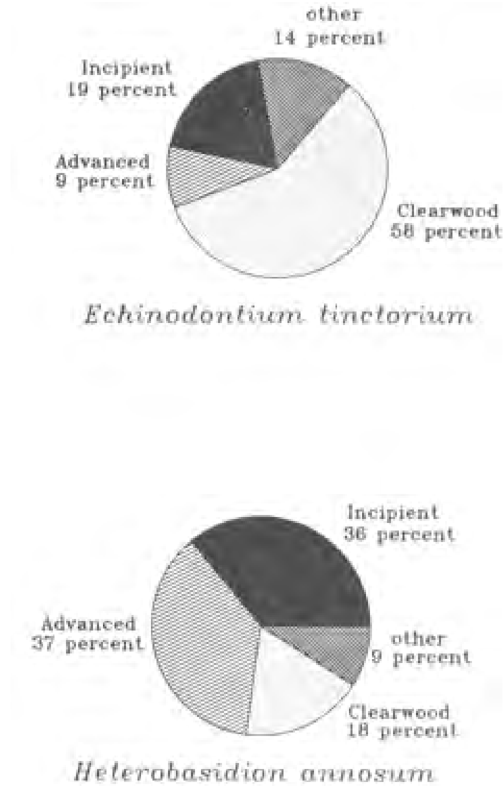
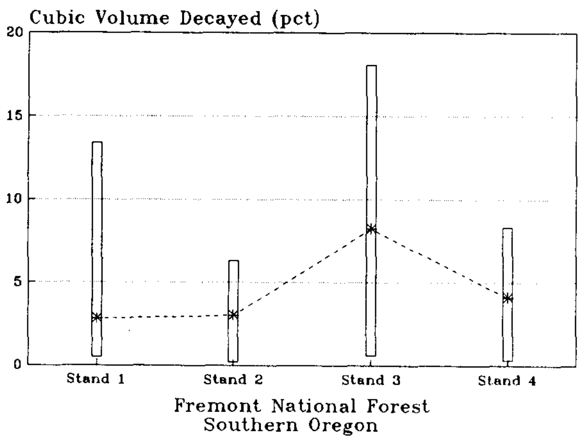


Figure 4--Source of isolations of Heterobasidion annosum and Echinodontium tinctorium from 98 white fir and grand fir trees in eastern Oregon and Washington.

Southern Oregon Comparisons

Heterobasidion annosum is responsible for stem decay (Aho and others 1987) and mortality (Schmitt and others 1984) in southern Oregon white fir stands. In 1984, an evaluation was conducted to determine the incidence of decay in four stands of white fir that had been underburned between 1962 and 1982 on the Fremont National Forest in southern Oregon (Goheen and others 1985). The fir decay equation (from above) was tested by determining if the decay values observed in the four southern Oregon stands were within their associated 95 percent prediction intervals. Prediction intervals were calculated using the SAS/STAT Package Version 6 (SAS Institute 1987). Observed decay values for all four stands were within their associated prediction intervals (fig. 5). It appears that the fir decay equation can be used to reliably estimate stem decay in similar white fir stands in southern Oregon.



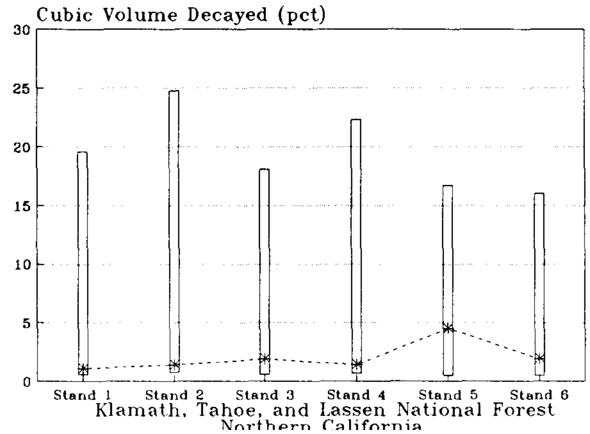


Figure 5--Levels of decay (bars) predicted by the fir decay equation for four underburned stands of white fir in southern Oregon. Stars within the bars represent actual decay volumes measured for each stand.

Figure 6--Levels of decay (bars) predicted by the fir decay equation for three stands of white fir (odd-numbered stands) and three stands of red fir (even-numbered stands) in northern California. Stars within the bars represent actual decay volumes measured for each stand.

This is not surprising: the equation was developed from data gathered in southern Oregon.

Northern California Comparisons

In 1981, a study was conducted to determine the incidence of decay in three stands of white fir and three stands of red fir on the Klamath, Lassen, and Tahoe National Forests in northern California (Aho and others 1983, 1989). Over 3 percent of the cubic volume of decay was caused by H. annosum. Data collected in 1981 were used in 1988 to test the fir decay equation. The observed decay values for the six stands in northern California were on the low end but still within the associated 95 percent prediction intervals (fig. 6). These comparisons suggest that the fir decay equation developed in Oregon and Washington can be used in northern California for white fir and for a previously untested species, red fir.

Northern Idaho Comparisons

In 1988, a study was conducted to determine incidence of stem decay in twelve 40- to 90-year-old grand fir stands in the Clearwater region in northern Idaho (Filip and others, in press). Although attempts were not made in this study to identify decay fungi, H. annosum has been shown to cause decay in grand fir throughout northern Idaho (Hudson 1972, Chacko and Partridge 1976). Observed decay values for all 12 stands were on the low end but still within the associated 95 percent prediction intervals (fig. 7). The fir equation appears valid for grand fir stands in northern Idaho, and the geographic range of the equation may be extended.

Western Oregon Comparisons

In 1978, a study was conducted to determine the incidence of stem decay in eight thinned and eight unthinned stands of 40- to 120-year-old western hemlock (Tsuga heterophylla (Raf.) Sarg.) in western Oregon and Washington (Goheen and others 1980). Nearly 50 percent of the cubic volume of stem decay was caused by H. annosum. The observed decay values for all 16 stands of hemlock were within their associated 95 percent prediction intervals (fig. 8). This is the first time that the fir decay equation was used to predict decay percentages in a genus other than Abies.

FUTURE TESTING OF THE FIR DECAY EQUATION

The fir decay equation has not been adequately tested in grand and white fir in the interior West nor has it been tested at all for other true fir species such as noble, Pacific silver, or subalpine firs. It is interesting that the fir decay equation may be valid for other species besides true firs such

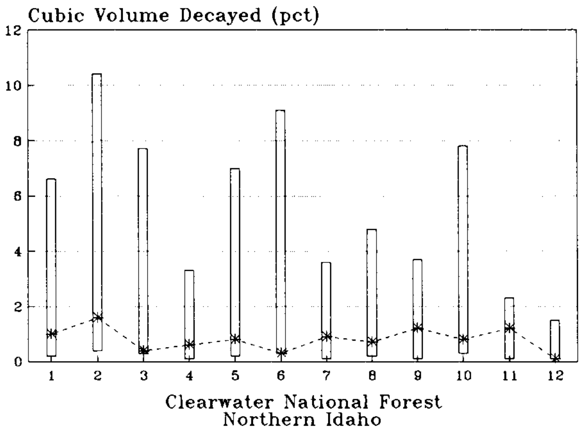


Figure 7--Levels of decay (bars) predicted by the fir decay equation for 12 stands of grand fir in northern Idaho. Stars within the bars represent actual decay volumes measured for each stand.

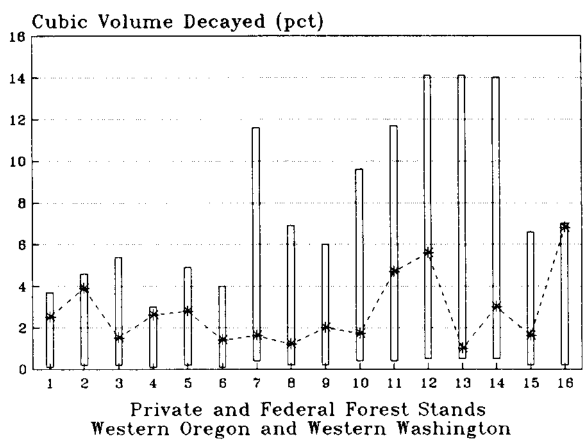


Figure 8--Levels of decay (bars) predicted by the fir decay equation for eight thinned stands (odd-numbered stands) and eight unthinned stands (even-numbered stands) of western hemlock in western Oregon and Washington. Stars within the bars represent actual decay volumes measured for each stand.

as western hemlock. Further testing on other species and in new areas is warranted. Dissection studies are relatively easy to perform: the northern Idaho study was completed in about three weeks with a crew of four. If necessary, the species and incidence of decay fungi associated with studied stands could be determined. However, procedures for collection, isolation, and identification of decay fungi require special expertise and are expensive and time consuming.

The testing of the fir decay equation on other conifer species and in other geographical areas might provide a useful tool for forest managers if the fir decay equation is proven valid. Also, the linking of the fir decay equation to growth and yield models can extend the usefulness and improve the accuracy of both models.

REFERENCES

Aho, P.E. 1977. Decay of grand fir in the Blue Mountains of Oregon and Washington. Res. Paper PNW-229. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 18 p.

Aho, P.E.; Fiddler, G.; Filip, G.M. 1989. Decay losses associated with wounds in commercially thinned true fir stands in northern California. Res. Paper PNW-RP-403. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 8 p.

Aho, P.E.; Fiddler, G.; Srago, M. 1983. Logging damage in thinned, young-growth true fir stands in California and recommendations for prevention. Res. Paper PNW-304. Portland, OR; Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 8 p.

Aho, P.E.; Filip, G.M.; Lombard, F.F. 1987. Decay fungi and wounding in advance grand and white fir regeneration. Forest Science 33(2): 347-355.

Chacko, R.J.; Partridge, A.D. 1976. Decay fungi isolated from conifers of northern Idaho. Plant Disease Reporter 60: 960-963.

Childs, T.W.; Shea, K.R. 1967. Annual losses from disease in Pacific Northwest forests. Resour. Bull. PNW-20. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 19 p.

Filip, G.M.; Aho, P.E.; Wiitala, M.R. 1983. Indian paint fungus: a method for recognizing and reducing hazard in advanced grand and white fir regeneration in eastern Oregon and Washington. R6-FPM-PR-293-87. Portland, OR: Pacific Northwest Region, Forest Service, U.S. Department of Agriculture; 24 p.

Filip, G.M.; Schwandt, J.W.; Hagle, S.K. Estimating decay in 40- to 90-year-old grand fir stands in the Clearwater region of northern Idaho. Res. Paper PNW-XXX. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; [In press]

Franklin, J.F. 1981. The true fir resource. In: Proceedings of the biology and management of true fir in the Pacific Northwest symposium, 1981 February 24-26; Seattle-Tacoma, WA. Seattle: University of Washington, College of Forest Resources; 1-6.

Goheen, D.J.; Filip, G.M.; Goheen, E.M.; Frankel, S.J. 1985. Injuries and potential decay losses in underburned white fir on the Fremont National Forest. FPM Office Report, Portland, OR: Pacific Northwest Region, Forest Service, U.S. Department of Agriculture; 5 p.

Goheen, D.J.; Filip, G.M.; Schmitt, C.L.; Gregg, T.F. 1980. Losses from decay in 40- to 120-year-old Oregon and Washington western hemlock stands. R6-FPM-045-1980, Portland, OR: Pacific Northwest Region, Forest Service, U.S. Department of Agriculture; 19 p.

Herring, L.J.; Etheridge, D.E. 1976. Advance amabilis-fir regeneration in the Vancouver Forest District. Joint Rep. No. 5, Victoria, BC: British Columbia Forest Service/Canadian Forest Service; 23 p.

Hudson, D.N. 1972. Microorganisms associated with decay in grand fir. Pullman: Washington State University; 66 p. Ph.D. Dissertation.

Morrison, D.J.; Larock, M.D.; Waters, A.J. 1986. Stump infection by Fomes annosus in spaced stands in the Prince Rupert Forest Region of British Columbia. BC-X-285, Victoria, BC: Canadian Forest Service/ Pacific Forestry Centre; 12 p.

SAS Institute Inc. 1987. SAS/STAT ™ Guide for personal computers, version 6 edition. Cary, NC. 1028 p.

Schmitt, C.L.; Goheen, D.J.; Goheen, E.M.; Frankel, S.J. 1984. Effects of management activities and dominant species type on pest-caused mortality losses in true fir on the Fremont and Ochoco National Forests. FPM Office Report, Portland, OR: Pacific Northwest Region, Forest Service, U.S. Department of Agriculture; 34 p.

Smith, R.B.; Craig, H.M. 1970. Decay in advanced alpine fir regeneration in the Kamloops District of British Columbia. Forest Chronicle June 1970, 217-220.

Simulation of Impacts of Annosus Root Disease with the Western Root Disease Model[1]

Charles G. Shaw, III Donald J. Goheen Bov B. Eav [2]

Abstract: The Western Root Disease Model as it currently exists is described, and the assumptions that were made to adapt the model to simulate attack by <u>Heterobasidion</u> <u>annosum</u> in coniferous forests of south-central Oregon are defined. Some simulations produced by this adapted model are presented to stimulate provocative discussion, thought, and action. These simulations indicate that with no action, or with continued improper management, annosus root disease will severely reduce timber yields in affected stands of true fir. Coupled with other information, this exercise provides a framework from which to build an annosus variant of the Western Root Disease Model.

HISTORY AND BACKGROUND

Tree root diseases occur on most forested lands in North America. Timber losses in the western United States alone are estimated at some 240 million cubic feet annually (Smith 1984). The most damaging tree root pathogens in the West are: pathogenic species of <u>Armillaria</u>; <u>Phellinus weirii</u> (Murr.) Gilbn.; and <u>Heterobasidion annosum</u> (Fr.) Bref.

Recognizing the seriousness of this economic loss, the USDA Forest Service initiated a project to develop a root disease model for use in silvicultural planning and management in western coniferous forests (Brookes 1985, McNarnee and others 1989, Stage and others 1989, Eav and Shaw 1987, Shaw and others 1985). At present, all actions in the model that are dictated by disease behavior can represent either pathogenic species of <u>Armillaria</u> (Wargo and Shaw 1985) or <u>P</u>. <u>weirii</u> (Thies 1984). Possibilities for further adaptation of this model to include several root diseases in the same stand or root diseases that spread by airborne propagules as well as through roots, as with <u>H</u>. <u>annosum</u>, were beyond the initial scope of the project.

In this paper, the Western Root Disease Model as it currently exists is described, and the assumptions that were made to adapt the model to simulate attack by <u>H</u>. <u>annosum</u> in coniferous forests of south-central Oregon are defined. Some of the simulations produced by this adapted model are presented to stimulate provocative discussion, thought, and action.

We are aware of two other models that simulate the effects of <u>H</u>. <u>annosum</u> on stand development and harvestable tree volumes (Alexander and others 1985, Pratt and others 1989). Neither of these models, however, appeared to be adaptable to annosus root disease in the West because they deal with plantations containing a single tree species, whereas forest conditions in the West frequently represent an array of management strategies applied in multi-storied, multi-species, and multi-aged stands of varying densities.

<u>Structure of the Western Root Disease Model</u>

The Western Root Disease Model consists of three main components: the root disease submodel, an "other agents" submodel, and a stand interface submodel. The root disease submodel considers the status and spread of root disease. The "other agents" submodel simulates the effects of wind-throw and three types of bark beetle behavior. This submodel is important because it provides a structure for considering the interactions between root diseases and other damaging agents. The stand interface submodel provides the interaction between the stand growth model to which the Western Root Disease Model must be attached, currently Prognosis (Wykoff and others 1982, Stage 1973), and the root disease and "other agents" submodels.

At present, the model provides a dynamic representation of the spatial and temporal

[1] Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, CA.

[2] Research Plant Pathologist and Project Leader, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO; Plant Pathologist, Forest Service, Pacific Northwest Region, U.S. Department of Agriculture, Portland, OR; and Operation Research Analyst, Forest Pest Management, Methods Application Group, U.S. Department of Agriculture, Forest Service, Fort Collins, CO.

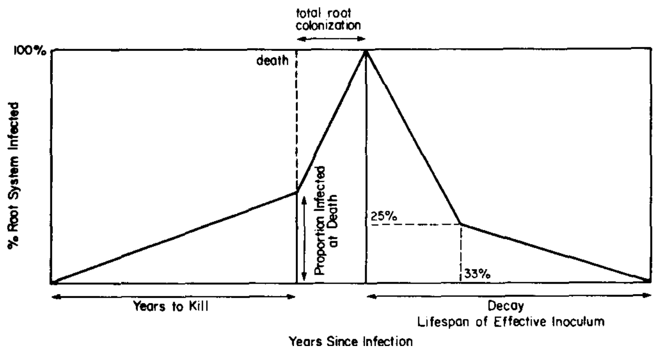


Figure 1--Pattern of root pathogen spread and inoculum buildup and decline in a single tree root system.

epidemiology of pathogenic species of Armillaria or P. weirii. The primary assumption for the model is that the distribution of root disease within a stand can be characterized by a number of spreading root disease centers, each of which contains infected trees, noninfected trees, and other inoculum sources (i.e., infected stumps). The disease centers are defined by their locations in the stand (coordinates) and their size (radii).

Three important characteristics of root disease centers are addressed: the dynamics of infection and inoculum within root disease centers; the expansion rate of spreading root disease centers; and the carry-over of root disease to a new stand following a clearcut.

Before characterizing the spread of root disease centers through a stand, we must describe disease spread through the roots of individual trees. Figure 1 depicts how live root systems become infected, how trees are killed, and how infection spreads in roots. In the model, the quantity of inoculum is measured as area occupied by infected roots since this quantity is directly related to the probability of root contact.

The time necessary to kill a Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) tree on Douglas-fir habitat in the interior region of

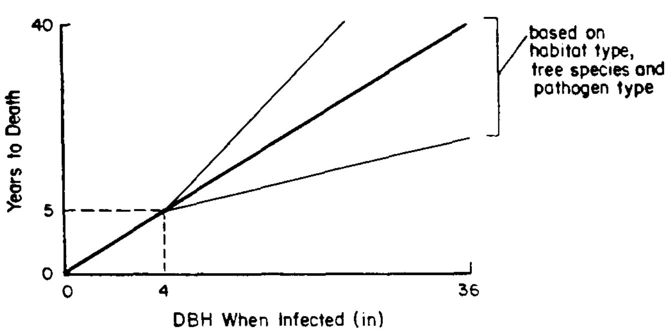


Figure 2--Time required from infection by Armillaria to tree death for Douglas-fir on a Douglas-fir habitat type.

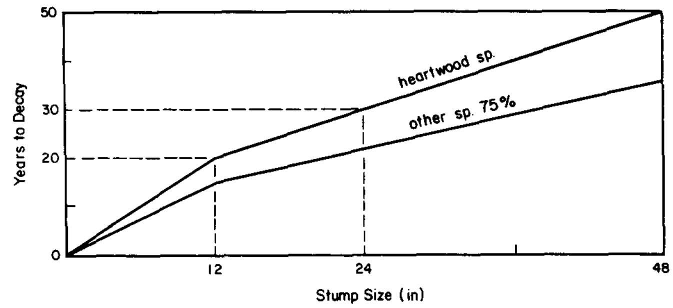


Figure 3--Lifespan of inoculum for various tree species infected with Armillaria; see text for detailed description.

the western United States is defined by the relationship shown in Figure 2. This relationship is modified for other species, pathogens, and habitat types, as shown in the figure, but the assumption is that all trees react similarly to infection. In the current model, variations between habitat types can be accommodated by using the appropriate Keywords to change parameter values (see below).

