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REGULATION OF SOIL ORGANISMS BY RED ALDER: A POTENTIAL BIOLOGICAL SYSTEM FOR CONTROL OF *Poria weirii*

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REGULATION OF SOIL ORGANISMS BY RED ALDER: A POTENTIAL BIOLOGICAL SYSTEM FOR CONTROL OF *Poria weirii*

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MOST WESTERN FORESTERS realize that *Poria weirii* (Murr.) Murr. is among the more destructive tree root pathogens of western North America, that it lethally attacks many species of native conifers, and that mortality occurs primarily in infection centers that may extend over many acres. Annual losses of timber volume from *Poria* have been estimated at 32 million cubic feet of just Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in western Oregon and Washington alone (4). Most foresters do not fully realize, however, that *P. weirii* kills young growth as well (Figure 1).

Recently, I visited several seriously infected stands of young Douglas-fir in western Oregon. Plantations as young as 10 years already had suffered substantial mortality. Examination of roots of live but slightly yellow saplings revealed widely distributed infection, which poses the prospect of a continuing high rate of mortality. The Tillamook Burn appears to have large areas of this kind in plantations from 20 to 30 years old. In the Coast Range near Corvallis, many stumps of cut trees in a thinned, 35-year-old stand showed infection, even though few trees had shown obvious symptoms.

My guess is that once foresters learn to recognize *P. weirii* damage in young stands, they will find it is widespread and sometimes devastating. This outlook raises several questions. How and why does *P. weirii* become a killer in young stands? What will be the impact on intensive forest management? And what can be done to reduce losses?

Poria weirii–A "DISEASE OF THE SITE"

Trees, not sites, become diseased, but the phrase "disease of the site" helps us to visualize the endlessly continuing damage that root diseases such as *P. weirii* can inflict. Once established in a site, *Poria* can persist in infected roots or buried wood for dozens of years (3). Logging, burning, or other standard practices seem to have little effect on longevity

Figure 1. Young *Abies* trees killed by *Poria weirii* (light colored trees, large seedling at left and two saplings in center). Roots of the Douglas-fir stump in center were infected heavily with *P. weirii*.

of the fungus in the soil. When roots of a young tree grow down and come in contact with *Poria* that has survived in rotted roots, a new infection can start. The disease then works along the root system to the root collar of the tree, which dies either from decimation of roots or from girdling. Adjacent trees become infected when their roots touch the diseased roots of infected trees (18). The persistence of *Poria* from one generation of trees to the next, coupled with the gradual expansion of the infected area, adds up to a grim prospect: damage generally can be expected to spread and intensify from rotation to rotation unless steps are taken to stop it.

PROBLEMS IN CONTROL OF ROOT DISEASES IN FORESTS

The technical literature is replete with recommendations for preventing new infections in stumps or wounded tree stems from spores of root pathogens such as *Fomes annosus* (Fr.) Cooke. Little has been published on how to control such diseases after they are established in forest soil. The problem is particularly difficult in north temperate to boreal forests, because the soil under the surface remains relatively cool throughout the year. The pathogens accordingly have a low metabolic rate and can persist for many years in buried wood without exhausting their food base.

The fact that root pathogens live underground compounds the difficulty of devising controls. The pathologist faces the frustrating challenge of pinpointing specific, subterranean sources of the fungus if he wants to study its biology in nature. He must deal with the most complex and variable of environments—a forest soil teeming with diverse, interacting organisms and replete with radically different microhabitats. Moreover, the chemical, physical, and microbiological characteristics of these microhabitats change in the course of the seasons and with changes in age and composition of the forest vegetation.

CONTROL ALTERNATIVES FOR *Poria weirii*

The forest manager has the option of establishing trees resistant to *P. weirii* where it is severe. The trees most resistant to *Poria* however, are hardwoods, pines, and western redcedar (*Thuja plicata* Donn), species that are often poor alternatives for sites in the Douglas-fir region in terms of value or adaptability. Resistant strains of Douglas-fir and other susceptible species may exist and are being sought, but so far none has been found.