The average portion of a root system that is colonized by the pathogen when a tree dies is a function of the pathogen species and tree species (Table 1). Following tree death, the progress of disease depends on the pathogen; Armillaria species colonize the entire root system within 5 years. For P. weirii, the proportion of infected roots does not increase after tree death. For both pathogens, inoculum is assumed to deteriorate rather rapidly after its maximum buildup. The lifespan of effective inoculum is a function of stump size and tree species (Figure 3). Tree species are grouped into heartwood and nonheartwood types. Species with heartwood include Douglas-fir, ponderosa pine (Pinus ponderosa Dougl. ex Laws.), white pine (P. monticola Dougl. ex D. Don), sugar pine (P. lambertiana Dougl.), lodgepole pine (P. contorta var. latifolia Engelm.), western red cedar (Thuja plicata Donn ex D. Don), and western larch (Larix occidentalis Nutt.); nonheartwood species include white fir (Abies concolor (Cord. and Glend.) Lindl. ex Hildebr.),

Table 1--Average percentage of root systems assumed to be infected at the time a tree is killed by root disease

Tree species	Fungal Species	
	Armillaria	P. weirii
	(pct root system infected)	
Douglas-fir	80	60
Pines	30	85
True fir	80	60
Hemlock	80	80
Spruce	75	65
Larch	85	75
Cedar	75	85

grand fir (A. grandis (Dougl. ex D. Don) Lindl.), western hemlock (Tsuga heterophylla (Raf.) Sarg.), and Engelmann spruce (Picea engelmannii Parry ex Engelm).

Inoculum is assumed to decay at a rate that reduces the radial extent of infected root systems by 75 percent during the first one-third of their lifespan. The remaining infected roots are assumed to decay at a steady rate over the remaining two-thirds of their lifespan.

Simulation of root disease dynamics

The simulation for enlargement of infection centers has three main components: an estimation of the average rate of enlargement; the translation of that rate into an area of stand newly encompassed by root disease; and translation of that area into the number of trees newly infected.

How root disease centers are affected by clearcutting and regeneration of a new stand is poorly understood. The model considers three different scenarios: root disease centers from the former stand cease to exist after clearcutting, and root disease in the new stand arises in a small number of new centers located within previously infected areas; root disease centers from the former stand retain their integrity, and, as the new stand matures, these centers enlarge, starting at their old boundaries; and after a clearcut and regeneration, root disease centers form around certain individual pieces of inoculum throughout the area affected in the former stand and these centers gradually expand and coalesce. These three scenarios actually form a continuum that is dependent on the density of inoculum and the probability of a piece of inoculum initiating a new center that is capable of expanding.

REPRESENTATION OF MANAGEMENT ACTIONS

Direct Control of Root Disease

The Western Root Disease Model can implement only one management action specifically used for control of root disease, that of "pushing" or removing infected stumps and their root systems. This option can be requested in a specific year, with a factor specifying the efficiency with which roots are removed and the minimum diameter of dead trees and stumps to be removed. Even though this practice is an accepted management alternative in certain stands, it is not universally applicable (Wargo and Shaw 1985).

Silvicultural Treatments

The wide variety of silvicultural options available with the Prognosis growth and yield model (Wykoff and others 1982) can also be invoked to analyze alternative methods for control of root disease. Regeneration systems ranging from single-tree selections to clearcutting can be simulated. In addition to the harvest of existing trees, new stands can be introduced following site preparation either by natural regeneration or by planting. Of these, modification of species composition in regenerated stands (through planting or choice of regeneration systems) is the most effective means of avoiding future root disease problems.

A full range of treatment alternatives may be considered when regenerating diseased stands, depending on economic constraints and stand management objectives. The most frequent approach to management of root disease problems in timber stands is regeneration to site-suited tree species that are disease tolerant. The model can be used to compare the effects of variations of this approach with the effects of other approaches. For example, the following options may be compared and considered:

- A clearcut, seed tree cut, or shelterwood cut followed by regeneration to a disease-tolerant species, or to a mixed stand with a predominance of tolerant species.

- Overstory removal from an understory of tree species that might be disease susceptible, disease tolerant, or a mixture of the two.

- A clearcut and stump removal, followed by planting of a disease-susceptible, but otherwise preferred species.

- No action--leave the stand "as is", but recognize presence of root disease.

- Stand regeneration to a disease susceptible species without stump removal.

- A straight simulation, without invoking the Western Root Disease Model, of the Prognosis growth and yield model; perhaps followed by planting of a preferred, but disease susceptible, tree species. These scenarios represent "control" simulations for the Western Root Disease Model.

WHAT DATA ARE REQUIRED?

The model is designed to start with sample inventories of actual stands. For example, the compartment examination procedure described by Stage and Alley (1972) and in the Forest Service Handbook for Region 1 (USDA Forest Service 1986) can supply the necessary stand data if it is augmented to include stumps infected with root disease.

In addition to the customary tree size attributes, the model uses information on the frequency of tree infection by root disease pathogens. This value can be compiled by the model from disease status codes of the individual sample trees, or supplied by the user from an overall estimate based on an independent sample of the stand. The Western Root Disease Model also uses data on the area of the stand and the sizes and distribution of disease centers to initiate the simulation. The model can start from bare ground by invoking the Regeneration/Establishment component of Prognosis (Ferguson and Crookston 1984), or from the stand description contained in the list of trees sampled in the inventory. Proportions of trees infected and proportions of roots infected within diseased areas can be supplied in the aggregate, or by specifying the disease status of each tree in the sample inventory.

KEYWORDS

The Western Root Disease Model is controlled, and its parameter values are modified, by 26 Keywords (Stage and others 1989) that are similar in structure and use to those in the Prognosis Keyword System (Wykoff and others 1982). To invoke the Western Root Disease Model, a sequence of its Keywords are inserted into the sequence of Prognosis Keywords through the Pest Model Submittal System (Gladden 1989). Users of the Data General Growth and Yield Submittal System of the USDA Forest Service (Sleavin 1989) can access the Pest Model Submittal System by selecting the Keyword "PEST" from the Keyword Main Entry Menu. The Western Root Disease Model Keywords allow users to:

1. Control program execution, including the nature of root disease processes simulated, and the interactions with other agents.
2. Describe initial conditions of the stand and its disease status.
3. Specify the management prescriptions to be invoked.
4. Change critical parameters, particularly those which can be either habitat specific or dependent on the source of new trees, and to assume static rates and probabilities for one or more of the processes governing root disease dynamics.
5. Investigate the effects of bark beetles and windthrow on root disease dynamics.

To simulate attack by _H_. _annosum_, we worked primarily through this Keyword system, as described later.

CHARACTERISTICS OF ANNOSUS ROOT DISEASE IN SOUTH-CENTRAL OREGON

In south-central Oregon the Western Root Disease Model is used with the SORNEC variant of Prognosis (Johnson and others 1986). The following characteristics of root disease caused by _H. annosum_ were considered important to this exercise in modeling the dynamics of annosus root disease.

1) Long-distance spread of the pathogen is by windborne spores that land on, germinate on, and colonize wounds or freshly cut stump surfaces. The latter are particularly important. Infection foci develop almost exclusively in trees that surround large, infected stumps of the same species or type (i.e., true firs around true fir stumps and pines around pine stumps) that are 18 inches or more in diameter. The proportion of stumps that act as infection foci is related to past cutting history. Surveys (Filip and Goheen 1982, 1984) suggest that, in general, 25 percent of the large stumps created in the first harvesting entry in a susceptible host stand become infection foci and 50 percent of the large stumps created in subsequent entries become infection foci. The distribution of newly infected stumps in a stand appears to be essentially random, although to some unknown degree it is probably influenced by wind patterns.

   Once the pathogen is established, at least in true firs, it spreads via root grafts and contacts to adjacent hosts at a rate very similar to that of _P. weirii_--approximately 1 foot per year. With pines, the rate of spread is similar, but mortality centers develop mainly within the rooting zone of old infected pine stumps. Thus, the fungus appears to spread at about 1 foot per year on the root systems of old infected pine stumps, but does not spread much from live tree to live tree in the new stand.

2) Inoculum buildup and decline for _H. annosum_ differs from that currently modeled for pathogenic species of _Armillaria_ in the following ways:
   a) _H_. _annosum_ invades and colonizes uninfected, dead root systems. This invasion may include colonization through root contacts as well as by spores on stump surfaces. For this exercise, however, we assumed that the above-mentioned percentages of stumps that become infected following stand harvest entries capture both of these actions.
   b) The rate of root colonization on an infected tree is the same before and after tree death.
   c) The minimum length of survival time for active inoculum is 20 years--the current default value for inoculum survival of _P_. _weirii_.
   d) The rate of inoculum decay in the years after total root colonization appears to be slower for _H_. _annosum_ than for either pathogenic species of _Armillaria_ or _P_. _weirii_ (Fig. 3). This action and item b above were not adequately addressed in this

exercise because the default values for _Armillaria_ were used. We do not, however, believe this difference to be serious.

3) Host susceptibility:
Very Susceptible--white fir, grand fir, ponderosa pine on very dry sites, and western juniper (_Juniperus occidentalis_ Hook.) on sites where ponderosa pine is affected.
Less Susceptible--Douglas-fir, incense cedar (_Librocedrus decurrens_ Torr.) in association with ponderosa pine, lodgepole pine, ponderosa pine (on all except very dry sites), sugar pine, white pine, and western larch.
In this geographic area, significant damage occurs exclusively in the very susceptible group. Infection of the less susceptible species may be more common than presently recognized, but mortality or noticeable tree decline is extremely rare.

4) Plant community type does not appear to influence development of annosus root disease on true firs. The significant factors with true firs seem to be the presence of large hosts and the stand's logging history. The disease is about equally severe on all habitat types in which true firs are a significant component of the stand and cutting has occurred. Plant community type is, however, a critical factor in identifying where annosus root disease will seriously affect ponderosa pine. Very dry habitat types are associated with damage. Indicator plants include western juniper, sagebrush (_Artemisia tridentata_ Nutt.), bitterbrush (_Purshia tridentata_ (Pursh) DC), wooly wyethia (_Wyethia mollis_ A. Gray), serviceberry (_Amelanchier_ sp.), Wheeler's bluegrass (_Poa nervosa_ (Hook.) Vasey), fescue (_Festuca_ sp.), and needle-grass (_Stipa_ sp.).

5) White and grand firs are affected by the "S" type of _H. annosum_ and ponderosa pine by the "P" type (Chase and others 1989). There appears to be little or no cross-over between pines and true firs as the fungal strains are rather host specific. For this exercise, we considered them to be specific which is why we indicated that trees become infected exclusively around stumps of the same species or type (i.e., true firs around true fir stumps).

6) Evidence suggests that infection centers caused by _H. annosum_, particularly in stands of true firs, retain their integrity through all stand entries.

7) If applied within 48 hours of cutting, borax treatment of stumps is over 95 percent effective in preventing surface infection by _H. annosum_ (Graham 1971, Smith 1970).

8) Stump removal has not been tried as a control measure for annosus root disease on true firs in Oregon. It should be biologically effective if economically feasible. It is unlikely, however, that it would be used in other than unusual cases.

9) Regarding interactions with other agents, _Scolytus ventralis_ LeConte commonly infests true fir infected by _H. annosum_, and _Dendroctonus ponderosae_ Hopkins is common on infected ponderosa pine. We assume that at root infection levels of 30 percent, trees of either species could be killed by bark beetles (see INFKILL Keyword). Windthrow of infected trees is rather uncommon. Trees usually die standing and some years later break off rather than being windthrown. Trees infected by _H. annosum_ are often infected by Armillaria spp. as well; however, that situation was ignored in this exercise.

STAND DESCRIPTION

For this exercise, we selected a 22 acre, 60-year-old stand located at an elevation of 3100 feet on the Deschutes National Forest. Current (1987) species composition (number of trees) is 89 percent white fir, 3 percent Douglas-fir, 3 percent ponderosa pine, and a 5 percent mixture of other conifers. These numbers are dominated by some 1625 white firs per acre that are $\leq$ 1 inch DBH which is why we indicated an understory removal in most of the simulations. The intent was to destroy these small trees, an action we felt would occur during logging activities designed to remove the overstory. This overstory removal coincident with destruction of the understory is considered to be a reasonable operational scenario for stands of this type in Eastside Oregon forests.

In terms of volume, the stand currently has 27,720 board feet per acre with 38 percent white fir, 28 percent ponderosa pine, 12 percent Douglas-fir, and 22 percent other species. This test stand is fairly typical of many mixed conifer stands on the Deschutes National Forest and is similar to stands on many other forests in the area as well.

Root disease is currently damaging in the stand and our initialization of infected area at 3.28 acres, as described below, probably under-represents current disease severity.

BRIEF DESCRIPTION OF KEYWORDS THAT WERE CRITICAL TO THE SIMULATION OF ANNOSUS ROOT DISEASE

Readers are referred to the User's Manual for the Western Root Disease Model (Stage and others 1989) for descriptions of all Keywords.

BBTYPE3--Specifies a Type 3 bark beetle event that kills trees infected by root disease. The user specifies a year and intensity to switch this agent on. The event will not occur before the specified cycle year and will not occur until the specified conditions are present. The Type 3 bark beetle routine is switched off after one outbreak has occurred. The description for Run 4B provides the defaults we used to simulate an attack by S. ventralis on true firs.

INFKILL--Specifies at what level of root infection trees die. Infection proceeds through a root system until a particular infection level is reached and then the tree dies. For this exercise, these values were set by tree species as follows:

WP	WL	DF	TF	C	LP	ES	PP[3]
.95	.95	.95	0.5	.95	.95	.95	1.0

INFMULT--Specifies infection probabilities for root disease contact and spread and allows the user to vary these probabilities for different tree species and sites. For this exercise, these values were set by tree species as follows:

WP	WL	DF	TF	C	LP	ES	PP[3]
.1	.1	.1	.6	.1	.1	.1	.1

INOCSPAN--Specifies the minimum life span of inoculum, in years, for each root disease type. That value was set at 20 years for this example.

RRIN--Used in the Prognosis simulation system to invoke the Western Root Disease Model.

RRINIT--Used when root disease conditions are initialized from user-supplied data (initialization is not directly from the input tree list). Indicates the area in root disease, and if known, the location of root disease centers. The user may specify a total area in root disease and the number of centers. In this case, the model randomly located root disease centers throughout the stand. Initially, each center will be of equal size, calculated as the total area in root disease divided by the number of centers. The alternative is to provide a list of root disease centers with X and Y coordinates and a radius for each center. This Keyword is mandatory and must be present.

For all simulations in this exercise we initialized the area of root disease at 3.28 acres equally distributed among 70 disease centers. These values were determined by hand calculating how many white firs •18 inches DBH were removed during the overstory removal of all trees •17 inches DBH. Based on the assumptions mentioned above, 25 percent (70) of these trees were destined to become infected by H. annosum. The equation in the model that calculates root extent based on tree diameter and species was extracted and used by hand to calculate the areas of root extent for these 70 trees; these areas totaled 3.28 acres.

RRJUMP--Specifies the extent, as measured in root system radii, to which root disease will expand outward from existing centers after a cut. The intent is to simulate disease spread through root systems on infected trees that are removed from around the edge of root disease centers when the stand is thinned or clearcut.

This Keyword became critical to completion of this exercise because it provided the only mechanism to increase the area of root disease in the stand after thinning. Based on the above-mentioned assumptions concerning annosus root disease in this geographic area, we calculated, as described for RRINIT, the area occupied by the root systems of 50 percent of the white firs •18 inches DBH that were removed in the first thinning. We then set RRJUMP at various levels and examined the root disease model output to see what level provided an area increase equal to what was calculated (about 4 acres). The value 0.5 provided the best estimate.

To allow use of this value required model reprogramming because in the current version of the Western Root Disease Model, RRJUMP could only be set as an integer value. We had to use 0.5 for the second thinning as well because, once initiated, we could not change the value for RRJUMP. We also could not change the number of centers, so the "new" area in root disease was added to the previous total and distributed randomly among the existing centers. This limitation did not greatly concern us because with 70 centers in 22 acres there is already a considerable degree of center overlap, a condition that the models captures, and increasing the number of centers would only increase this probability. This procedure was necessary because we could not stop and restart the base Prognosis model during the simulation to enter additional information on the status of root disease.

RRMINK: No differentiation was made for effects of annosus root disease on large or small trees on various habitat types.

RRTYPE--Specifies the root disease type to be simulated. -We specified the "Armillaria type" and then modified it for this exercise.

SAREA--Specifies the stand area to be simulated and recalculates the linear dimension for the stand. In the Western Root Disease Model, all stands are assumed to be square.

SPREAD--Specifies the type of root disease spread routine to be simulated. The dynamic

[3] WP-white pine; WL=western larch; DF-Douglas-fir; TF-grand fir or white fir; C-cedar; LP-lodgepole pine; ES-Engelmann spruce; PP-ponderosa pine

spread routine was used in this exercise.

TDISIN--Describes the type of tree distribution in the stand. A random distribution was assumed for the simulations of root disease.

TTDMULT--Changes the time-to-death multipliers for mortality caused by root disease. The multipliers permit the user to vary the time-to-death by site and tree species. Values were set by tree species as follows for this exercise:

WP	WL	DF	TF	C	LP	ES	PP[3]
10.0	2.0	2.0	.75	2.0	2.0	2.0	10.0

STREAD--Although this Keyword was not used directly in these simulations it is important to understand its use because it may be useful in future modeling of annosus root disease. The Keyword is used to initialize stumps within root diseased areas of the stand. These stumps serve as inoculum sources from which infection spreads during the simulation. No parameter fields are read in conjunction with this Keyword. The user, however, is expected to supply records that contain the necessary stump information.

Stumps are defined as any infected trees that are killed by any means. The tree can be a stump formed by cutting, a dead standing tree, or a tree which has been snapped off by wind. The important attribute of these stumps is that they represent trees infected by root disease, regardless of how they actually died. We did not use this Keyword because we worked strictly with area in root disease (RRINIT), not specific pieces of inoculum.

DESCRIPTION OF SIMULATIONS FOR ANNOSUS ROOT DISEASE

The following simulations (runs) were made to provide some output from the Western Root Disease Model, as modified to represent annosus root disease, and to indicate the effects of various management alternatives.

RUN1A (Base run with under- and overstory removal):

- Under- and overstory removal (all stems < 1 inch and ≥ 17 inches DBH) in year 1987
- Run with no further stand entry until year 2107; assume no root disease

RUN1B (Base run with a clearcut and planting with ponderosa pine):

- Clearcut in year 1987
- Planted with ponderosa pine (PP), 305 stems per acre, in year 1988
- No root disease; continue the simulation until year 2107

RUN1C (Same as RUN1B, except planted with white fir)

RUN2A (Base run with under- and overstory removal and two thinnings from above):

- Under- and overstory removal (all stems < 1 inch and ≥ 17 inches DBH) in year 1987
- Thin from above in year 2027 to remove 20 percent of existing Basal Area
- Thin from above in year 2057 to remove 20 percent of existing Basal Area
- Assume no root disease; continue simulation until year 2107

RUN2B (Disease run, no control operations):
Under- and overstory removal (all stems < 1 inch and ≥ 17 inches DBH) in year 1987

- Root disease present on 3.28 acres, 70 centers. No "jump" after cut; INOCSPAN, INFKILL, INFMULT, and TTDMULT as prescribed for *H. annosum* on this site.
- Thin from above in year 2027 to remove 20 percent of existing Basal Area. RRJUMP set at 0.5 to add about 4 acres to the root disease area at thinning.
- Thin from above in year 2057 to remove 20 percent of existing Basal Area. RRJUMP set at same rate as in year 2027 to increase root disease area at thinning.
- Continue simulation until year 2107

RUN3A (Disease run with no thinning):

- Under- and overstory removal (all stems < 1 inch and ≥ 17 inches DBH) in year 1987
- Root disease present on 3.28 acres, 70 centers. INOCSPAN, INFKILL, INFMULT, and TTDMULT set as prescribed for *H. annosum* on this site.
- No thinning; continue simulation until year 2107

RUN4A (Simulated control at both thinnings, but not during overstory removal):

- Under- and overstory removal (all stems 1 inch and ≥ 17 inches DBH) in year 1987
- Root disease present on 3.28 acres, 70 centers. INOCSPAN, INFKILL, INFMULT, and TTDMULT set as prescribed for *H. annosum* on this site.
- In year 2027 thin from above to remove 20 percent of existing Basal Area. RRJUMP set at 0.0 to simulate control.
- In year 2057 thin from above to remove 20 percent of existing Basal Area. RRJUMP set at 0.0 to simulate control.
- Continue simulation until year 2107

RUN4B (Bark Beetle attack in year 2027):

- Under- and overstory removal (all stems < 1 inch and ≥ 17 inches DBH) in year 1987
- Root disease present on 3.28 acres, 70 centers. INOCSPAN, INFKILL, INFMULT, and TTDMULT set as prescribed for *H. annosum* on this site.
- BBTYPE3 invoked in year 2027 on white fir: minimum DBH, 10 inches; minimum

density, five trees per acre; mortality rate of 0.88; and 0.30 as the minimum level of root infection necessary for eligibility for bark beetle attack.
- Continue simulation until year 2107

RUN6B (Same as RUN2B, but with a moderate preference for removal of PP during thinning)

RESULTS AND DISCUSSION

Figure 4 depicts timber volumes after 120 years, including timber recovered by thinning, that were predicted by the various simulations. As seen in Run 2A, the site would be reasonably productive (93,763 board feet per acre) with proper management and no root disease. The difference in volumes predicted by the clearcut and plant options (Runs 1C and 1B), indicates that the site, in the absence of root disease, is better suited to growing white fir (total recoverable volume of 85,312 board feet per acre) than ponderosa pine (72,398 board feet per acre). In fact, without root disease, planting ponderosa pine (RUN 1B; 72,398 board feet per acre) would be a less desirable alternative than an overstory removal in 1987 followed by no further management (Run 1A; 80,696 board feet per acre).

The reality of root disease markedly alters the desirability of many of these alternatives. For example, with root disease the no-management option (RUN 3A) produces substantially less volume (57,283 board feet per acre) than the option to clear-cut and plant ponderosa pine (RUN 1B; 72,398 board feet per acre). The thinning that looked so desirable in the absence of root disease (RUN 2A; 93,763 board feet per acre) becomes a questionable alternative as recoverable volume shrinks considerably (RUN 2B, 61,687 board feet per acre).

Interestingly, results from RUN 4A (66,331 board feet per acre) suggest that control through stump treatment at both thinnings is only marginally beneficial--most likely because root disease became established throughout the stand during the 1987 overstory removal. If thinning favors removal of ponderosa pine, which is disease resistant on this site (an action we believe timber managers may invoke to "sweeten the pot" to attract bids on the thinning sale), then the effects of root disease are further exacerbated (RUN 6B; 56,260 board feet per acre).

The effect of an attack by bark beetles (RUN 4B; 53,468 board feet per acre) reduced volumes less than anticipated (compare to RUN 3A; 57,283 board feet per acre), probably because most

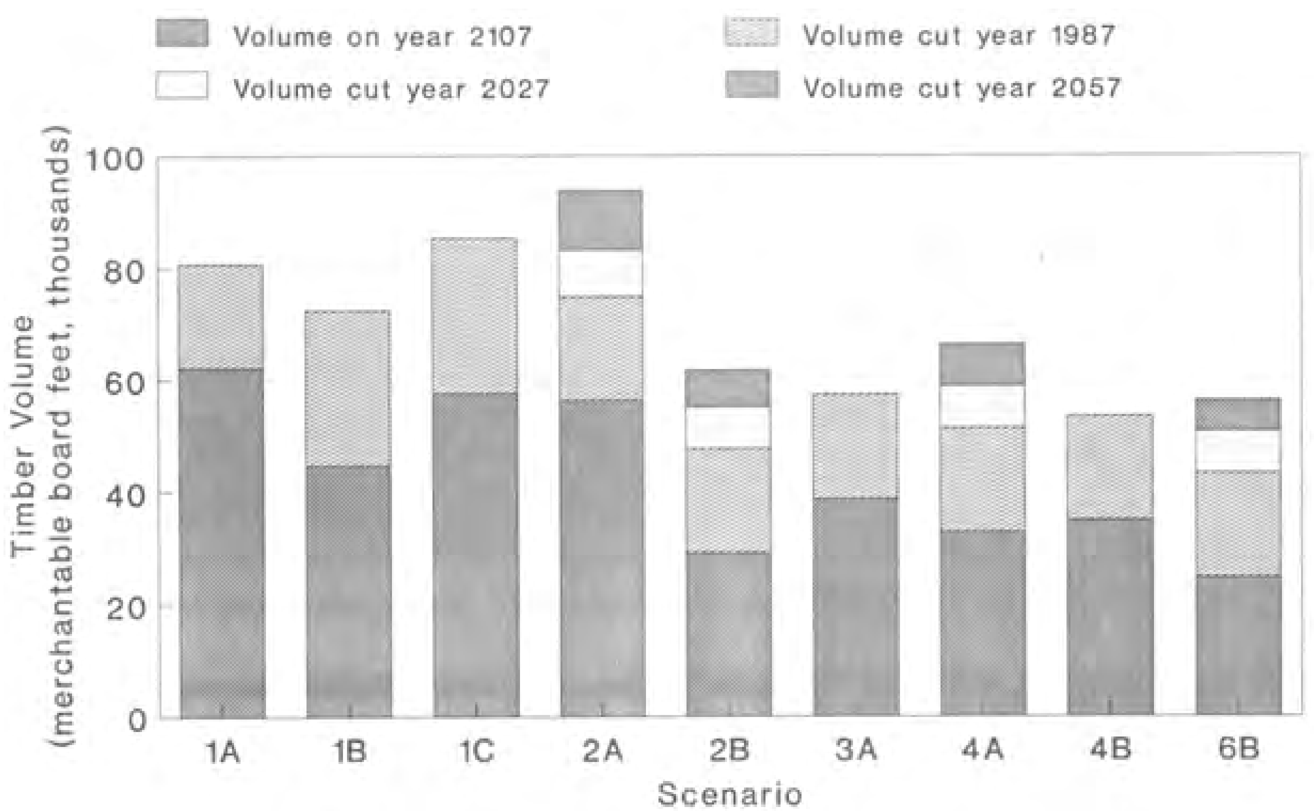


Figure 4--Projected merchantable timber volumes for the nine simulations made with the experimental annosus variant of the Western Root Disease Model.

trees killed by bark beetles eventually would have died from root disease. Whether this simulation actually portrays effects of an endemic rather than an epidemic level of bark beetles is certainly open to discussion, as are the criteria we set to invoke the attack. Interestingly, more stringent criteria did not allow the attack to occur at all.

Figure 5 provides a temporal view of the area encompassed by root disease. Regardless of what management actions were invoked, the stand area occupied by root disease was rather constant with only stump treatment showing a slight reduction. This result suggests that, based on the assumptions we made, any scenario that leaves white fir in the stand without treatment of stumps at the initial entry (the 1987 overstory removal in this case) will lead to development of severe disease conditions within the planned 120-yr rotation.

CONCLUSIONS AND CONCERNS

We believe this exercise clearly demonstrates that the Western Root Disease Model has considerable potential, primarily through its User-Controlled Keyword System, for adaptation to represent effects of annosus root disease in the coniferous forests of western North America. We say this with full recognition that data sets are not available to evaluate the accuracy of these simulations. Our experience, however, suggests they are reasonable and provide a useable estimate of what could occur if the various management actions were implemented.

Surely many problems and concerns exist. Nevertheless, we believe this paper provides a suitable base from which to develop a model for evaluating alternative management scenarios in affected stands and to help develop forest plans in areas impacted by annosus root disease. Before assuming that this little exercise has solved all the problems, however, we urge you to consider the following questions:

1. Where, when, and how will we get data sets to evaluate the accuracy of these simulations?
2. Are our epidemiological assumptions reasonable for other geographic areas?
3. What about stands in which pine alone, or both pine and white fir, are affected by annosus root disease?
4. How variable are disease dynamics by location, habitat, fungal type, etc.?
5. What other Keywords might be useful?
6. What data sets are available to help justify modification of model equations?
7. Is critical epidemiological information missing? If so, how do we obtain it?

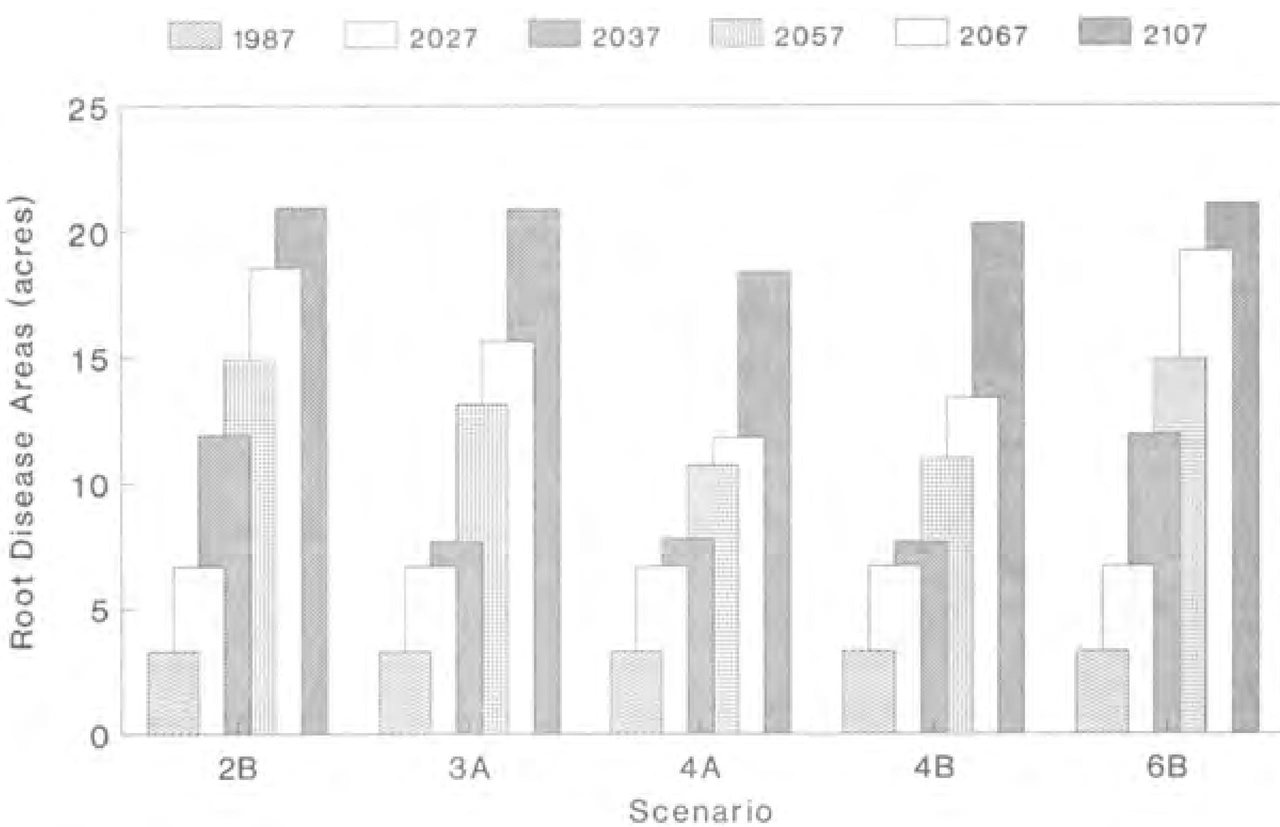


Figure 5--Projected acres of root disease area for the nine simulations made with this experimental annosus variant of the Western Root Disease Model.

8. Is the interaction with bark beetles adequately captured by the model?
9. Will forest managers find the model useful and use it as a tool?
10. How costly will it be to develop an annosus root disease model as an on-line, functional entity, and who (or what agency) should be responsible for doing so?
11. Can the Prognosis model's program be changed to allow the base Prognosis model to be stopped and restarted during a simulation to enter additional disease information?
12. Is stump treatment with borax during intermediate stand entries a more effective control than these simulations suggest ?

These currently unanswered questions are posed to stimulate interest and to suggest paths of investigation. We believe this paper provides a viable beginning for a model that, with further development, can help forest pathologists and forest managers understand and control annosus root disease in the coniferous forests of western North America.

REFERENCES

Alexander, S.A.; Hokans, R.H.; Faneili, E.S. and others. 1985. Methods for estimating annosus root rot in loblolly pine stands. In: Integrated Pest Management Research Symposium: The Proceedings. Gen. Tech. Rep. SO-56. New Orleans, LA: Southern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 56-58.

Brookes, M. 1985. Scientists, managers, and modelers work on root diseases. Forest Research West. August issue; 12-15.

Chase, T.E.; Ullrich, R.C., Otrosina, W.J. and others. 1989. Genetics of Intersterility in Heterobasidion annosum. Pages 11-19 in: D.J. Morrison, ed. Proceedings 7th IUFRO Conference on Root and Butt Rot in Forest Trees; 1988 August; Vernon and Victoria BC; Pacific Forest Research Centre. 680 p.

Eav, B.B.; Shaw, C.G. III. 1987. The Western Root Disease Model: A status report. Pages 84-92 in: G.A. Denitto, ed. Proceedings 35th Western International Forest Disease Work Conference; 1987 September; Nanaimo, BC. 192p.

Ferguson, D.E.; Crookston, N.L. 1984. User's guide to the regeneration establishment model--a Prognosis model extension. Gen. Tech. Rep. INT-161. Ogden, UT: Intermountain Research Station, Forest Service, U.S. Department of Agriculture; 23 p.

Filip, G.M.; Goheen, D.J. 1982. Tree mortality caused by a root pathogen complex in Deschutes National Forest, Oregon. Plant Disease 66:240-243.

Filip, G.M.; Goheen, D.J. 1984. Root diseases cause severe mortality in white and grand fir stands in the Pacific Northwest. Forest Science 30:134-142.

Gladden, J. 1989. Data General Pest Model Submittal System. Fort Collins, GO: Forest Pest Management, Methods Applications Group, Forest Service, U.S. Department of Agriculture; 228 p.

Graham, D.A. 1971. Evaluation of borax for prevention of annosus root rot in California. Plant Disease Reporter 55:490-494.

Johnson, R.R.; Dixon, G.E.; Schroeder, D.I. 1986. The South Central Oregon/Northeastern California Prognosis (SORNEC). Fort Collins, CO: Washington Office Timber Management, Forest Service, U.S. Department of Agriculture; 46 p.

McNamee, P.; Sutherland, G.; Shaw, C.G. III and others. 1989. Description of a multi-species root disease model developed for silvicultural planning and management in coniferous forests of western North America. Pages 320-335 in: D.J. Morrison, ed. Proceedings 7th IUFRO Conference on Root and Butt Rot in Forest Trees; 1988 August; Vernon and Victoria BC; Pacific Forest Research Centre. 680 p.

Pratt, J.E.; Redfern, D.B.; Burnard, A.C. 1989. Modelling the spread of Heterobasidion annosum over several rotations in Sitka spruce plantations in Britain. Pages 308-319 in: D.J. Morrison, ed. Proceedings 7th IUFRO Conference on Root and Butt Rot in Forest Trees; 1988 August; Vernon and Victoria BC; Pacific Forest Research Centre. 680 p.

Shaw, C.G. III; Stage, A.R.; Webb, T.M. 1985. Development of a root disease subroutine for use with stand growth models of western forests. Pages 48-54 in: W.G. Thies, ed. Proceedings 33rd Western International Forest Disease Work Conference; September 1985; Olympia, WA: 160 p.

Sleavin, K.E. 1989. Data General Growth and Yield Submittal System User Guide. Version 2:34:03:89. Fort Collins, CO: Washington Office Timber Management Unit, Forest Service, U.S. Department of Agriculture; 194 p.

Smith, R.S., Jr. 1970. Borax to control Fomes annosus infection of white fir stumps. Plant Disease Reporter 54:872-875.

Smith, R.S., Jr. 1984. Root disease-caused losses in the commercial coniferous forests of the western United States. Fort Collins, CO: Forest Pest Management, Methods Applications Group Rep. No 84-5.; Forest Service, U.S. Department of Agriculture; 21 p.

Stage, A.R. 1973. Prognosis model for stand development. Res. Paper INT-137. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 32 p.

Stage, A.R.; Alley, J.R. 1972. An inventory design using stand examinations for planning and programing timber management. Res. Paper INT-126. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 17 p.

Stage, A.R.; Shaw, C.G. III; Marsden, M.A. and others. 1989 [In Press].Users' Manual for Western Root Disease Model. Gen. Tech. Rep. INT. Ogden, UT: Intermountain Research

Station, Forest Service, U.S. Department of Agriculture; XX p.
Thies, W. G. 1984. Laminated root rot. The quest for control. Journal of Forestry 82:345-356.
USDA Forest Service. 1986. Field instructions: stand exam: Region 1. Timber management data handbook FSH2409.21h. R-1 chapter 400. Missoula, MT: Northern Region R-1; Forest Service, U.S. Department of Agriculture; 442p.
Wargo, P.M.; Shaw, C.G. III. 1985. Armillaria root rot: The puzzle is being solved. Plant Disease 69:827-832.
Wykoff, W.R.; Crookston, N.L.; Stage, A.R. 1982. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, .U.S. Department of Agriculture; 112 p.

Management Strategies— Case Studies

Forest-Site Planning and Prescription for Control of Annosus Root Disease in Ponderosa Pine and Mixed Conifer Stands[1]

John Nesbitt [2]

Abstract: In order to successfully combat € pathogens such as annosus root rot, the land € manager and pathologist must have periodic € dialogue about the pest, its identification, € effects, impacts, and cures. The author € presents four important topics to structure this € dialogue. These are (1) training from the € pathologist to the silviculturist or other land € manager, (2) site specific input, by the € pathologist to silvicultural prescriptions, (3) € risk assessment models, and (4) marginal € analysis models. €

Pathologists, silviculturists, and other € forest managers need to work very closely € together to minimize damage from root rots in € general and annosus root disease in particular. € This is not news, but bears repeating and € re-emphasizing. The forest manager needs to be € frank and specific about what is wanted from a € pathologist, who can help name the problem, € measure its magnitude and offer possible € solutions. It is frustrating to both the € pathologist and the forest manager to consider a € cry for nebulous assistance. Four major € categories of guidance that can be provided by € the pathologist follow: €

1. Training for the manager and his or her € troops. €
2. Site-specific input to silvicultural € prescriptions, including detection and € curative or ameliorating alternatives. €
3. Risk assessment. €
4. Marginal analysis. €

Many of the presentations at this conference € discuss measuring the impacts of the pathogen, € rating the pathogen as a hazard, and suggesting € possible solutions. Thus, we are already on the € proposed trail. €

[1]Presented at the Symposium on Research and € Management of Annosus Root Disease in Western € North America, April 18-21, 1989, Monterey, € California. €

[2]Fuels and Fire Behavior Specialist, Pacific € Northwest Region, Forest Service, U.S. € Department of Agriculture, Portland, Oregon. €

TRAINING €

Training is done with enthusiasm and € professionalism by pathologists in Region 6 of € the Forest Service. For instance, a team € annually visits the Fremont National Forest and € presents a demonstration-and-solution session € covering all forest diseases and insects of € interest specific to that part of the Region. € This training session is semi-formal and all € personnel, no matter what their discipline, are € invited. The audience is usually made up of € silviculturists, although other professionals € can benefit. €

The Forest Pest Management division of € Region 6 has also established an advanced € session, specifically for those writing and € signing silvicultural prescriptions. These € sessions have been very well received and some € nonprescribers have attended and benefited € immensely. In addition, the pest managers have € often provided training on the Fremont National € Forest for problems such as the mountain pine € beetle, enemies of white fir, and annosus on € ponderosa pine in seed orchards. This latter € instruction has usually been informal, with much € give and take between instructor and student. €

District and forest land managers should € constantly analyze training needs to determine € the following: €

1. Are there new problems with which they € must deal? €
2. Do new people need training? €
3. Is more intensive and specific training € on a particular disease needed? €
4. How long has it been since information € has been presented on the district for € everyone and is a refresher course € needed? €

Field people are in the best position to € identify training needs. Instruction can be € provided most successfully by pathologists when € field people have carefully considered their € needs and then given the pathologist sufficient € time to prepare for training. €