Mechanical removal of buried wood that contains *Poria* might be possible on some clearcuttings. The Canadian Department of Fisheries and Forestry is testing this approach in British Columbia, but results have not yet been evaluated. If effective and practicable, mechanical removal could be helpful on some sites that would be highly productive except for extensive infection centers. Presumably, however, mechanical treatment would not change the site characteristics that permitted *Poria* to flourish in the first place; reinfection of the site then remains a possibility.

Fertilization, especially with nitrogen, may help reduce the viability of buried *Poria*. Nitrogen might encourage growth of soil organisms that compete with, inhibit, or parasitize *Poria* itself (13, 15, 16). Other chemicals that reduce the viability of the fungus in soil also might be found, but none is known at present. Of course, widespread application of chemicals, even fertilizers, is currently under challenge, and the outlook for its continuation is uncertain. Whether such chemicals would alter site characteristics enough to reduce spread and reinfection over extended periods is unknown.

I want to emphasize the ecological desirability of *long-term* alteration of sites to the detriment of *P. weirii*. The most likely and quite possibly the most economical way of attaining this goal is by establishing perennial, nitrogen-fixing plants. With present knowledge about factors that reduce survival of *Poria* in soil (13, 16), the nitrogen-fixer ideal for this purpose should result in a high content of nitrate nitrogen in the soil. It should add other pathogen-inhibiting compounds to the soil. It should be resistant to infection by the pathogen to be controlled. It should be able to grow over a wide range of habitats. If it can produce a marketable product in addition, so much the better. Species of *Alnus*, especially red alder (*A. rubra* Bong.), appear to meet these criteria for the Douglas-fir region better than any others.

RED ALDER AS A REGULATOR OF SOIL ORGANISMS

Direct Effects

Red alder resists attack by *P. weirii* (18). The fungus, therefore, lacks a satisfactory, living food base in pure alder stands. Much of the buried *Poria* in clearcuttings likely would be starved out if a rotation of alder were grown for several decades. Alder mixed with susceptible conifers also might reduce damage, because *Poria* spreads primarily along root contacts. Root systems of the interspersed alders would reduce chances for root contact between healthy and infected conifers. We should note that alder is susceptible to *Armillaria mellea* (Fr.) Kummer, so would be unlikely to help in combating spread of that disease. Alder's susceptibility to *Fomes annosus* is not well established.

Red alder produces large amounts of *Poria*-inhibiting compounds such as phenolics and fatty acids (5, 8). Such compounds are probably important in its resistance to infection by *P. weirii*. Oxidation of the phenolics in air accounts for the reddish-brown color that develops in freshly cut alder wood. Some of these compounds occur in soil under alder (8, 9), leached from leaves or litter and possibly secreted by roots. Such compounds undoubtedly contribute to the change in populations of soil organisms that occurs with colonization by alder and subsequent development of the stand.

Root surfaces of alder harbor quite different populations of bacteria than does Douglas-fir (11), a phenomenon dependent largely on the particular substances contained in or secreted by the roots. The bacteria that form nitrogen-fixing nodules with alder (Figures 2 and 3) are in the