SITE-SPECIFIC INPUT €

The second category of guidance is € site-specific input to a given prescription. € For instance, in forests of the high desert of €

Oregon, three very general forest types can be € loosely described: ponderosa pine, white fir, € and lodgepole pine. As one walks through the € white fir forests, many large stumps are found € because for decades high-value old trees have € been picked and plucked, and white fir snags and € culls have been felled. Circles of standing € dead trees around some stumps are found € especially in the desert fringe area. This € white fir forest has been called, by one expert, € the finest annosus zoo in the world. €

Annosus was a known problem of white fir but € not considered a problem in ponderosa pine until € recently. Before, prescriptions were easy: € clearcut fir and plant pine. But although € plantations of young ponderosa pine were well € stocked and grew at good rates, brown seedlings € begun to surround stumps from the previous € stand. As a result, a joint study by an € ecologist, a pathologist, and a silviculturist € discovered certain dry ponderosa pine sites had € significant infections of annosus root rot in € ponderosa pine (Hopkins and others 1988). €

A biological evaluation by Schmitt and € others (1984) found only stumps 18 inches and € greater in diameter generally serve as disease € centers in the Pacific Northwest. Nonetheless, € exceptions have been observed. For instance, a € seed orchard with stumps less than 18 inches is € now showing mortality from annosus root rot. € The seed orchard was treated with borax, and a € year later the stumps were cut lower. This € second cutting was for accommodating machinery € in the seed orchard. The stumps were not, € however, dried sufficiently and were receptive € to the annosus spores. €

On a wet and productive site, where annosus € is not a problem with ponderosa pine, the € disease does occur on sugar and white pine. € Questions remain about whether annosus will € cross over to ponderosa pine on this site and, € if it does cross over, will it kill or just € cause some butt rot? €

These cases have changed opinion on how to € solve problems of annosus root rot on specific € sites. The special problem analysis used and € input to silvicultural prescriptions have been € very valuable to silviculturists involved. € Although silviculturists can usually make daily € decisions unassisted, the help of the € pathologist is critical in special cases such as € those presented here. €

Forest pest managers in Region 6 are being € moved to smaller zones to provide help to groups € of National Forests. The pest managers will be € available more for stand-specific analysis and € input. We view this as a very positive step in € forest management because we don't believe one € can use cookbook treatments for insects and € disease any more than one can for reforestation, € cutting methods, timber stand improvement, or € any other facet of silviculture. €

RISK ASSESSMENT €

Risk assessment is important because € broadbrush treatment causes unnecessary € treatment in some areas and lack of treatment in € other areas where significant damage results. € Just as cookbook solutions to diagnosed problems € cannot always be used, stands cannot be treated € for "just in case". The probability of a€ disease appearing when nothing is done and when € preventive measures are taken needs to be € examined. Currently risk assessment has been € done on white pine blister rust, Indian paint € fungus, and the mountain pine beetle in both € lodgepole pine and ponderosa pine (Dolph 1983, € Filip and others 1983, Harvey 1983). €

A model for assessing the risk of annosus € root rot would be very appropriate for the land € manager. The model could use size of stumps, € dryness or wetness of the site, species mix, € past harvest practices, and other variables. € This model could be used for site-specific € prescriptions to determine when to treat and € when not to treat for annosus root rot. The € money spent on collecting more data to run the € model would likely be offset by not treating for € annosus where unnecessary. €

MARGINAL ANALYSIS €

Marginal analysis has been used in fire € management in the the [sic] Fuels Analysis Process € program. This program integrates per-acre € values that will be lost if the stand burns, € with the probability of any given acre burning. € With this process, the cost of changing the fuel € loading and structure to reduce the effects of € fire can be compared with the value of the stand € if it burns. The bottom line is--cost of € protection is not usually worthwhile if it is € greater than the value of the stand (timber and € nontimber values are included). €

Similar programs have been developed for € pest management. Silviculturists examined the € effect of controlling dwarf mistletoe in € lodgepole pine on the measured productivity of a € site. At the time, pest managers in Region 6 € had developed a program for a hand-held € calculator. Mean annual increment (MAI) was € calculated with and without the presence of € dwarf mistletoe. The 20-cubic-foot rule for MAI € (a stand producing less than 20 cubic feet per € year is not considered for timber management) € was incorporated into the program. The rule has € subsequently been changed, but the tool is still € useful. €

Another example of marginal analysis is a € program being developed, by pest management in € Region 6, that will integrate timber values, € dwarf mistletoe infection levels, and site € productivity for indicating whether the € silvicultural prescriber should clearcut a € ponderosa pine stand because of dwarf mistletoe €

infection and regenerate or should sanitize the € stand. This program simply equates the cost of € regenerating now with the value of the growth € loss in the future because of dwarf mistletoe. €

One recommendation for controlling phellinus € is growing red alder for one or two rotations € and then returning the stand to Douglas-fir € (Nesbitt 1976, Hadfield 1985). If the loss from € phellinus per acre was unknown, however, one € could not determine if it was economically € better to live with the disease or to change to € a lower value species. A marginal analysis has € since been completed for determining this (Filip € and Wiitala 1984). €

We must constantly be aware of both the cost € of doing business and the value incurred from € doing that business. Marginal analysis helps € the land manager make good investments. €

SUMMARY €

In closing, it is important for pathologists € to give periodic updated, state-of-the-art € instruction to silviculturists and other land € managers. The pathologist's expertise is needed € for site-specific prescriptions for some€ stands. We also need the pathologist's help in € determining the likelihood of a disease € occurring and spreading. For without this € assistance, we can either be blindsided by not € seeing the disease coming or treat everything € and drive up costs unnecessarily. Lastly, € pathologists are needed to help develop marginal € analysis for determining if more is being gained € than being spent on a treatment. €

REFERENCES €

Dolph, R. E. 1983. How to hazard rate lodgepole € pine or second-growth € ponderosa pine stands and develop management € guidelines to prevent future mountain pine € beetle losses. Unpublished Biological € Evaluation. Forest Pest Management, Pacific € Northwest Region, USDA Forest Service. 17 p. €

Filip, G. M.; Aho, P.E.; Wiitala, M. R. 1983. € Indian paint fungus: A method € for recognizing and reducing hazard in € advanced grand and white fir regeneration in € eastern Oregon and Washington. Portland, OR: € USDA Forest Service, Pacific Northwest € Region. R6-FPM-PR-293-87. 24 p. €

Filip, G. M.; Wiitala, M. R. 1984. Economics of € controlling laminated root € rot in Pacific Northwest forests. € Unpublished Biological Evaluation. Forest € Pest Management, USDA Forest Service, € Pacific Northwest Region. € 34 p. €

Hadfield, J.S. 1985. Laminated root rot: A guide € for reducing and preventing € losses in Oregon and Washington forests. € Portland, OR: USDA Forest Service, Pacific € Northwest Region. 13 p. €

Harvey, Jr. R.D. 1983. A white pine blister rust € management tool. Unpublished € Biological Evaluation. Forest Pest € Management. Pacific Northwest Region, USDA € Forest Service. 9 p. €

Hopkins, W.E.; Goheen, D.J.; Goheen, E. € Michaels; Forry, K. 1988. Evaluation € of annosus root disease on ponderosa pine in € the Fremont National Forest and Lakeview € District, Bureau of Land Management. € Unpublished Biological Evaluation, USDA € Forest Service, Pacific Northwest Region. € R6-88-04. 6 p. €

Nesbitt, J. 1976. A Land Manager's concern about € root rot. Unpublished € proceedings of the 24th Annual Western € International Forest Disease Work € Conference; 1976 September 13-17; Coos Bay, € Oregon. Compiled at Washington Department of € Natural Resource, Olympia, WA: 86-89. €

Schmitt, C. L.; Goheen, D. J.; Goheen, E. € Michaels; Frankel, S. J. 1984. € Effects of management activities and € dominant species type on pest-caused € mortality losses in true fir on the Fremont € and Ochoco National Forests. Unpublished € Impact Evaluation. Forest Pest Management, € Pacific Northwest Region, USDA Forest € Service. 34 p. €

Prescribing Control in Mixed Conifer Stands Affected by Annosus Root Disease[1]

Gary Petersen[2]

Abstract: Tree mortality caused by root diseases € constitutes a major drain on Forest productivity € of mixed-conifer stands. Factors such as changes € in species composition, selective harvesting, € unfavorable economic climate, and optimizing of € short-term benefits have contributed to current € stand conditions. Computer simulation models, € such as the "RRMOD Computerized Root Disease € Simulation Model", are currently available to € managers to evaluate the effects of stand € management under different silvicultural € prescriptions. Several management strategies are € available to managers to reduce losses caused by € Annosus root disease. €

Tree mortality caused by root diseases € constitutes a major drain on forest productivity € of "east side" mixed-conifer forests in the € western United States. Mixed-conifer stands tend € to be most seriously affected. Documented losses € averaging as high as 45 percent for 98 randomly € selected stands have been noted (Schmitt and € others 1984). Numerous individual stand surveys € show that mortality of 10 percent-80 percent of € the trees with 10 percent-60 percent basal area € reduction is common (Goheen and Hagle 1988). In € one specific survey of a 2,500-acre (1012 € hectare) mixed-conifer stand on the Sisters € Ranger District, Deschutes National Forest, 19.0 € percent of all trees over 5 inches (12.8 € centimeters) diameter breast height (DBH) € representing 21.8 percent of the merchantable € board foot volume were found to have been killed € by root disease during the previous 20 years € (Filip 1980). €

On east side forests, three fungal pathogens € generally are responsible for most losses due to € root diseases. These pathogens are *Armillaria*€ *ostoyae*, *Phellinus* *weirii*, and *Heterobasidion*€ *annosum*. €

In recent years, more attention has been € focused on the role and effect of root disease in € tree stands. Increased public use of national € forests along with increased awareness of € forest managers have resulted in a perception of € declining forest tree health. €

The root disease problems now being faced € are probably a direct consequence of past € management or utilization activities. €

First, a general change in species € composition has occurred in east side € mixed-conifer forests in the last 75 years. € Sites that were once park-like in appearance and € dominated by ponderosa pine or western larch are € now stocked with more shade-tolerant climax € species, primarily the true firs or Douglas-fir. € This change is largely due to fire exclusion in € these stands (Arno 1980; Gruell and others 1982). €

Second, many forest stands have been € subjected to past selection harvesting, often € with repeated entries over the same ground. € Frequently, only high-value, large trees, mainly € ponderosa pine or western larch, were removed € during these entries. Not only did selective € harvesting remove the more root disease-resistant € species of a stand, but partial-cutting harvest € techniques often left numerous infection sites in € the form of damaged residual trees and freshly € cut stumps. Stand compositions were altered in € ways that steadily increased the proportion of € highly susceptible tree species left in the € stand. €

Third, there has long been an unfavorable € economic climate for the harvest and € manufacturing use of some species. Many forest € operators simply found it uneconomical to remove € large volumes of white fir or grand fir € material. Consequently, large acreages of € highly susceptible species were left on site. €

Finally, the long-term consequences of € management activities often have not been well € thought-out or considered. Some forest managers € and public groups are too willing to optimize € short-term benefits while foregoing long-term € interests. Overriding concerns about short-term € benefits may prove detrimental by causing forest € managers to give too little weight to significant € long-term consequences. Failure to address root € rot problems in areas such as National Forest € full retention visual management allocations is a € good case in point. €

MANAGEMENT CONSIDERATION - SILVICULTURAL € OPPORTUNITIES €

Root disease management is basically an €

[1]Presented at the Symposium on Research € and Management of *Annosus* Root Disease in Western € North America, April 18-21, 1989, Monterey, € Calif. €

[2]District Silviculturist, Sisters Ranger € District, Forest Service, U.S. Department of € Agriculture, Sisters, Oreg. €

ecological and social issue. Direct control measures are not effective in the management of forest tree root diseases because the long-term problem is not resolved. However, resolution of the root disease problems can be achieved silviculturally. Silvicultural control of root disease requires some degree of knowledge of root disease organisms, how diseases respond to management activities, long- and short-term consequences of decisions, and silvicultural techniques. Silvicultural control of root disease requires reversing past management patterns, primarily by manipulating tree species composition to develop stands less favorable for root pathogens (Goheen and Hagle 1988).

Knowledge of Root Diseases

Many forest managers are grossly unprepared to deal with root disease problems. Some foresters working in the field today graduated from accredited schools without any formal class work in forest pathology. Fortunately, people can gain skills on the job. Leaflets, brochures, studies, proceedings, papers, and numerous other reference materials are available. Most state, private, or federal forest managers have access to trained forest pathologists to assist with disease problems. Recent technological advances have provided access to computers and programs, including development of simulation models.

The RRMOD Computerized Root Disease Simulation Model

One such model available in Region Six is the root disease model known as "RRMOD". The root disease model is linked to several versions of the prognosis stand model and is designed to work with existing forest inventories. While the model was developed primarily for the pathogenic fungal species of Armillaria and Phellinus, managers are able to generate reasonable "stand responses" to H. annosum by manipulating some of the model's component interactions.

The model can be used to evaluate the effects of stand management under different silvicultural prescriptions with varying levels of infection by fungal root pathogen (fig. 1).

The model can also be used to track the effects of stand management decisions for long-term planning (fig. 2).

The basic components of the model include relative susceptibilities of trees to infection, resistance of trees to death resulting from root pathogen attack, disease-related growth reduction, decay of infected root systems, and the life span of root disease pathogens. Because trees weakened by root disease are subject to attack by bark beetles and windthrow, the model also simulates the impact of those agents (Eav and Marsden 1988).

Silvicultural Techniques

Many management alternatives are available to land managers to minimize timber losses in mixed-conifer stands growing on sites affected with annosus root disease. Fortunately, a treatment method that works for one particular pathogen will often work for other pathogens as well.

Several management strategies to reduce losses caused by annosus root disease are available. All management strategies consider the following recommendations:

1. Manage stands in short rotations, generally less than 120 years.

2. Minimize wounding of trees during thinning or harvest operations.

3. Retain or favor more disease resistant species such as ponderosa pine, lodgepole pine, western larch, and western white pine.

4. Ponderosa pine has not been seriously affected by H. annosum in Oregon except in a few locations. Special measures to prevent damage are needed only in stands within one mile of severely infected stands. Borax treatment of pine stumps will prevent infection (Hadfield and others 1986).

5. True firs should not be regenerated on sites infested with large amounts of well distributed inoculum of H. annosum (Hadfield and others 1986).

Some case examples of silvicultural prescriptions directed toward minimizing root disease losses are:

1. Clearcut Harvest System
   - a Clearcut harvesting eliminates highly susceptible tree species on the site.
   - b. Regeneration of harvested sites with seral species such as ponderosa pine, lodgepole pine, or western larch.
2. Shelterwood Harvest System
   - a. Discriminate against true firs with special selection of low disease-risk trees of more resistant species to serve as leave trees.
   - b. Site preparation activities should discriminate against true fir advanced reproduction.
   - c. A major objective should be to regenerate the site with seral species.
3. Selection Harvest (Full Retention Visual Objective)
   - a. Small patch clearcut around every identified infected tree, using 50-ft. (15.2 meters) radius from infected tree.

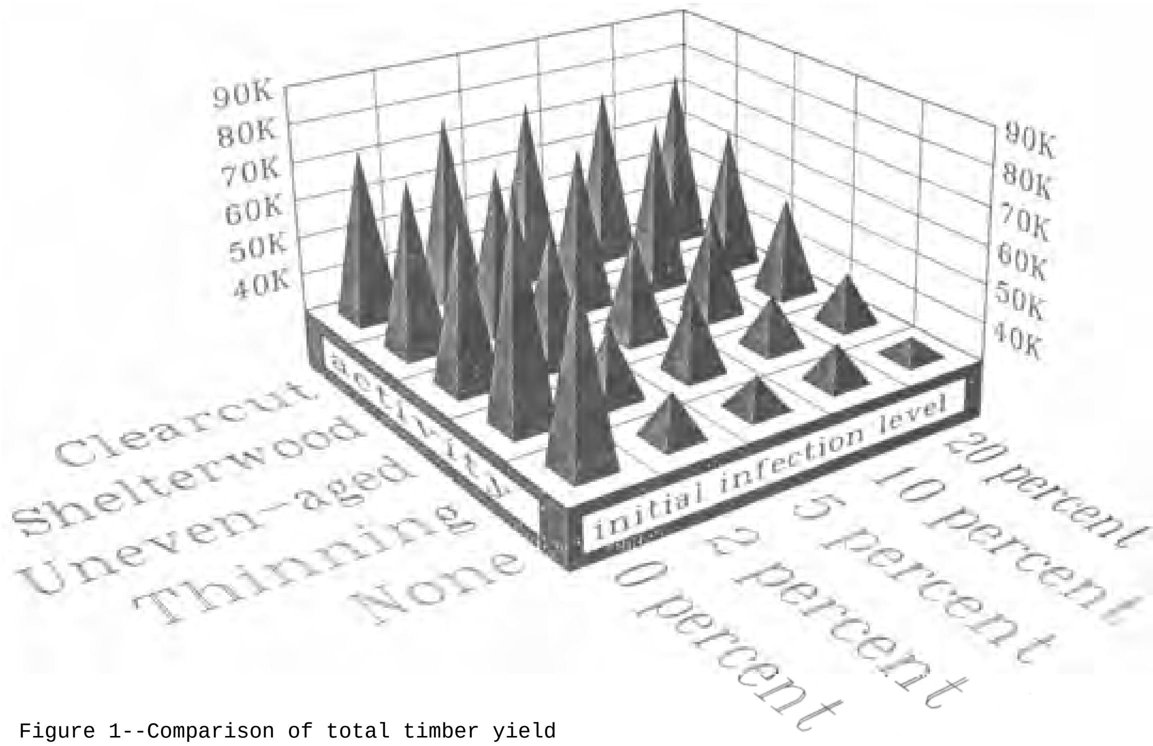


Figure 1--Comparison of total timber yield merchantable board feet) in Stand 216 over two rotation periods (240 years). Stand was modeled under 5 different silvicultural prescriptions, each exhibiting 5 different initial annosus infection levels.

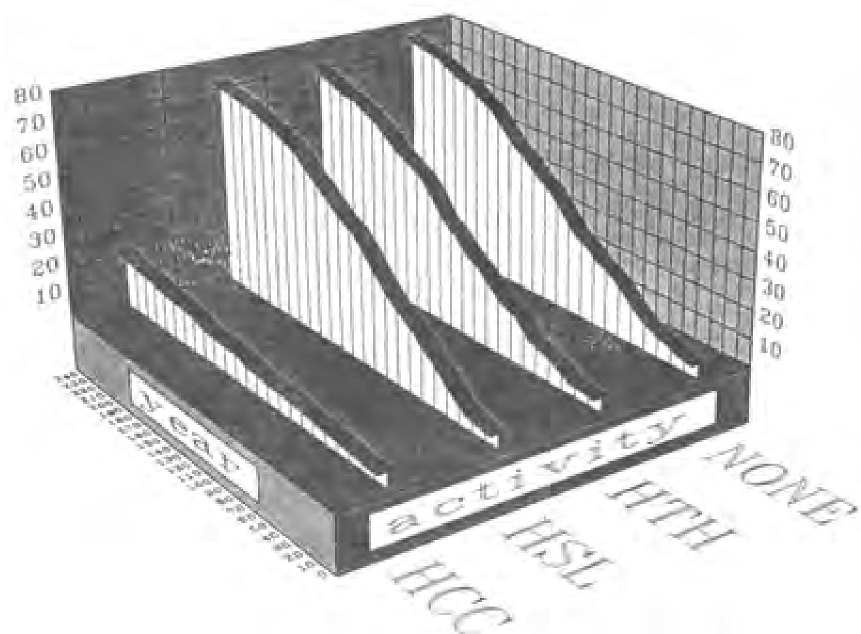


Figure 2--Annosus infection center development over time under different silvicultural prescriptions. Initial infection level is 5 percent (scale 0-80 percent). HCC, HSL, HTH, and NONE represent prescriptions of clearcut, selection, thinning, and no treatment, respectively.

b. Plant small clearcut with resistant tree species such as ponderosa pine or western larch.

4. Selection Harvest, Mixed-Conifer Stands

a. Selection harvest (such as commercial thinning or uneven-aged management) of stands with root diseases present is not an attractive alternative. Infection levels as low as 2 percent can cause appreciable long-term yield losses. Volume yield on one modeled stand with 5 percent initial H. annosum was only 66 percent of that obtained from the same stand by using a clearcut harvest system (table 1).

CONCLUSIONS

The mixed-conifer stands of the western United States have been heavily impacted by root diseases. Current levels of root disease are related largely to fire exclusion, selective cutting, uneconomical forest practices, and optimizing short-term benefits.

Silvicultural control of root disease can be accomplished. Control must be considered both a social and ecological issue. Managers must be knowledgeable about root disease biology, and the various publics must be willing to consider the long-term consequences of decisions.

Silvicultural techniques such as clearcutting, shelterwoods, or selection harvest are available to reduce root disease losses. Major emphasis should be given to minimizing wounding in stands, to reducing true fir components within stands, and to regenerating sites with resistant species such as ponderosa

Table 1--Total timber yield in Stand 216 (mixed-conifer stand, Sisters Ranger District, Deschutes National Forest) two rotations (240 years).

Harvest Treatment	0 pct	Total timber yield from stand exhibiting infection levels of: 2 pct	5 pct	10 pct	20 pct
Clearcut	74,089	77,816	77,223	75,423	75,890
Uneven-aged	73,643	65,012	56,704	58,059	54,986
Thinning	88,425	48,109	50,643	43,171	43,009
Shelterwood	73,670	71,865	71,745	73,002	66,380
No Silv. Treatment	78,009	41,378	38,557	39,853	34,831

REFERENCES

Arno, S.F. 1980. Forest fire history in the northern Rockies. Journal of Forestry. 78(8): 460-465.

Eav, Bov B.; Marsden, Michael A. 1988. Pest models for the inland mountain west. In: Proceedings, Future Forests of the Mountain West: A Stand Culture Symposium; 1986 Sept. 29-Oct. 3; Missoula, MT: General Technical Report INT-243. Ogden, UT: Intermountain Research Station, U.S. Department of Agriculture, Forest Service; 140-144.

Filip, Gregory M. 1980. Timber loss due to root disease in the Wagon Sale Area, Sisters Ranger District, Deschutes National Forest, Oregon. Forest Insect and Disease Management, Pacific Northwest Region; U.S. Department of Agriculture, Forest Service; 30 P.

Goheen, Donald J.; Hagle, Susan K. 1988. Root disease response to stand culture. In: Proceedings, Future Forests of the Mountain West: A Stand Culture Symposium; 1986 Sept. 20-Oct. 3; Missoula, MT: General Technical Report INT-243. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 303-309.

Gruell, G. E.; Schmidt, W. C.; Arno, S. F.; Reich, W. J. 1982, Seventy years of vegetative change in a managed ponderosa pine forest in western Montana - Implications for resource management. General Technical Report INT-130. Ogden, UT: Intermountain Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service; 42 P.

Hadfield, James S.; Goheen, Donald J.; Filip, Gregory M.; Schmitt, Craig L.; Harvey, Robert D. 1986. Root diseases in Oregon and Washington conifers. Portland, OR: Pacific Northwest Region, Forest Pest Management, U.S. Department of Agriculture, Forest Service; 27 p.

Schmitt, C.L.; Goheen, D.L.; Michaels, E.; Frankel, S.J. 1984. Effects of management activities and dominant species type on pest-caused mortality losses in true fir on the Fremont and Ochoco National Forests. Portland, OR: Pacific Northwest Region, State and Private Forestry, U.S. Department of Agriculture, Forest Service; 34 p.

Management of Westside Washington Conifer Stands Infected with *Heterobasidion annosum*[1]

Elvira Young[2]

Abstract: Timber stands in western Washington are managed for many purposes. Such stands yield commodity and noncommodity outputs, such as recreation, wildlife, visual resources, or watershed benefits, and often from the same stands. Annosus root disease is widespread in many mixed conifer stands within the western hemlock, mountain hemlock, and Pacific silver fir zones west of the Cascades. In stands managed on commercial (commodity output) rotations, annosus root disease is not considered a major management concern. This is not true of stands managed principally for noncommodity outputs such as recreation, wildlife habitat, visual resource, or watershed benefits. Such stands are typically on rotations in excess of 140 years. For this reason, experimental stump treatment with borax was considered for the reduction of potential future inoculum. This paper describes one technique for the application of borax to treat stumps in two units of a commercial timber sale in the westside Washington Cascades.

Heterobasidion annosum is commonly spread by airborne spores that land on open tree wounds or on freshly cut stump surfaces. Infection by spores occurs soon after woody tissue is first exposed. Infection of freshly cut stumps by hyphae that develop from spores of H. annosum is the major avenue by which new annosus root disease foci are initiated. Mycelia from germinating spores grow into stumps, and after colonizing them, spread out in the roots. Spread of infection to neighboring trees occurs via root to root contact. (5)(10)

Annosus root disease appears to be rather widespread in old-growth western hemlock, mountain hemlock, and Pacific silver fir stands west of the Cascades. This accounts for the often significant levels of butt defect in harvested timber and collapse or failure in severely decayed trees. Before multiple-use management, annosus root disease was never considered a threat to any westside timber resource. That has changed. As other. nontimber resources have increased in importance, so has awareness that tree diseases such as annosus root disease should be carefully evaluated and their impacts considered when proposing silvicultural prescriptions for long-rotation forest stand management. In western Washington, commercial rotations for western hemlock, mountain hemlock, and Pacific silver fir rarely exceed 100 years. In contrast, rotations for hemlocks and Pacific silver fir in stands that feature nontimber benefits (that is, recreation, wildlife. watershed, and visual benefits) typically are maintained for 150-200 or more years. Levels of infection by H. annosum are often high in young, immature hemlock or Pacific silver fir stands. and damage severity is typically low or insignificant. Stands that have progressed beyond maturity, however, have similarly high infection levels, but damage severity may be great and it continuously increases with advancing stand age. For this reason, it is important, when considering long rotation silviculture of western hemlock, mountain hemlock, or Pacific silver fir, that management of annosus root disease be integrated into the overall prescription.

A good example of the need to manage tree species susceptible to damage by annosus root disease is illustrated in management of mountain goat habitat. Good mountain goat habitat typically consists of large contiguous areas of mature or old-growth timber at elevations ranging from 2800 to 5500 feet in western Washington. Most often these stands are of Pacific silver fir and mountain hemlock, both of these species are susceptible to serious butt defect caused by H. annosum, once they are overmature. A commercial rotation length for stands in the same mountain goat management area would range in length from 90 to 110 years, and annosus root disease would cause only minor damage.

Long rotations are most often selected to meet specific recreation, visual wildlife, or

---

[1]Presented at the Symposium on Research and Management of Annosus Root Disease (Heterobasidion annosus) in Western North America, April 18-21, 1989, Monterey, California.

[2]Reforestation Forester. Packwood Ranger District, Gifford Pinchot National Forest, Packwood. Washington.

watershed needs. Keeping the timber resource €
healthy to meet the other resource management €
objectives can be difficult. On the western side €
of the Cascades there is little site-specific €
information on the distribution of *H. annosum* and €
how it will affect timber stands in the future. €
It is known to be widespread and numerous €
severely damaged stands have been found. €

METHODS €

On the Packwood Ranger District. Gifford €
Pinchot National Forest. Washington State, two €
severely infected stands were identified during €
timber sale reconnaissance. The silvicultural €
prescription for the stand featured a rotation €
length of 140 years. to increase locally the €
areas of available mountain goat habitat. The €
infected stands are high-elevation stands at €
altitudes ranging from 3800 feet to 4400 feet, €
and both have a species composition that includes €
Pacific silver fir, Douglas-fir, noble fir. €
western and mountain hemlock. In order of €
decreasing susceptibility to damage by *H. annosum*€
they are: western hemlock, mountain hemlock, and €
Pacific silver fir, all severely damaged; noble €
fir, which is moderately damaged; and Douglas-fir €
which is seldom damaged. These stands have been €
identified for low-intensity management in the €
Forest Plan, which means wider spacing at initial €
planting (14 feet by 14 feet). no precommercial €
thinning, one commercial thinning entry, and a €
final harvest. To reach the desired future €
condition for mountain goat habitat, reduction of €
potential stump inoculum was considered €
important. Consultation with one of the Regional €
Office forest pathologists led to the decision to €
use borax on freshly cut stumps in the harvest €
units to prevent further spread of annosus root €
disease. District personnel had previously used €
borax to treat stumps in campgrounds to prevent €
spread of annosus root disease. €

To accomplish this objective, a special €
contract provision was added to the timber sale €
contract: €

> C6.412# (OPTION 2) - TREATMENT OF STUMPS. €
> (5/88) Unless otherwise agreed to in writing, €
> in areas shown on Sale Area Map, Purchaser €
> shall treat the stumps of all live _____€
> trees cut by Purchaser that have a stump €
> diameter larger than________inches. Treatment €
> shall consist of removing sawdust and other €
> loose debris from the cut surface of the€
> stump including exposed wood surfaces on all €
> sides, and shaking a light coat of borax €
> powder uniformly over the entire cut surface €
> of the stump, including exposed wood surfaces €
> of the sides, the same day such cutting €
> occurs. Forest Service shall furnish borax €
> powder for Purchaser's use without charge. €

The first blank should be filled in with€
the name of the tree species needing treatment. €

This requires the fallers to apply a thin €
layer of borax powder on freshly cut surfaces of €
stumps larger than or equal to 12 inches in €
diameter. Treatment was to be accomplished €
within 24 hours after telling. To regulate the €
granular size and content, the Forest Service €
provided borax for the fallers. Based on €
information obtained from Forest Service and Pest €
Management personnel in California, sodium €
tetraborate decahydrate. 5-mil particle size. €
granular type. was the recommended formulation. €

RESULTS AND DISCUSSION €

Stands were to be cut in the summer of 1988 €
but, because since the purchasers had other €
timber sales pending closure, and the summer €
drought was again severe (causing logging €
shutdown), the subject stands were not cut. I €
therefore have no data to present on how €
effective the borax stump treatment was and €
whether the special contract provision worked €
satisfactorily. In spite of that, several €
important categorized questions have been €
generated that need answering. €

Can the special contract provision be €
effectively administered? Contracting operators €
can be suspended until the borax is applied €
correctly, but what about the stumps that are €
missed during the treatment? What should the €
quality assurance standard be? How should the €
quality standard be enforced? €

Also, how will falling timber and rolling €
logs on steep slopes affect treated stumps? €
Stumps will have to be treated immediately after €
trees are severed to prevent subsequently felled €
trees from covering them, thereby making later €
treatment impossible. Will there be any borax €
left on stumps once nearby trees are felled? €

Another question. How should we determine €
when enough borax has been applied by the €
operator without visiting each treated stump? €
That is, how do we evaluate purchaser compliance €
with the special contract provision? We are in €
the process of making a photo card that shows €
stumps with too little, too much, and just enough €
borax. The Pacific Northwest Region. Forest Pest €
Management Division. Portland. Oregon. has €
produced a similar card for marking laminated €
root rot (*Phellinus weirii*) affected stumps €
(Figure 1). €

Recognizing Laminated Root Rot in Freshly-Cut Douglas-Fir Stumps

Laminated root rot, caused by Phellinus weirii, is a common root disease of Douglas-fir. Other conifer species, such as grand fir, white fir, Pacific silver fir, larch, and hemlock may also be infected and have similar patterns of stain or decay in affected wood. This guide will help you identify laminated root rot on freshly cut stumps so they can be distinguished in timber sales requiring marking.

It is important to mark infected stumps so that they can be located following site preparation (burning). When the site is replanted, tree species which are not susceptible to laminated root rot can be used around infected (marked) stumps.

In infected trees, stain and decay of laminated root rot usually extend upward from the roots several feet into the main bole. At the stump surface, stain usually will be seen as 1 to 2 inch wide crescent shaped bands in the inner sapwood-outer heartwood area (Figure 1). Sometimes stain will also be found in the center of the heartwood (Figure 2). It will range in shade from a slightly darker color than the surrounding wood (Figure 3), to a dark brown, wet-appearing discoloration (Figure 4). Stumps must be marked soon after tree felling since characteristic stain fades within several days. Stain is the initial stage of wood decay. After several years stained wood will develop into advanced rot. Advanced decay will often be found in the center of stained wood (Figure 5). Advanced decay is characterized by wood separating (delaminating) at the annual growth rings. There are small pits on both sides of the sheets and red-brown fuzzy fungal growth on the surface. In infected old growth trees, hollows will often form in the butt after years of decay.

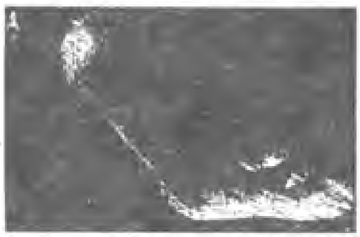


Figure 1. One to two inch-wide, crescent-shaped bands of stained and/or decayed wood in the inner sapwood/outer heartwood.

The size of laminated root rot disease centers can vary from one tree to hundreds or thousands of trees. Usually if one stained stump is found, stain will be found also in one or more adjacent stumps.

Other stains or decays may be confused with laminated root rot. Old wounds that heal often leave a zone of stain or decay behind the wound face (Figure 6). Other types of root and butt decay may be confused with laminated root rot. A common example is red-brown butt rot of Douglas-fir (Figure 7). This damage is common in mature over-mature Douglas-fir. Stumps with this dry crumbly red-brown decay should not be marked.
To best meet contract specifications, stumps with laminated root rot stain or decay at the cut surface should be marked with a saw within one hour of felling. Stumps should be marked by making two parallel grooves, 2 inches deep and 6 inches apart (Figure 8).

Figure 2. Stain and decay in the inner heartwood and the sapwood.

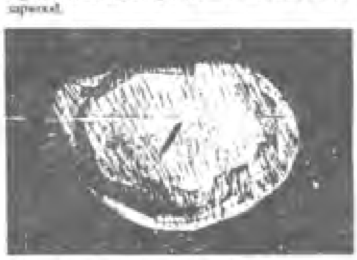


Figure 3. Stain appearing as a light shade of discoloration.

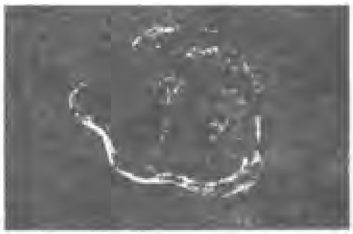


Figure 4. Stain appearing as a dark brown discoloration.

Figure 5. Decayed wood surrounded by stain. Decay is laminated; separating at the annual rings.

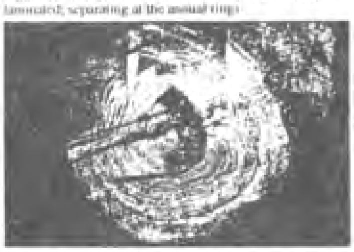


Figure 6. This stain and decay is the result of an old wound. It is not laminated root rot. Do not mark this stump.

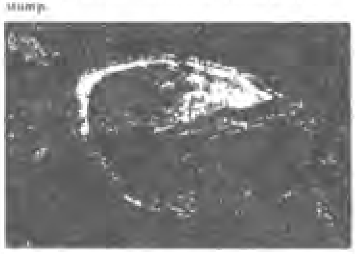


Figure 7. Brown cubical decay, the result of another disease. Do not mark this stump.

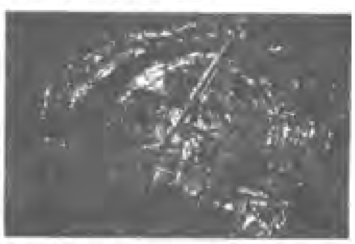


Figure 8. Example of marking infected stumps. Two parallel grooves, 2 inches deep, and 6 inches apart.

Copies of This Guide Can Be Obtained by Contacting:

USDA-Forest Service
Pacific Northwest Region
Forest Pest Management
PO Box 3623
Portland, Oregon 97208

Phone: (503) 221-3608 or
FTS: 427-2727

CONCLUSION €

In conclusion, the plan is to monitor the € treatment of the stumps in this pilot effort € during summer 1989 and get some of the answers to € these questions. The District now plans to use € Borax treatment as part of timber sale contracts € where the disease has been identified and € treatment considered appropriate. €

We anticipate that stump treatment with borax € will effectively prevent initial colonization of € freshly cut stumps by H. annosum. Similarly, € borax application should be beneficial following € commercial thinning entries. What remains to be € seen is whether treated stands will be € significantly better off at rotation, at whatever € age, than those that receive no treatment. €

BIBLIOGRAPHY €

(1)Driver, C.H., and Ginns, J.H., 1968, Practical € Control of Fomes Annosus in Intensive Forest € Management. College of Forest Resources, € University of Washington. Contributor No.5. €

(2)Edmonds, R.L., Driver C.H., and Russell. K.W., € 1969. Borax and Control of Stump Infection by € Fomes Annosus in Western Hemlock. Plant Disease € Reporter Vol.53:216-219. €

(3)Goheen, D.J., Filip G.M., Schmitt C.L., and € Gregg, T.F., 1980. Losses From Decay In 40 to 120 € Year Old Oregon and Washington Western Hemlock € Stands, U.S. Forest Service. Forest Pest € Management. State and Private Forestry. Portland, € Oregon. €

(4)Graham, D.A., 1971. Evaluation of Borax For € Prevention of Annosus Root Rot in California. € Plant Disease Reporter, Vol.55 No.6:490-4. €

(5)Hadfield. J.S.. Goheen, D.J., Filip, G.M., € Schmitt. C.L., and Harvey, R.D. 1986. Root € Diseases In Oregon and Washington Conifers, USDA € Forest Service, Pacific Northwest Region. Forest € Pest Management, Portland. Oregon. €

(6)Hodges. C.S., 1974, Cost of Treating Stumps to € Prevent Infection by Fomes Annosus, Journal of € Forestry. 72(7):402-4 €

(7)Koenigs. J.W.. 1969. Growth and Survival of € Fomes Annosus at High Concentrations of Borax, € Phytopathology, Vol.55 No.11:1717-21. €

(8)Nelson, E.E. and Li. C.Y.. 1980, Preliminary € Test of Two Stump Surface Protectants Against € Fomes Annosus, USDA, PNW Forest and Range € Experiment Station. Research Notes PNW 363. €

(9)Smith. R.S.. 1970, Borax to Control Fomes € Annosus Infections of White Fir Stumps, Plant € Disease Reporter, Vol.54 No.10:872-5. €

(10)Summaries of the Proceedings of the 1985 € Western Forestry Conference, Western Forestry and € Conservation Association, Portland, Oregon. €

Management Strategies for Annosus Root Disease in Pacific Northwest Coastal Western Hemlock[1]

Kenelm W. Russell [2]

Abstract: Actual loss from annosus root disease infections in hemlock stands is difficult to determine. As political trends move toward protecting old-growth timber, greater market demand will be placed on second growth western hemlock. These stands must be kept healthy for maximum productivity. The paper compares the following 70-year rotation timber management scenarios: The first has a single juvenile spacing entry and low infection. The second has early spacing plus a commercial thinning with considerable crop tree wounding and high infection. Operational guidelines are presented for management of coastal western hemlock to minimize losses due to annosus root disease.

Annosus root disease (Heterobasidion annosum (Fr.) Bref.) in the second-growth coastal western hemlock (Tsuga heterophylla) timber type of western Washington and Oregon has been investigated and discussed for more than 25 years. Although much progress has been made in understanding annosus root disease, the picture of its true impact is not yet complete (Chavez and others 1980; Edmonds 1968; Morrison and Johnson 1978; Russell and others 1973; Wallis and Morrison 1975).

The advent of recent concern over saving more old-growth timber, particularly in the western Cascade Mountains and Coast Ranges of Washington and Oregon, means that greater demand for wood fiber may be placed on second-growth stands of coastal western hemlock. This means probable increases in multiple stand entries and a potential for higher losses from annosus root disease. After observing and working on disease aspects of western hemlock in this region for almost 25 years, I am convinced that skilled and careful entries for periodic removal of fiber can be done without excessive losses caused by annosus root disease.