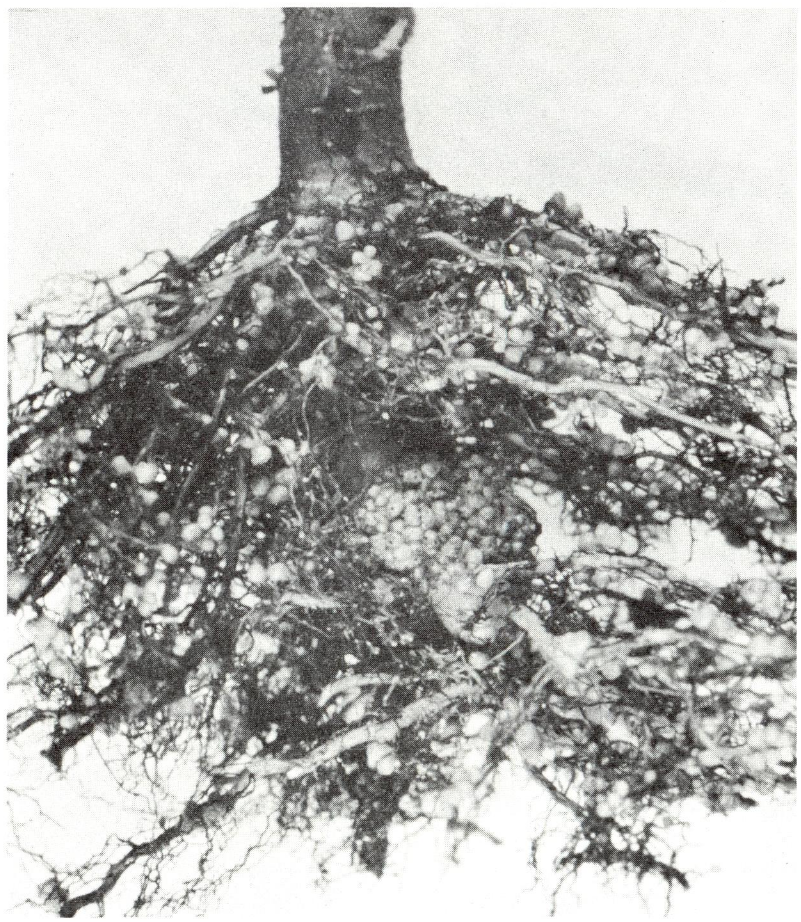

Figure 2. Excavated, nodulated root system of young red alder (photograph courtesy of Dr. Harold Evans, Dept. of Bot. and Plant Path., Ore. State Univ.).

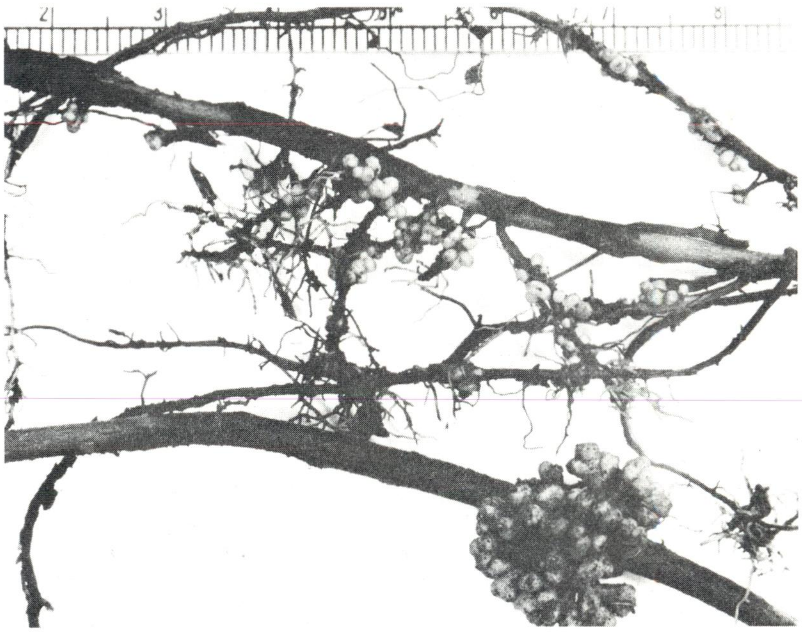

Figure 3. Nitrogen-fixing nodules on red alder root.

Order Actinomycetales (1), which includes such renowned antibiotic producers as *Streptomyces* spp. Most mycorrhizal fungi of alder seem to be different from those of conifers (12; Trappe, unpublished data), so that the presence of alder introduces these quite specialized fungi to the soil (Figures 4 and 5).

For control of root disease, the planting of alder, which resists *Poria* and adds substances to the soil that inhibit pathogens, obviously has potential value. Effects of alder on other soil organisms may not seem pertinent, but these effects may be equally or more significant than root secretions in reducing damage from root rot. Through such organisms, alder may exert indirect as well as direct control of pathogens.

Indirect Effects

The profound influence of alder on chemical properties of soil centers around its ability to fix nitrogen and its production of unusual amounts of phenolic compounds, fatty acids, amino acids, and other organic compounds. The chemical quality of the environment is as important to soil organisms as it is to us. In anthropomorphic terms, the

Figure 4. Mycorrhizae of red alder mantled by a dark brown, symbiotic fungus.

Figure 5. ***Alpova cinnamomeus*** **Dodge, a subterranean-fruiting mycorrhizal fungus associated with red alder.**

soil provides its organisms with the breath and food of life. Toxic substances in this environment are infinitely more hazardous to soil organisms than pollution is to man, because the organisms cannot leave for fairer places.

As R. F. Tarrant has pointed out in these proceedings, a large increase of total nitrogen in the soil results from alder's nitrogen-fixing nodules. The nitrogen increment is largely nitrate (2). Many soil organisms can utilize nitrate-nitrogen; others, including *Poria weirii*, cannot for lack of the requisite enzyme system (6, 7). The high nitrate under alder naturally works to the competitive advantage of those organisms that can use it. Alder's production of phenolics and other organism-affecting compounds couples with the high nitrate levels to produce radical differences in populations of soil microorganisms between stands containing alder and pure conifer stands. The precise quality and quantity of these differences are difficult to assess. They vary with season and locality, but clearly they do exist (10, 17). Definitive, comparative studies are in progress by the U.S. Forest Service in cooperation with Oregon State University Department of Microbiology.

The important consideration for the forest manager is the net effect of alder-induced populations of soil organisms on root pathogens. In a current study by the Pacific Northwest Forest and Range Experiment Station, early data indicate that the numbers and proportions of organisms that inhibit growth of *P. weirii* are vastly greater in soils of alder-conifer mixtures than in soils of pure conifer stands (Figure 6). For example, samples from the mixture contained some 600,000 inhibitory *Streptomyces* per gram of soil, but those from the pure conifer stand had only about 175,000 (C. Y. Li and K. C. Lu, personal communication).

FIELD EVIDENCE ON EFFECTS OF RED ALDER ON *Poria weirii*

An initial field experiment at the Cascade Head Experimental Forest of the Pacific Northwest Forest and Range Experiment Station indicated that *P. weirii* survived longer in wood cubes buried under a pure conifer stand than under pure alder or alder-conifer mix (14). Subsequent studies have not confirmed this first result, however, so more extensive experiments are being installed to resolve the conflict (E. E. Nelson, personal communication).

More positive indication has come recently from a comparison of six pairs of adjacent, equal-aged, pure Douglas-fir and alder-Douglas-fir stands in western Washington (J. M. Trappe and J. T. Wortendyke, unpublished

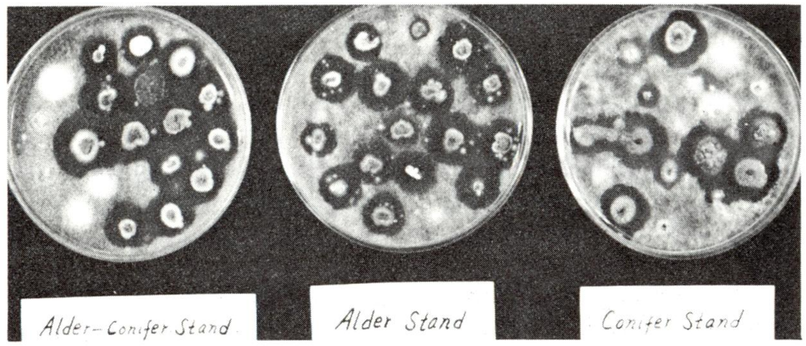

Figure 6. Assay plates for inhibition of *Poria weirii* by randomly selected isolates of soil microfungi from a mixed alder-conifer stand (left), a pure alder stand (center), and a pure conifer stand (right). *Poria* grows uniformly on the agar surface except for clear zones around colonies of inhibitory fungi.

data). The pairs were selected carefully so that both stands of each pair were on apparently similar sites. In all, 1,300 trees were examined for *P. weirii* infection in transects through the stands. *Poria* was found on 6.3 percent of the trees in the pure Douglas-fir stands, but on only 1.2 percent of the Douglas-fir in the alder-Douglas-fir stands. In the mixed stands, *P. weirii* infections were detected *only where the Douglas-fir occurred in groups without alder nearby.*

CONCLUSIONS

The direct and indirect effects of alder on *P. weirii* discussed here are hypothetical; they are derived primarily from analysis of field samples and experiments in the laboratory. We have no data to confirm that these direct and indirect effects occur together in nature in the same way that they occur individually in laboratory experiments. Indeed, the complexity of the soil ecosystem in nature may well preclude isolation of the effects of any one factor from the other. We can, however, construct a theoretical, biological control model from the individual pieces of information. This must be done and be continually refined if we are to understand the processes involved in biological control. An understanding of the components of the system and how they interact can help enormously in the development of usable measures for biological control.