1 Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America. April 18-21, 1989, Monterey, California.

2 Manager/Forest Pathologist, Forest Health, Washington State Department of Natural Resources, Olympia, Washington.

The actual amount of fiber loss is difficult to pinpoint. Losses caused by annosus root disease in coastal western hemlock in Washington and Oregon do not arise from tree mortality as in other regions such as in eastern Oregon Cascade Mountains, or in the southeastern United States. Annosus-caused mortality in coastal western hemlock is rare; usually another root disease, such as armillaria, is responsible.

Loss caused by annosus root disease generally starts as stands reach precommercial spacing size. Contacts by young trees with roots of old infected stumps may be the first stage of disease transfer to the new crop. The next stage of infection occurs at root closure, or root contact and grafting, resulting in tree-to-tree spread within the stand. Spores germinating on freshly cut precommercial thinning stumps channel Heterobasidion annosum into crop trees through the root grafts and contacts. Crop trees may also be directly infected from spores that land on mountain beaver or bear wounds. When stands are commercially entered, logging equipment makes additional wounds on roots and lower stump areas, creating opportunity for more decay development. Any of these modes of entry throughout the rotation result in either annosus decay columns or wetwood columns without decay. Of course, it is understood that other decay organisms as well may enter the tree, but they will not be discussed in this paper.

When stands are well into maturity, or after about age 45 to 50 years, annosus-caused root degradation can result in localized severe windthrow from periodic winter storms. Windthrow from "major event" storms could, on occasion, destroy stands that have roots infected by annosus root disease.

How does the forest manager estimate yield loss? In theory, it seems relatively easy to assess the decay from each event and subtract it from the total potential yield over the length of the rotation. One of the most logical ways, when stands are timber oriented, is to use rotation age as the sideboard for visualizing quantitative loss. What is the difference in yield produced between a stand without annosus over a 60-year rotation and a similar but infected stand with the same rotation? There is a valid loss of fiber. When does it occur?

Foresters commonly use decades as convenient time units in forest management. Beginning with about the third decade of the managed western hemlock stand rotation, losses caused by annosus or shrinkage in any form of cubic volume measurement can be pinpointed at the end of each succeeding decade. It is important to carefully define the kind of loss. Is incipient decay (which may not really be a loss) included in the estimate or is only advanced decay considered? The kind of manufactured wood product may determine the degree to which loss must be considered.

Obtaining the amounts of decay in some form of cubic measure takes years of detailed and time-consuming studies that gradually piece the puzzle together. From studies done thus far, decay loss may not be as bad as we once thought. Yield tables in use today usually account for normal mortality only. They do not account for the insidious decay that creeps up through infected roots. The amount of decay may in some cases be substantial or it may be considered a normal and acceptable loss. Forest managers need to know what is happening to their managed stand yields.

VISUALIZING LOSSES FROM ANNOSUS ROOT DISEASE

Two western hemlock management regimes have been prepared to illustrate when annosus losses may occur in a rotation. These management regimes portray the growth of hemlock stands from 30 to 70 years and are typical for those managed by any large timber organization in the western hemlock zone described above. Each regime shows a normal yield and a yield with an estimated amount of loss from annosus root disease.

The first management regime is a western hemlock stand that is programmed for entry only at age 15 for precommercial thinning. This stand will carry more stems per acre, resulting in smaller-diameter trees that might be used for pulp or a special export log. The assumption for this regime is that incidence of annosus root disease would be relatively low because of both the single entry and little infection from previous stands.

The second regime is a "worst case" situation in which the stand is precommercially thinned in normal fashion at age 15 and then commercially thinned at age 35 during which many trees are damaged by careless logging. It is assumed that this stand could have substantial loss caused by annosus root disease.

These two stand management regimes are presented in a series of tables showing yield at each decade from 30 to 70 years. Trees were dissected into standard 32-foot logs with volumes in board feet and stand volumes in board feet per acre. The tables were generated from a Washington Department of Natural Resources computer program (DNRIMPS) developed for intensive management of stand yield projections (Chambers, 1988). The program computes volumes in Scribner log scaling rules for western Washington, based on stems per acre, diameter at breast height, and tariff tables for a given 50-year site index. A few shortcuts were taken in calculations in the tables presented here, and volumes were rounded off for clarity. Final volumes in the tables are similar to those strictly generated by the computer. Losses caused by annosus root disease are shown as a percent of the normal yield under an intensively managed regime.

The tables that form a model for typical western hemlock stands could be useful for managers and researchers alike to aid in pinpointing when and how much decay occurs in managed stands. The tables could be used in making better yield predictions once regional, local, or stand incidence of annosus root disease is known. The tables will also help researchers plan better investigations in pinpointing where and how to measure loss. The model also illustrates to loggers how careless damage to crop trees can cause serious yield loss.

Management Scenario for Low Annosus Impact

Tables 1-3 depict the yield and loss by annosus root disease through each decade for the low-decay incidence regime. The only entry before the rotation harvest was the precommercial thinning at age 15. The tables flow from one to the next. The final percent of loss caused by annosus root disease for each decade is found in table 3.

Management Scenario for High Annosus Impact

Tables 4-6 depict the yield and loss by annosus root disease through each decade for the high decay incidence regime. This stand was precommercially thinned at age 15 and then commercially thinned at age 35. Many crop trees were damaged during the logging. Decay may be significant if the rotation harvest is more than 20 years away. If the stand harvest is within about 10 years, much of the decay resulting from logging damage will be outside the scaling cylinder (Quam, 1977). The Scribner log scaling rule used in the Pacific Northwest measures logs from the small end, allowing a cone of unmeasured wood. In larger logs unmeasured wood amounts to considerable volume. If the unmeasured volume has been damaged by careless logging, the buyer receives less "free wood". The tables below flow from one to the next as in the low-impact regime. The final percentage of loss caused by annosus root disease percent for each decade is found in table 6.

The discussion and Tables 3 and 6 presented thus far predict only managed rotation losses from annosus root disease for standing trees. Additional volume loss of green timber may occur during storms of near-hurricane proportions if trees had excessive root decay. Windthrow loss is difficult to predict, but could be reasonably estimated if the stand infection is known.

MINIMIZING LOSS CAUSED BY ANNOSUS ROOT DISEASE IN MANAGED STANDS

Foresters need to become familiar with incidence of annosus root disease in western hemlock stands within their local area. By sampling stands of various ages, a

Table 1--Yield of an intensively managed site index 105 (105 ft, 50 yrs) western hemlock stand from age 30 to 70 with a single precommercial spacing entry at age 15. Normal stand mortality is accounted for, but loss from annosus root disease decay is not included.

Age	Diameter Breast Height	T/Ac[1]	No. 32' Logs[2]	BF/log[3]	BF/tree[4]	Scribner BF[5]
yr.	in.					vol acre
30	11.4	249	1	40	40	10,000
40	14.1	239	2	90,20	110	26,300
50	15.2	230	2	140,30	170	39,100
60	16.0	223	3	160,60,10	230	51,300
70	16.5	215	3	190,70,10	270	58,000

[1]Number of trees per acre (T/Ac) generated by DNRIMPS computer program.
[2]Number of 32-forrt-long logs per tree.
[3]Board feet per log.
[4]Board feet per tree.
[5]Scribner volumes rounded off to nearest 100 board feet; Age 30 volume per acre calculation: 249 x 40 = 9,960, etc.

Table 2--Breakdown of loss from annosus root disease in a western hemlock stand (precommercially spaced at age 15).

Age	T/Ac[1] Healthy	T/Ac[2] Infected	Pct[3]	Volume Loss[4]		
yr.				Pct/log	BF/log	BF/tree
30	174	75	30	5	38	38
40	155	84	35	9,0	81,20	101
50	138	92	40	15,3	119,29	148
60	111	112	50	17,6,0	133,56,10	199
70	75	140	65	22,10,0	148,63,10	221

[1]The number of healthy trees per acre.
[2]Calculation for number of infected trees at age 30, per acre is: .30 x 249 9T/ac col. table 1) = 75, etc.
[3]Percentage of trees infected by annosus root disease is a regional estimate of the average number of infected western hemlock trees per acre (T/Ac). These values may vary considerably.
[4]Percent log volume lost is a regional estimate of decay loss. The estimates are a composite of completed and on going studies. These numbers may vary. Compare Board-foot-per-log and board-foot-per-tree columns with the same columns in table 1.

rotation long, decade-by-decade estimate of impact can be obtained. The incidence of annosus root disease in an existing stand should influence harvesting method, number of stand entries, season entered, and rotation length of the replacement stand. For example, it would not be wise to shelterwood harvest a hemlock stand with a high incidence of annosus root disease because of the possibility of windthrow from decay weakened roots. High incidence of annosus root disease could also initiate changing the new crop to Douglas-fir, a species rarely impacted by the disease.

Table 3--Yield of the intensively managed stand of western hemlock (precommercially spaced at age 15) that estimates percent loss from annosus root disease for decades 3 through 7.

Age	Healthy Trees[1]	Trees Infected by Annosus[2]	Net Volume	Loss due to Annosus[3]
Yr.	BF/acre	BF/acre	BF/acre	Pct
30	7,000	2,800	9,800	2
40	17,000	8,500	25,500	3
50	23,500	13,600	37,100	5
60	25,500	22,300	47,800	7
70	20,200	30,900	51,100	12

[1] Volume per acre of 30-year-old healthy trees is: 174 (Healthy T/Ac col. table 2) x 40 (BF/tree col. table 1) = 7,000, etc.

[2] Volume per acre of 30-year-old trees infected with annosus root disease is: 75 (Infected T/Ac col. table 2) x 38 (BF/tree col. table 2) = 2,800, etc.

[3] Percent loss due to annosus root disease at age 30, is: $100-\left[\frac{9{,}800 \text{ net board feet per acre}}{10{,}000 \text{ Scribner volume (table 1)}} \times 100\right] = 2$, etc.

Table 4--Yield of an intensively managed site index 105 (105 ft, 50 yrs) western hemlock stand from age 30 to 70, precommercially spaced at age 15 and commercially thinned at age 35 with crop tree damage. Normal stand mortality is accounted for, but loss from annosus root disease decay is not included.

Age	Diameter Breast Height	T/Ac[1]	No. 32' Logs[2]	BF/log[3]	BF/tree[4]	Scribner BF[5]
yr.	in.					vol./acre
30	11.4	249	1	40	40	10,000
40	14.5	146	2	110,20	130	19,000
50	17.2	138	2	150,50	200	27,600
60	19.2	131	3	230,120,20	370	48,500
70	20.5	127	3	320,120,20	460	58,400

[1]Number of trees per acre (T/Ac) generated by DNRIMPS computer program.
[2]Number of 32-foot-long logs per tree.
[3]Board feet per log.
[4]Board feet per tree.
[5]Scribner volumes rounded off to nearest 100 board feet; Age 30 volume per acre calculation: 249 x 40 = 9,960, etc.

All thinning operations must be carefully planned to minimize chances for entry by the annosus organism. The following operational guidelines are useful in the Pacific Northwest region for reducing infection potential.

* Conduct juvenile spacing only; no commercial entry until rotation end.

* Conduct juvenile spacing plus 1 or more commercial thinnings.

Table 5--Breakdown of loss from annosus root disease in a western hemlock stand (precommercially spaced at age 15 and commercially thinned at age 35).

Age	T/Ac[1] Healthy	T/Ac[2] Infected	Pct[3]	Volume Loss[4]		
Yr.				Pct/log	BF/log	BF/tree
30	174	75	30	5	38	38
40	88	58	40	12,0	97,20	117
50	69	69	50	20,4	120,48	168
60	39	92	70	23,8,0	117,110,20	307
70	25	102	80	26,11,0	237,107,20	364

[1] The number of healthy trees per acre.
[2] Calculation for number of infected trees at age 30, per acre is: .30 x 249 (T/Ac col. table 4) = 75, etc.
[3] Percentage of trees infected by annosus root disease is a regional estimate of the average number of infected western hemlock trees per acre (T/Ac). These values may vary considerably.
[4] Percent log volume lost is a regional estimate of decay loss. The estimates are a composite of completed and on going studies. These numbers may vary. Compare board-foot-per-log and board-foot-per-tree columns with the same columns in table 4.

Table 6--Yield of the intensively managed stand of western hemlock (precommercially spaced at age 15, commercially thinned with crop tree damage at age 35) that estimates percent loss from annosus root disease for decades 3 through 7.

Age	Healthy Trees[1]	Trees Infected by Annosus[2]	Net Volume	Loss due to Annosus[3]
yr.	BF/acre	BF/acre	BF/acre	Pct
30	7,000	2,800	9,800	2
40	11,000	6,800	18,200	4
50	13,800	11,600	25,400	8
60	14,400	28,200	42,600	12
70	11,500	37,100	48,600	17

[1] Volume per acre of 30-year-old healthy trees is: 174 (Healthy T/Ac col. table 5) x 40 (BF/tree col. table 4 = 7,000, etc
[2] Volume per acre of 30-year-old healthy trees infected with annosus root disease is: 75 (Infected T/Ac col. table 5 x 38 (BF/tree col. table 5) = 2,800, etc
[3] Percent loss due to annosus root disease at age 30, is 100- $\left[\frac{\text{9,800 net board feet per acre}}{\text{10,000 Scribner volume (table 4)}} \times 100\right]$ = 2, etc.

* Shorten the rotation age.

* Educate the logging crew about consequences of damage to crop trees.

* Restrict logging during the bark slipping season in the spring.

* Match logging equipment to terrain and timber size.

* Use low ground pressure skidders.

* Avoid commercial thinning of steep slopes.

* Plan skid trails before logging and make them permanent.

* Build straight line skid trails.

* Leave turn and bump trees until last turn of logs.

* Log skid roads first.

* Cut low stumps in skid roads.

* Mark leave trees.

* Use directional falling for best log access to skid roads.

* Match log length with final spacing.

* Limb and top trees prior to skidding.

* Apply borax to commercial thinning stumps only when degree of protection is greatest.

* Prevent wounds on crop trees.

Note that applications of borax to stumps for controlling annosus root disease are not advocated in juvenile or precommercial thinnings. Even though the successful use of borax has been demonstrated, we have not elected to recommend it for all timber harvesting in the region (Russell and others 1973). Borax may be recommended when the incidence of annosus root disease is low or when trees to be protected are in a recreation site where people are concentrated.

Foresters using the above guidelines when contemplating stand entries will not suffer excessive losses from annosus root disease. Continued investigations by regional forest pathologists will fill in the gaps in the impact numbers and improve understanding of annosus root disease in western hemlock.

REFERENCES

Chambers, C. 1988. Intensive Management Program Simulation, version 8.1 Washington State Department of Natural Resources. Unpublished.

Chavez, T.D., Jr.; Edmonds, R.L.; Driver, C.H. 1980. Young-growth western hemlock stand infection by *Heterobasidion annosum* 11 years after precommercial thinning. Canadian Journal of Forest Research 10: 389-394.

Edmonds, R.L. 1968. Natural occurrence and control of *Fomes annosus* in precommercially thinned stands of western hemlock. College of Forest Resources, University of Washington, Seattle: Master's Thesis.

Morrison, D.J.; Johnson, A.L.S. 1978. Stump colonization and spread of *Fomes annosus* 5 years after thinning. Canadian Journal of Forest Research 8:177-180.

Quam, R. 1977. The impact of thinning damage on product value in western hemlock. In executive summary of proceedings of the Western Forestry and Conservation Association annual meeting; Seattle, Washington. November 30 - December 1, 1977. Page 118.

Russell, K.W.; Thompson, J.H.; Stewart, J.L.; Driver, C.H. 1973. Evaluation of chemicals to control infection of stumps by *Fomes annosus* in precommercially thinned western hemlock stands. Washington State Department of Natural Resources report 33.

Wallis, G.W.; Morrison, D.J. 1975. Root rot and stem decay following commercial thinning in western hemlock and guidelines for reducing losses. Forest Chronicles 51:203-207.

Borax Stump Treatment for Control of Annosus Root Disease in the Eastside Pine Type Forests of Northeastern California[1]

John T. Kliejunas[2]

Abstract: A historical perspective and description of recent studies on the use of borax to treat pine stumps against infection by Heterobasidion annosum in eastside pine stands of northeastern California are presented. The studies indicate that boraxing of pines in eastside pine stands is an effective means of preventing annosus infection. Data and observations suggest that the lower stump diameter limit for treating chain saw-cut pines with borax could be raised from the currently recommended 8 inches (20.3 cm) to about 16 inches (40.6 cm) with little or no risk of creating active annosus root disease centers.

The eastside pine type forests of northeastern California lie in the region east of the Sierra Nevada-Cascade crest between the 4,000 and 6,500 foot (1220 and 1982 meter) elevations (fig. 1) where the climate is cold and dry and the principal tree species are ponderosa pine and Jeffrey pine (McDonald 1983). Other vegetation consists of varying amounts of western juniper, sagebrush, grasses, and occasional mountain mahogany. The incidence of Heterobasidion annosum in eastside pine type stands is especially high and locally damaging (Olson 1941; Wagener and Cave 1946), due to past heavy cutting of pines and an apparently favorable environment for the pathogen. Work by Bega and Smith (Bega and Smith 1966; Smith and others 1966) supported earlier statements of Meinecke (1914) and Wagener and Cave (1946) that increased forest management activity has contributed to an increased incidence of annosus root disease, with the greatest losses being associated with pine stumps left after thinning and harvest cutting operations.

This paper briefly discusses the history of the use of borax to treat tree stumps against infection by H. annosum in California, describes some recent studies on the incidence of annosus root disease in eastside pine type stands in relation to the use of borax and stump diameter, and concludes with a summary of the current status of borax use.

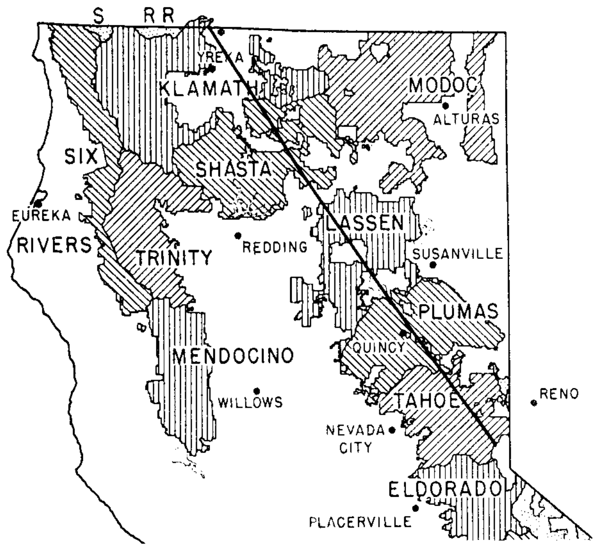


Figure 1. The eastside pine type forests of northeastern California lie in the area east of a line extending from Lake Tahoe northwestward to Highway 5 at the Oregon border.

HISTORICAL PERSPECTIVE

Recommendations for direct suppression or prevention of annosus root disease in California, based on research and surveys by Pacific Southwest Forest and Range Experiment Station and Pacific Southwest Region pathologists, were formulated in the 1960's. Direct suppression attempts in an area of high-value pines, which involved the pulling of stumps and fumigation (Bega 1962), proved too costly and impractical in most forest situations. Other control possibilities were suggested, but these either showed no promise under California conditions (biological control) or were not adequately field tested (the clear felling of trees around disease centers).

A silvicultural control method, which involved thinning during warm, dry periods unfavorable for growth of the fungus, was developed for eastside pine stands by R.S. Smith, Jr. (unpublished data[3]). High stump temperatures inhibited or blocked stump colonization by H. annosum in studies done in the southeastern Unites States (Gooding and others 1966; Ross 1973). Smith monitored stump

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, at Monterey, Calif.

[2]Supervisory Plant Pathologist, Pacific Southwest Region, U.S. Department of Agriculture, Forest Service, San Francisco, Calif.