A tentative and incomplete model has evolved from the knowledge outlined in this paper. In summary, alder produces *Poria*-inhibiting compounds that are added to the soil—compounds that could reduce the pathogen's longevity in buried inoculum. These compounds, together with the relatively high nitrate-nitrogen levels under alder, result in a selective increase in populations of organisms that actively compete with, inhibit, or parasitize *P. weirii*. As a *Poria*-resistant species, moreover, alder provides no satisfactory food base for maintenance of the pathogen's viability. The net hypothetical potential of these phenomena is a decrease in viable *Poria* in the soil; if alder prevails on a site long enough, *Poria* might well be eradicated from the site. How long this might take is unknown at present.

What are the implications to forest management in the Douglas-fir region if this model is confirmed by future research? I would not propose that foresters engage in wholesale spewing of alder seed on cutover land. Rather, let us think primarily of sites that have heavy incidence of *P. weirii*. Such sites offer poor chance of producing a well-stocked merchantable stand of Douglas-fir or other susceptible species. The best management alternative clearly is to restock with resistant species. If our hypotheses about alder are correct, and I think they are, a rotation of alder not only would produce a potentially marketable crop and improve soil fertility, but also might cleanse the site of *P. weirii*.

To go a step farther, sites with a scattering of *P. weirii* pockets might be planted largely to Douglas-fir or a Douglas-fir-alder mix, with pure alder established in the *Poria* pockets. Unfortunately, the silviculture of alder-conifer mixtures has yet to be developed for the Douglas-fir region—perhaps we should get at it!

A final postscript: *P. weirii* can survive indefinitely and extend its area of occupancy through successive generations of conifers. Apparently, no widespread resistant strains of host species such as Douglas-fir have evolved, even though the pathogen and its host seem to have coexisted from long-past geological periods. Why, then, has not *P. weirii* virtually wiped out its host species in habitats where it thrives? I would suggest one reason: until the advent of forest management, coniferous forests that were catastrophically destroyed generally were replaced by seral communities of brush and hardwoods. In the Douglas-fir region, red alder was often the dominant invader; at higher elevations and eastward or southward, the nitrogen-fixing genus *Ceanothus* often predominated. The successional intervention of such species between destruction of and subsequent redomination by conifers may well have reduced periodically the carryover of buried *Poria*. Perhaps a deeper appreciation of the phenomena involved in natural succession can lead to solution of silvicultural problems that are aggravated by forest management practices.

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QUESTIONS

Audience. How do you identify *Poria?*

Trappe. Many kinds of fungi grow around the base of trees, but typically, *Poria* on an infected tree can be found by scraping away the humus around the root collar and down among the root crotches and then digging in the bark with a jack knife for small pockets of white mycelium. Look at the mycelium with a hand lens for little brown hairs—they may be very sparse, or they may be so abundant that they make the fungus look brown. If you find even a few little brown hairs associated with the white mycelium, it is a good indicator of *Poria. Armillaria mellea* differs from *Poria*. Often with *Armillaria*, resin exudes from the bark around the base of the tree. You may have white mycelium but no little brown hairs. If you chop into the base of the tree you often will find a heavy felt of mycelium in the inner bark; *Poria* never has this.

Audience. Will *Ceanothus* have the same effect as alder? I'm thinking of sites where alder will not grow.

Trappe. We don't know. My guess would be yes, but I've not made even cursory observations on this. Good opportunities for observation occur in the Oregon Cascades, where *Poria* infects mountain hemlock and true fir.

Audience. Does *Poria* attack incense cedar?

Trappe. My guess is yes, but I'm not sure. It might be a butt rot similar to that in western redcedar.

Audience. Have any studies indicated the magnitude of *Poria* infestation in Douglas-fir in southwestern Oregon? For instance, in the Roseburg area?

Trappe. We have very little data on mortality. Estimates are very rough, because no systematic survey has been made. The managers of a particular tract of forest land probably would know better than anyone else. Even then, unless you know what to look for, it often goes unnoticed because its occurrence is spotty and does not affect entire stands. My guess is that it is common because a lot of *Poria* occurs in mountain hemlock and true fir in the higher Cascades—Diamond Lake and Windigo Pass, for instance.