[3]Unpublished data on file, Pacific Southwest Region, U.S. Department of Agriculture, Forest Service, San Francisco, Calif.

temperatures of cut and inoculated ponderosa pine saplings and poles on the Lassen National Forest. Assays of discs cut from the stumps suggested that _H_. _annosum_ will not survive the summer in stumps less than 6 inches (15.2 cm) in diameter because lethal temperatures above 104°F (40°C) are reached in the tops of the stumps.

Preventive measures such as chemical treatment of freshly cut stumps also were investigated in the 1960's. Choice of chemicals to test was based on success elsewhere (Berry and Bretz 1964; Hodges 1970; Driver 1963). High-nitrogen compounds (urea, ammate) that stimulate competing fungi, and borax, which is toxic to _H_. _annosum_ spores, were tested in 1965 and 1966 on the Lassen National Forest. Results were inconclusive. In 1969, Graham (1971) demonstrated that treatment of 2- to 6-inch diameter Jeffrey and ponderosa pine stumps in young eastside pine stands on the Lassen National Forest with technical grade borax (sodium tetraborate decahydrate) prevented infection. After artificial inoculation with the fungus, less than 1 percent of the borax-treated stumps became colonized, but over 61 percent of the similarly inoculated but untreated control stumps became colonized. In 1969, Smith (1970) demonstrated that dry granular borax also prevented infection of white fir stumps, and did so to a greater degree than did a mixture of borax, water, and sticker.

By the early 1970's, observations and research discussed above had resulted in an accepted list of control recommendations, with the realization that prevention by treatment of freshly cut stumps with borax was the best recourse. In developed recreation sites, high-use areas, and areas with high-value trees such as seed orchards, treatment of stumps of all conifer species with dry granular borax immediately after felling was recommended because of the assumed high value of the trees. In timber stands, the use of borax needed to be justified by weighing the dollar cost of control against the dollar value of losses prevented. Treatment of all pine stumps during thinning or timber sales was recommended if damage by the fungus had been established.

True fir was not included in the recommendations for borax treatment in timber stands for several reasons, not the least of which was the low stumpage value of the species. Other reasons included the knowledge that _H_. _annosum_ infects true fir through wounds as well as through stump surfaces, and the lack of pilot testing to demonstrate cost effectiveness on an operational basis.

Pacific Southwest Region pathologists (Byler and others 1978) developed a survey and subsequent benefit/cost analysis procedure to determine if application of borax to pine stumps is economically justified in eastside pine type stands. The procedure involves a strip cruise of a proposed sale area to determine the proportion of stumps from previous cuttings that had become annosus infection centers. The assumption is made that, without treatment, the proportion of stumps that become infected and cause mortality centers in the upcoming sale will be similar to that of previous sales. Data collected are used to calculate the economic feasibility of borax treatment of stumps created from the proposed timber sale. The benefit of borax treatment is the product of the estimated impact resulting from the sale, the effectiveness of borax stump treatment (assumed to be 90 percent) and a present net worth factor (based on the discount rate and the number of years until harvest). A summary of the procedure follows:

BENEFIT/COST ANALYSIS FOR BORAX STUMP TREATMENT

1. IMPACT = A x B x C x D x E

where: A = number of trees to be cut
B = Pct stumps currently infected
C = average center size (acres)
D = yield at rotation (M bd ft)
E = present stumpage value ($/M bd ft)

2. $\text{BENEFIT/COST} = \dfrac{\text{IMPACT} \times F \times G}{H}$

where: $F = \dfrac{1}{(1+i)}n$ and n = years until harvest

G = treatment efficiency = 0.90
H = treatment cost = number trees cut x $1.00

3. PERTINENT INFORMATION

A = number of trees to be cut .... [1]
B = Pct stumps currently infected .. [2]
C = average disease center size ...[1]
D = yield at rotation (M bd ft) ...[1]
E = present stumpage value ($/M bd ft) .... [1]
i = interest rate (discount factor) ....see FSM 1971.71
G = treatment efficiency 0.90
H = treatment cost $1.00/stymp
n = years until final harvest .... [1]

[1] Information supplied by Forest/District
[2] Information obtained from survey

Initially, all proposed timber sales in eastside pine type forests were surveyed according to the procedure described above. Because results of these and other surveys indicated extensive areas of eastside pine with disease centers originating from stumps created by past cutting, it became forest policy in about 1978 on the Lassen National Forest to apply borax to all pine stumps in timber sales. At about the same time, incidence as high as 65 percent stump infection on some sale areas on the Devils Garden Ranger District on the Modoc National Forest prompted the district to adopt the same policy.

A stump diameter limit for borax treatment, based on Smith's stump temperature studies, was added for pine in timber stands. Smith's research suggested that, because of the high, lethal temperatures reached in small diameter stumps, pine stumps less than 6 inches (15.2 cm) in diameter need not be treated with borax to control H. annosum infection. This lower diameter limit to treat was increased to 8 inches (20.3 cm) because observations indicated no spread of the disease from stumps created in pre-commercial thinnings.

Although the above recommendations for use of borax were once part of the Forest Service Directives System, the only directive now in effect is FSM 2303.14, R-5 Supp. 164, 9/86, which states..."To perpetuate the forest environment in and around developed recreation sites, treat all freshly cut coniferous tree stumps to prevent introduction and spread of Fomes annosus."

Suggestions for preventing or reducing the occurrence and the severity of annosus root disease in eastside pine type stands were summarized in 1982 (Smith 1983):

1. Because small stumps tend not to carry the infection, and solar radiation will kill H. annosum on or in the stump, thin eastside pine stands once, early and heavy, before the stumps reach 6 inches (15.2 cm) diameter.
2. Manage on an even-aged basis and minimize the number of entries after the trees reach pole-size.
3. Where survey of stumps from past cuttings indicates a stump infection rate of 5-10 percent or higher, consider treating all pine stumps larger than 8 inches (20.3 cm) in diameter with borax at the time of cutting.

As foresters and pathologists moved on to other positions or retired in the late 1970's and early 1980's and were replaced by others without the historical perspective and experience with annosus root disease, some of the reasoning behind the recommendations for borax treatment became vague, if not lost.

During the early 1980's, precommercial thinning of eastside pine type stands by mechanical shearing became an accepted and economical technique on portions of the Lassen National Forest and on the Doublehead Ranger District on the Modoc National Forest. The technique involves shearing standing trees at ground level. Because of the historical evidence of the impact of annosus root disease, the Lassen National Forest routinely boraxes all sheared pine stumps 8 inches (20.3 cm) or larger in diameter. The Doublehead Ranger District on the Modoc National Forest did not because of the lack of survey data indicating an annosus root disease problem. A biological evaluation of the shear and stack technique in 1985 (Kliejunas 1985) suggested that, because stumps sheared at ground level may be more favorable for successful infection than stumps cut higher, and because of the known high rates of infection centers in other portions of the eastside pine type stands, treatment of sheared pine stumps 8 inches (20.3 cm) or larger with borax would be prudent.

RECENT SURVEYS

The 1985 evaluation, and questions from silviculturists, including why boraxing was routinely done on the Devils Garden Ranger District, but not on other districts on the Modoc National Forest, prompted several subsequent surveys and studies. The questions and results of the subsequent surveys and studies follow.

1. What are the current levels of annosus root disease in eastside pine type stands on the Modoc National Forest?

Surveys of similar stands on the Lassen National Forest have indicated that 5 to 15 percent of stumps from previous cuttings are infected (Smith 1983). The only historical information from the Modoc National Forest was from the Fletcher sale on the Devils Garden Ranger District, where 60 percent of the stumps were found infected in a 1975 survey (Byler and others 1978).

To determine the incidence of annosus root disease on the Modoc National Forest, ten 8- to 15-year-old sale areas were examined in May 1986 (Kliejunas 1986). Six of the sales were on the Devils Garden Ranger District and four on the Doublehead Ranger District. All sale areas were in eastside pine type stands. Stumps had not been boraxed in the sale areas.

In each sale area, a one-chain (20.1 meter) -wide strip survey was run for 20 to 40 chains (402 to 804 meters) parallel to a road. All stumps within the strips were measured for diameter and examined for the presence of H. annosum. If H. annosum conks were found in or on a stump, the stump was recorded as infected. If no conks were present, it was tallied as not infected. Dead and dying trees around the stumps were noted and estimates of area of root disease centers were made. The total area sampled varied in each sale area.

Results from the ten sale areas examined are presented in table 1. Stump infection averaged 50 percent, ranging from 20 percent on the Timbered Ridge sale to 80 percent on the Craig Spring sale. Levels of stump infection were low on the Crowder, Timbered Ridge, and Cupboard sales, but still were over 20 percent.

Table 1--Incidence of pine stump infection by *Heterobasidion annosum* on ten non-boraxed timber sale areas surveyed in 1986 on the Modoc National Forest

Sale	Year cut	Area sampled	Pine Stumps infected[1]		Active infection centers[2]		Dead pines[3]
		Acres	No.	Pct	Total	Per acre	No.
Devils Garden R.D.[4]							
Craig Spring	1970	4.0	39/49	80	12	3.0	21
Everly	1971	3.5	14/35	40	8	2.3	22
Knobcone	1973	4.0	38/54	70	13	3.3	50
Widow Valley	1974	4.0	28/51	55	8	2.0	31
Poindexter	1976	2.0	19/40	48	4	2.0	5
Crowder	1977	2.0	9/40	23	3	1.5	6
Doublehead R.D.							
Warm Springs	early 70's	4.0	22/40	55	7	1.8	14
Bird Springs	mid-70's	4.0	26/36	72	11	2.8	54
Timbered Ridge	mid-70's	4.0	7/35	20	1[5]	0.3	2
Cupboard	late 70's	3.5	11/42	26	0[5]	0.0	0
	TOTALS	35	213/422	50	67	1.9	205

[1] Ratio of the number of stumps with conks of *H. annosum* to the total number examined.

[2] Based on the presence of at least one dying or recently dead pine adjacent to the stump infected by *H. annosum*. An area with more than one stump associated with the dying or recently dead trees was counted as one active annosus root disease center.

[3] Total number of dying or recently dead pines adjacent to stumps infected by *H. annosum*.

[4] R.D. = Ranger District.

[5] The area was recently thinned with mechanical tree shearer. This thinning would have removed dead or dying trees in the vicinity of stumps remaining from previous timber sales.

Size of annosus infection centers varied. In many cases only one or two dead or dying pines were associated with each infected stump. In some sale areas (Knobcone, Craig Spring, and Bird Springs) however, dead and dying pines within areas of an acre (0.4 ha) or more were associated with infected stumps. Recently dead or dying sapling, pole, or sawtimber-sized ponderosa pines on the Knobcone and Bird Springs sales averaged about 12 trees per acre (0.4 ha). Juniper and sagebrush also were infected with *H. annosum* in these root disease centers.

The number of active annosus root disease infection centers varied from none on the Cupboard sale to 3.3 per acre (0.4 ha) on the Knobcone sale, and averaged 1.9 infection centers per acre (0.4 ha) for all sales. If, by conservative estimate, each active center averaged 0.1 acre (0.04 ha), then about 20 percent of each acre (0.4 ha) surveyed was out of production due to annosus root disease. In terms of the total survey, trees on 7 (2.8 ha) of the 35 acres (14.2 ha) examined were infected by *H. annosum.*

The actual numbers of infected stumps in the sale areas examined on the Modoc National Forest were probably higher than recorded because only stumps with conks were counted as infected. These high rates of infection, as evidenced by the number of dead pines, result in at least 20 percent of each acre (0.4 ha) being currently out of production. Since *H. annosum* can survive in infected stumps for many years, a conservative estimate is that about one fifth of the area in non-boraxed timber sales in the eastside pine type on the Modoc National Forest will not produce merchantable pines for the next 20 to 40 years.

2. Is boraxing of pine stumps in eastside pine type stands actually beneficial?

In 1987, six 5- to 11-year-old sale areas (three on the Modoc National Forest and three on the Lassen National Forest) where stumps were

Table 2--Incidence of pine stump infection by Heterobasidion annosum on boraxed and non-boraxed timber sale areas on the Modoc and Lassen National Forests.

Forest	Sale Area	Year cut	Year surveyed	Boraxed	Acres sampled	Pine stumps infected	
						No.[1]	Pct
Modoc							
	Fletcher	1976-77	1987	yes	11	2/100	2
	Crowder	**1977**	**1986**	**no**	**2**	**9/40**	**23**
	Knobcone Fire	1978-79	1987	yes	2.8	1/50	2
	Wart	1980-81	1987	yes	4.1	3/70	4
	Knobcone	**1973**	**1986**	**no**	**4.0**	**38/54**	**70**
Lassen							
	Mt. Home	1977	1987	yes	6.1	1/50	2
	Juniper	1978	1987	yes	3.7	1/50	2
	Suicide	1978-79	1987	yes	3.4	0/25	0

[1]Ratio of the number of stumps with conks of H. annosum to the total number of stumps examined.

boraxed at the time of cutting were examined (J.T. Kliejunas, unpublished data[4]). A one-chain-wide strip survey as previously described was used, and all stumps created during the most recent sale that were within the strip were examined for the presence of H. annosum. These data were then compared to those of the 1986 survey.

Results are presented in table 2. On the three boraxed sales on the Modoc National Forest, 2 to 4 percent of the stumps were infected. The Fletcher sale is adjacent to the non-boraxed Crowder sale area examined in 1986. Only 2 percent of the stumps in the boraxed Fletcher sale were infected compared to 23 percent in the non-boraxed Crowder sale. The non-boraxed Knobcone sale is located between and within a few miles of the boraxed Wart and Knobcone Fire sales. Four and two percent of the stumps in the boraxed Wart and Knobcone Fire sales, respectively, were infected, compared to 70 percent in the non-boraxed Knobcone sale.

From none to 2 percent of the stumps examined on the three boraxed sales on the Lassen National Forest were infected. Some historical information on the Mt. Home and Juniper sales exists. Pre-sale surveys in 1975 by Forest Pest Management found that 15 percent of stumps from previous cuttings were infected with H. annosum. Based on the assumption that, without borax treatment, about 15 percent of the stumps created would be infected, the decision was made to borax. About 10 years after borax treatment, only 2 percent of the boraxed stumps were infected.

[4]Unpublished data on file, Pacific Southwest Region, U.S. Department of Agriculture, Forest Service, San Francisco, Calif.

3. If boraxing is done, what diameter class of stumps should be treated?

Policy regarding lower limits of stump diameter to treat with borax varies by forest and district, depending largely on historical information, current observations, and other considerations. In 1985, thinned ponderosa pine stands on the Hat Creek Ranger District on the Lassen National Forest were surveyed to determine the lower limit of stump diameter on which H. annosum is not an effective pathogen in eastside pine type stands, rendering borax treatment unnecessary (DeNitto 1985).

Only eight of 83 mortality spots checked did not have stumps greater than 18 inches (45.7 cm) in diameter as an apparent source of infection. Two of these eight centers had no obvious source (within reasonable limits), and the remaining six centers had numerous small stumps as possible sources of infection.

The present policy on the Lassen National Forest in eastside pine type stands is to use borax on all commercial timber sales. Borax is not used in precommercial thinnings, except in those that are mechanically sheared. In general, stumps in precommercial thinnings are 8 inches (20.3 cm) or less in diameter. The survey results support that policy.

Stump diameters were measured during a survey on the McCloud Ranger District, Shasta-Trinity National Forests, in 1988 (DeNitto 1988). The survey objective was to determine the levels of annosus root disease in eastside pine stands and mixed conifer stands with previous harvesting activity. Two mixed conifer stands had an average of 4 percent of the stumps infected, and four eastside pine stands averaged 18 percent stump infection.

Figure 2 presents a summary of the percentage of stumps infected by diameter class for the four eastside pine stands. Results suggest that stumps less than 14 inches (35.6 cm) in diameter will not support active annosus infection centers.

The 1986 survey on the Modoc National Forest (Kliejunas 1986) also revealed a relationship between stump diameter and infection (table 3). Although the data should be interpreted with caution because of the low numbers of stumps 12 inches (30.5 cm) or less in diameter, larger diameter stumps were more likely to be infected than smaller diameter stumps.

4. What is the incidence of infection of sheared stumps by H. annosum, and are stumps sheared at ground level actually more favorable for infection?

Some information on the incidence of infection of sheared stumps by H. annosum is available (J.T. Kliejunas and W.J. Otrosina unpublished data[5]). In 1986 and 1987, 14 mechanically sheared stands on the Doublehead Ranger District were selected according to time since shearing and time of year that shearing occurred. Discs or wood chips were collected by diameter class from 10 randomly selected sheared stumps in each stand and samples were incubated to determine colonization by H. annosum. The fungus was present in 4 of the 14 stands. The four stands were thinned 1 or 2 years previous to sampling and at all seasons of the year.

To determine whether sheared stumps are more favorable for infection by H. annosum than stumps cut by chain saw, a stump temperature study similar to R.S. Smith Jr.'s needs to be done. The hypothesis is that stumps cut at ground level and often covered by duff are more favorable for infection owing to lower temperatures and higher moisture.

DISCUSSION

The studies and observations summarized in this paper indicate that boraxing of pines in eastside pine type stands is an effective means of preventing annosus infection and reducing future losses. These studies also suggest that, in timber sales, the diameter limit for treating with borax could be raised from 8 inches (20.3 cm) to "commercial" trees. In eastside pine type stands, "commercial" can vary from about a 12-inch (30.5 cm) diameter stump in normal sales to 16 to 18 inches (40.6 to 45.7 cm) in fire salvage sales. Although one research study (R.S. Smith, Jr., unpublished data) indicated

[5]Unpublished data on file, Pacific Southwest Region, U.S. Department of Agriculture, Forest Service, San Francisco, Calif.

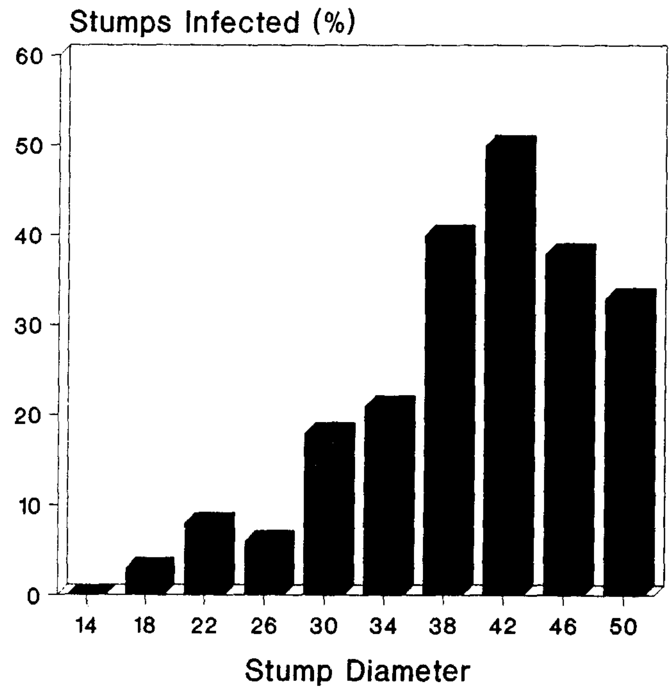


Figure 2. Percent of pine stumps infected by Heterobasidion annosum by diameter class.

Table 3-- Ponderosa pine stumps with conks of Heterobasidion annosum, by diameter class, on ten non-boraxed timber sale areas on the Modoc National Forest

	Stumps		
Diameter	Total observed	With conks	Infected
Inches	No.	No.	Pct
12 or less	20	0	0
14 to 18	7	0	0
18 to 22	12	2	17
22 to 26	29	10	35
26 to 30	73	30	41
30 to 34	88	45	51
34 to 38	86	52	60
38 to 42	62	42	68
42 or more	45	33	73

that stumps 6 inches (15.2 cm) in diameter and larger in eastside pine type stands are susceptible to infection, field observations only rarely indicate H. annosum spreading from pine stumps less than about 16 inches (40.6 cm) in diameter and causing active annosus root disease infection centers. The diameter of stumps susceptible to infection may well be smaller than the diameter needed to successfully carry H. annosum to adjacent live trees.

The decision as to what lower stump diameter limit to treat with borax should be based on the risk the forest or district is willing to take versus the cost of the borax treatment. When thinning by mechanical shearing, which creates stumps at ground level often covered by duff, the risk of infection may be greater. Since the oldest sheared stands in the eastside pine type are only about 10 years old, active centers may not have had time to develop. Until more information is available, the decision as to the lower limit at which to treat sheared stumps should be weighted toward the 8-inch (20.3-cm) limit indicated by research results.

REFERENCES

Bega, R.V. 1962. Tree killing by Fomes annosus in a genetics arboretum. Plant Disease Reporter 46: 107-110.

Bega, R.V.; Smith, R.S., Jr. 1966. Distribution of Fomes annosus in natural forests of California. Plant Disease Reporter 50: 832-836.

Berry, F.H.; Bretz, T.W. 1964. Urea and other chemicals effective against colonization of short leaf pine stumps by Fomes annosus in Missouri. Plant Disease Reporter 48: 886-887.

Byler, J.W.; Estes, K.M.; Srago, M.D. 1978. Application of a decision tool for annosus root disease prevention to three timber sales in northeastern California. Unnumbered Report. San Francisco: Forest Insect and Disease Management, Pacific Southwest Region, U.S. Department of Agriculture, Forest Service; 8 p.

DeNitto, G.A. 1985. Evaluation of Fomes annosus in precommercially thinned pine stands on the Lassen National Forest. Rept. No. 85-36. San Francisco: Pacific Southwest Region, U.S. Department of Agriculture, Forest Service; 2 p.

DeNitto, G.A. 1988. Evaluation of annosus root disease on McCloud Ranger District. Unnumbered Report. Redding, CA: Northern California Service Area, Pacific Southwest Region, U.S. Department of Agriculture, Forest Service; 3 p.

Driver, C.H. 1963. Effect of certain chemical treatments on colonization of slash pine stumps by Fomes annosus. Plant Disease Reporter 47: 569-571.

Gooding, G.V.; Hodges, C.S., Jr.; Ross, E.W. 1966. Effect of temperature on growth and survival of Fomes annosus. Forest Science 12: 325-333.

Graham, D.A. 1971. Evaluation of borax for prevention of annosus root rot in California. Plant Disease Reporter 55: 490-493.

Hodges, C.S. 1970. Evaluation of stump treatment chemicals for control of Fomes annosus. Hodges, C.S.; Rishbeth, J.; Yde-Andersen, A., eds. Proceedings, third international conference on Fomes annosus; July 29-August 3, 1968; Aarhus, Denmark. International Union of Forest Research Organizations. U.S. Department of Agriculture, Forest Service; 43-53.

Kliejunas, J.T. 1985. A biological evaluation of pests associated with the shear and stack technique for precommercial thinning on the Doublehead Ranger District, Modoc National Forest. Rept. No. 85-18. San Francisco: Pacific Southwest Region, U.S. Department of Agriculture, Forest Service; 8 p.

Kliejunas, J.T. 1986. Incidence of Fomes annosus stump infection on the Doublehead and Devils Garden Ranger Districts, Modoc National Forest. Rept. No. 86-21. San Francisco: Pacific Southwest Region, U.S. Department of Agriculture, Forest Service; 4 P.

McDonald, P.M. 1983. Climate, history, and vegetation of the eastside pine type in California. Robson, T.; Standiford, R.,eds. Proceedings of the symposium on management of the eastside pine type in northeastern California; June 15-17, 1982; Susanville, CA: Northern California Society of American Foresters; 1-16.

Meinecke, E.P. 1914. Forest tree diseases common in California and Nevada. A manual for field use. Washington, D.C.: U.S. Department of Agriculture; 67 p.

Olson, A.J. 1941. A root disease of Jeffrey and ponderosa pine reproduction. Phytopathology 31: 1063-1077.

Ross, E.W. 1973. Fomes annosus in the southeastern United States: relation of environmental and biotic factors to stump colonization and losses in the residual stand. Tech. Bull. 1459. Washington, D.C.: U.S. Department of Agriculture, Forest Service; 26 p.

Smith, R.S., Jr. 1970. Borax to control *Fomes annosus* infection of white fir stumps. Plant Disease Reporter 54: 872-875.

Smith, R.S., Jr. 1983. Diseases of eastside pine types. Proceedings of the symposium on management of the eastside pine type in northeastern California; June 15-17, 1982; Susanville, CA: Northern California Society of American Foresters; 79-81.

Smith, R.S., Jr.; Begs, R.V.; Tarry, J. 1966. Additional hosts of *Fomes annosus* in California. Plant Disease Reporter 50: 79-81.

Wagener, W.W.; Cave, M.S. 1946. Pine killing by the root fungus *Fomes annosus* in California. Journal of Forestry 44: 47-54.

Management of Annosus Root Disease Caused by *Heterobasidion annosum in* Coniferous Trees in Yosemite National Park[1]

Lorne West[2]

Abstract: Trees affected by the annosus root disease are easily windthrown or fall without visible symptoms that might warn forest recreation managers of impending failure. Some of the trees have struck cabins or campsites, causing death or destroying vehicles and recreational facilities. To prevent loss of life or property, and to save as many trees as possible for landscaping purposes, the management option of creating a buffer zone by removing the first line of trees from around each infection center was selected. However, the selection of buffer zone cutting resulted in removing 249 trees or nearly 90 percent of the overstory trees over a 3-year period. This effectively clear cut much of the area since many smaller centers had coalesced into a few large centers. As a result of the cutting, two other management concerns developed: 1) the need to revegetate the area, and 2) the need to remove a single line of trees that remained between some centers and were subject to windthrow. Revegetation is continuing with native trees and shrubs.

This paper presents a history and an accounting of the damages and cost that can be caused in established root disease infection centers within developed recreational sites, the specific management options available, and the problems encountered in removing trees and in revegetating the developed areas.

[1] Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2] Park Forester, Yosemite National Park, California.

HISTORY

For 40 years in Yosemite Valley the removal of both insect-killed trees and defective trees considered hazardous to visitors and property greatly increased the number of annosus root disease infection centers caused by <u>Heterobasidion annosum</u>. During that time it was not known that the cut stumps should have been treated with a fungicide or borax to prevent the establishment of new infection centers. The increasing number of infected stumps eventually led to many otherwise healthy trees being infected through contact with the roots of infected stumps.

In 1970 and 1971, 56 infection centers were identified in undeveloped areas throughout Yosemite Valley. Within developed sites 105 centers were identified. The Yosemite Lodge complex with 21 centers had the most dense concentration of centers and was the area of greatest management concern.

In Yosemite Valley, through a combination of root disease and easterly foehn (Mono) winds since 1982, the concessioner lost over $500,000 dollars in property damage and an unknown amount of loss in revenue, while visitors lost at least $100,000 in vehicles. The National Park Service suffered complete loss of a seasonal housing area, which required the building of an apartment complex outside of the park for nearly $6 million. The recent fatalities in Yosemite have not been from rot-affected falling trees, but from wind storms.

The initial infection center was first identified in 1940, on the west end of the Lodge area. From that time on, the dying of trees scattered through the Lodge complex was attributed to bark beetle attacks on trees weakened by competition, compaction, or the paving over of their roots. It was not until about 1969 that some trees, usually incense cedar and white fir and occasionally a pine or two, began falling unexpectedly on clear nonwindy days for no apparent reason. One look at the root ball, usually about 20 inches in diameter on an 18 inch DBH tree, provided visible evidence as to why the tree failed.

To determine the magnitude of the problem, we asked the Forest Service for assistance, and they contracted with the pathology department at University of California, Berkeley, for help in determining the extent of the "Fomes problem". The initial findings, since the search was limited to developed sites, implied that site development and tree failures were related. To clarify this implication, the survey was extended the following year into undeveloped areas where many infection centers were also found. We then recognized that tree removals without stump treatment for several years of beetle control also had contributed to the development of many infection centers.

One of the objectives in developed areas is to maintain tree cover for as long as possible for landscaping needs. Therefore, even though a tree has crown symptoms indicating poor health, these symptoms may not be caused by annosus root disease, and if it is not likely to fall unexpectedly and does not need to be removed as an immediate hazard, it can be retained for many years. However, trees in poor health and near a known infection center are assumed to have root disease and are removed. About 1976, a cooperative study was conducted with the Forest Service and the University of California, Berkeley, to develop criteria by which trees affected by annosus root disease could be identified by observing crown symptoms. A printed guide was developed for incense cedar but not for other coniferous species.

Since the printed guide did not totally solve the problem, existing options were reviewed and new options were sought. We rejected the existing options of: no action, clear cutting the area, or moving the entire Lodge complex to another location. For new options we again called upon the Forest Service. Their additional options included taking core samples from the root crown for culturing to identify infected trees, cutting a buffer zone around each infection center and seasonally closing various public use areas.

MANAGEMENT OPTIONS

The following is a review of the alternatives available to management and the reasons for their acceptance or rejection.

No Action

This alternative means do nothing, accept the risk, and continue to lose lives, equipment and facilities. It was rejected as morally unacceptable.

Remove the Target-of-Value

A target-of-value is either people or property. The removal of people and vehicles already is applied in part. People and vehicles are evacuated whenever high wind conditions either are present or are predicted and certain other risk criteria are met. Facilities cannot be moved since most of the trees on the Valley floor have some degree of root disease and areas outside the Valley have a limited water supply. Also moving the structures and adding the related infrastructure of underground utilities, roads, and parking areas in new locations would cause unacceptable resource damage.

Remove All the Trees

If all trees were removed, their aesthetic and landscaping value and their value as a sound barrier to vehicular traffic would be lost. Therefore, this alternative was not selected.

Buffer Zone Cutting

Buffer zone cutting involves removing the next line of trees surrounding the known infection centers. This line of trees, in theory, would most likely have a higher degree of root disease than the next line of trees and would be more likely to be windthrown. Although this alternative would enlarge the infection centers and openings in the canopy, it would not necessarily stop the spread of the annosus root disease and still leave some trees for cover. This alternative was selected as being the least manipulative, least costly, and least controversial.

Seasonal Closures

Areas with a record of damage by winter storms would be closed, and sites with low damage potential could still be operated. Storm damage is dependent on which site is struck by “Mono Winds”. Because all developed site in the Valley are subject to wind damage, the units easiest to operate to the winter are left open and all others are closed. This alternative has also been selected for some other areas

We selected the buffer cutting option and applied it to the Yosemite Lodge area because it had the greatest number of tree failures and the largest dollar amount of property loss of any area in the Park. We were required to schedule tree removals at times least disruptive to the concessioner's operation, before the winter storms, and during periods of low visitation.

METHODS

Selecting the Area

Three criteria were used for selecting the infection centers for buffer cutting: unmapped centers with repeated blowdowns, mapped disease centers with blowdowns, and adjacent mapped disease centers without blowdowns.

Selecting the Trees

Maps made previously by Det Vogler from the Forest Service included boundaries of predicted rates of spread for 10-year and 20-year intervals. The first line of standing trees at the edge of the infection center and closest to the 10-year interval were selected for removal. Most of these tree were near where one would expect the 15-year interval to be. Root crowns of the next line of trees were sampled and inspected for symptoms of root disease, and tissue samples from them were cultured to detect the presence of *H. annosum*.

Sampling and Culturing Techniques for Detecting Annosus Root Disease

Two samples were taken from the root crown of each tree. One sample was from the side nearest the infection center and one was from the opposite side. Though we were successful in culturing the pathogen from only 4 samples out of 200, the technique still has merit for identifying infected trees for immediate removal. By using greater care and better sampling techniques, the success rate in culturing for *H. annosum* from green trees can be improved.

Tree Removals and Disposal

Trees 180 feet tall are found between cabins at Yosemite Lodge. Most cabins are within 20 feet of one another, leaving minimal room for removal of trees. Many times we can simply pick up and move the cabin with a leader, drop the tree and then replace the cabin. In this treatment area many of the cabins could not be moved. When cabins are not involved the average cost of tree removal is $638. However, often it was necessary to climb, limb, and top the trees which increased the cost of removal and cleanup up to $3,000 per tree. Approximately 80 to 100 trees are removed each year from the Lodge area. The trees are sold as firewood from a local woodyard or by contract sale as merchantable timber to the highest bidder.

Currently, some of the logs are used for bumper logs, firewood, split roil fences, and benches within the park. Suggestions are needed for rapid, efficient, politically and philosophically sound ways to dispose of the rest of the 400 logs or 200,000 board feet of wood harvested nearly every year.

The need for a disposal method other than timber sales results from a philosophical point of view. National parks, especially Yosemite, are prime examples of a land management ethic for nonexploitive use of natural resources such as sales, minerals, livestock range management, or water power generating capacities. Authorizing logging trucks to enter and leave Yosemite weakens the basic philosophical concept of the purpose of national parks worldwide.

REVEGETATION

Approximately 60 to 70 percent of the trees (about 900) trees at Yosemite Lodge have been removed as part of our hazardous tree program. The concessioner has voluntarily started revegetation of the area. To date, 75 black oaks, 30 white alder, 12 big leaf maple, 36 incense cedars, and various native shrubs have been planted. The cedars (which are susceptible to annosus root disease) are being used as nurse trees to provide shade to the young broadleaf and as a quick growing screen to landscape the buildings. As the cedars reach about 50 feet in height, and before they become hazardous, they will be removed if they have not already been killed by root disease. Successive plantings of the cedars will be made until the broadleaf trees provide the desired degree of shade and screening. The possibility of funding for revegetation through USDA Forest Service has not been investigated to date.

RESULTS AND CONCLUSIONS

Openings caused in the forest canopy by drought, insect kills, the infection centers, and enlargement of them by buffer cuttings have left the remaining trees subject to possible windthrow. To prevent further loss of life and property, 125 trees in one guest cabin area and an employee tent area were removed this past winter. The trees that were removed may or may not have been hazardous, but were removed because of the record of annual windthrow, the loss of one life, the destruction of 15 or more cabins, and no guarantee that the area could be successfully evacuated prior to the next windstorm. The continuing removal of most of the trees from the Lodge area is inevitable.

The questions are: Is the protection of development to take precedence over resource protection? Should development be removed to protect resources? Should the resource be modified or altered to provide completely safe access by the user?

The majority of visitors who now enter natural areas do not recognize the inherent dangers. Is warning the visitor that use of an area may be dangerous and may have to be evacuated sufficient protection to continue use of an area? Should managers of natural areas consider developed forested recreation areas to be urban forests? Should they abandon the concept of naturalness and manage those areas as a planned environment for safe use and occupancy by uninitiated, and unaware urban dwellers? This would be a radical departure from present policies but it might be forced upon park management by population pressure and annosus root disease.

Summary

A Summary of Information Needs for the Management of *Heterobasidion annosum* in Coniferous Forests in Western United States[1]

William J. Otrosina Kenelm W. Russell[2]

The previous sessions in this symposium have provided valuable information of interest to researchers and land managers. During the course of the summary session, numerous questions dealing with various aspects of the disease were put forth by the participants. These questions summarized here dealing with various aspects of *H. annosum* hopefully will stimulate new research that addresses problems and concerns of land managers and forest pest management specialists.

What is the role of host stress (air pollution, moisture, etc.) on disease development and tree mortality?

What is the effect of *H. annosum* on long term-site productivity?

What is the nature and significance of interactions of *H. annosum* with *Armillaria mellea*?

Do "minor" or understory species influence spread of *H. annosum*?

What role does *H. annosum* play regarding ecological diversity in forest stands?

At what rate does *H. annosum* spread in commercially thinned western hemlock stands?

How do we identify genotypes of various affected tree species that are resistant to *H. annosum*?

What is the relationship between pathogenicity and biological species in *H. annosum*?

How are bark beetle population dynamics and *H. annosum* infection related in commercial coniferous tree species?

How do we accurately determine and report incidence of *H. annosum* and intensity of infection in the field?

What is the role of conidia in the infection process?

What effects does fire have on annosus root disease development?

What are the relative competitive saprophytic abilities of the biological species of *H. annosum* and how do the biological species interact within stump root systems and within stands?

How do we rapidly diagnose biological species of *H. annosum* in the field?

Do we need to develop an annosus root disease model, and if so, what biological parameters must be obtained for accurate loss projections?

What are the principal fungal competitors of *H. annosum* in stumps and soil, and what are their roles in restricting disease development?

What is the impact of annosus root disease on mixed conifers in uneven-aged management regimes?

Why is annosus root disease more damaging in the east-side pine type versus west side pine?

What procedures do we use for hazard rating annosus root disease in pine?

Are rates of decay loss due to *H. annosum* known?

Can we successfully regenerate pine sites infested with annosus root disease?

What is the feasibility of using chemical or mechanical barriers in the soil to prevent spread of *H. annosum?*

What is the cost of living with annosus root disease?

What is the incidence of annosus root disease in upper slope forest types?

What is the relationship between tree size and disease center enlargement?

These questions represent an extensive, but not all encompassing, illustration of current gaps in our knowledge of this root disease. Despite the need for information that will contribute to minimizing losses to this disease, the current budget climate has resulted in a scarcity of funding for research on root diseases.

---

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, at Monterey, California.

[2]Research Plant Pathologist, Pacific Southwest Forest and Range Experiment Station, Berkeley, California; and Manager/Forest Pathologist, Forest Health, Washington State Department of Natural Resources, Olympia, Washington.

Participants in this symposium have contributed ideas and advice on ways we as researchers, and other workers dealing with root diseases, can increase the level of support for this important work. A summary of suggestions that arose from discussions during this session are presented below.

1) There is a need to do a better job of publicizing impacts of root disease and to increase general public awareness of forest health issues.

2) Research emphasis should be problem oriented.

3) Management should be better informed of consequences of root diseases. Loss information should be stated in terms of dollars for land management decision makers.

4) Pest management pathologists and researchers should work on getting disease loss data into stand projection models.

5) Researchers need to emphasize technology transfer and address root disease affecting non-timber resources.

6) Legislators need to be informed and dialogues between them and root disease workers need to be established.

Poster Paper

Annosus Root Disease in Noble Fir Christmas Trees[1]

Alan Kanaskie Gene Milbrath Kai Sjoblom[2]

Annosus root disease (causal fungus = Heterobasidion annosum) caused mortality and discoloration of 6- to 8-year-old noble fir (Abies procera) Christmas trees at one location in northwestern Oregon. The plantation has been cropped continuously with noble fir for 30 years, with harvesting occurring as selective removal of individual trees. Infection apparently occurred through root wounds or from contacts with roots of stumps created during previous harvests.

Thirty percent of crop trees harvested in 1988 were infected (table 1). Lightly infected trees (less than 12 percent of stump surface discolored) were merchantable. Severely and moderately infected trees were not merchantable because of poor color.

[1]Presented at the Symposium on Research and Management of Annosus Root Disease in Western North America, April 18-21, 1989, Monterey, California.

[2]Forest Pathologist, Oregon State Department of Forestry, Salem, Oreg.; Plant Pathologist and Nursery Inspector, respectively, Oregon State Department of Agriculture, Salem, Oreg.

Many Christmas tree growers cut merchantable trees above the lowest whorl and train a remaining branch for a crop tree in the next rotation. This method of culture and the creation of stump during selection harvests may favor development of annosus root disease.

Table 1 -- Severity of annosus root disease in noble fir Christmas trees. Forest Grove, Washington County, Oregon. November 1988.

Crown Symptoms	Degree of infection	Stump surface discolored	Trees affected (N = 550)
		Pct	Pct
Visible	Severe	> 25	2.1
	Moderate	12-25	5.1
None	Light	1-12	23.5
	None	0	69.3

*U.S. GOVERNMENT PRINTING OFFICE: 1990 786-084/39059

The Forest Service, U. S. Department of Agriculture, is responsible for Federal leadership in forestry. It carries out this role through four main activities:

- Protection and management of resources on 191 million acres of National Forest System lands
- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Forest and Range Experiment Station

- Represents the research branch of the Forest Service in California, Hawaii, American Samoa and the western Pacific.