Audience. Have you noticed an increase in *Fomes annosus* around alder?

Trappe. No. None of our studies has been in an area in which *Fomes annosus* was present. But that's something we should investigate.

Audience. Dr. Charles Driver, forest pathologist at the University of Washington, made the comment the other day that *Poria weirii* is hard to distinguish from *Fomes annosus* in the field. Have you had any experience with this?

Trappe. To my knowledge, the sites that we have studied specifically have not had *Fomes annosus*, and I have not had occasion personally to make this kind of comparison. *Fomes* does not produce brown setal hyphae, but often they're not conspicuous on *Poria weirii* either.

Audience. Does *Fomes* separate into rings as *Poria* does?

Trappe. No. *Fomes annosus* is more of a pocket rot.

Audience. Can *Poria* be identified by examining the roots?

Trappe. Yes. The common name is laminated root rot because well-rotted wood separates along annual rings. The rotted rings can be pulled apart like so many leaves of paper. But this is at a very advanced stage, and at the younger stages this lamination effect is not obvious. On young trees, cut stumps for example, *Poria* will show initially as a crescent-shaped, brown stain on the stump, and then with more advanced infections the crescent shape may consume half or most of the stem. This brown crescent shape follows the annual rings initially so that this is a good indicator. I don't remember whether *Fomes* does that or not; I haven't looked at enough *Fomes* to be sure.

Forest Pest Leaflet No. 48 (3) describes *Poria*, its symptoms, and what it does.

Audience. Does Europe have the entomological and pathological problems that we have?

Bruce. We certainly didn't invent the root rot problem in this country. Plenty of *Fomes annosus* occurs in European countries.

Trappe. Poria is confined to western United States and Japan. It may be in Siberia and parts of China.

Audience. You said you didn't find *Poria* where an alder was nearby. What did you mean by nearby? Is this 10 feet or 100 feet?

Trappe. We can't say at present. In our survey, we found no *Poria* where Douglas-fir were separated by alder. Now, I don't mean to say that without this separation we always found *Poria*, because many, many Douglas-firs in pure stands didn't have *Poria*. But only in stands of pure Douglas- fir did we find *Poria.*

Audience. Could *Poria* be controlled with commercial fertilizers?

Trappe. Dr. Earl Nelson at the Forestry Sciences Laboratory has experiments on that now. The first field experiment produced no significant difference between any of the nitrogen fertilizer treatments and the control in the field. But when the nitrogen was incorporated into soil at the same rate as fertilizer broadcast in the field and *Poria*-infected wood was incubated in this soil in boxes in the laboratory, the differences were significant. In other words, the more nitrogen, and particularly the more nitrate, the shorter the time the *Poria* survived.

Audience. What was the rate of application in the field?

Trappe. It was 150, 300, and 600 pounds of nitrogen per acre.

Audience. How much free nitrogen is in an alder stand?

Tarrant. In the Coast Range, we've measured up to 16,000 pounds per acre; Cascades, about 3,000 to 4,000 pounds per acre.

Audience. In the laboratory tests, what rate of fertilization was used?

Trappe. Six hundred pounds per acre foot.

Audience. In addition to whatever nitrogen was in the soil?

Trappe. Yes, the soil was collected from the field fertilization site. Nelson now has an experiment on a combination of wood chips and nitrogen. Wood chips with a high nitrogen content are a good medium to grow inhibitory organisms in the laboratory. He thought that, because we're concerned with residues in the woods, chipping and fertilizing might be worthwhile if they would increase the number of *Poria*-inhibiting organisms. He's doing this both by surface application and by incorporating the fertilized chips around *Poria*-containing wood. If chips and fertilizer must be incorporated into the soil to have an effect on *Poria*, then this mechanical problem would need to be worked out.

Audience. How much free nitrogen is in an average Douglas-fir stand?

Tarrant. You mean available to the plant?

Audience. Available to the plant.

Tarrant. I don't know. I don't think anybody does.

Trappe. If it's put there by alder, it's all free. If you fertilize, it's $25.00 an acre.

Berg. About 2 months ago, Dr. Driver and Dr. Gordon Wallis from British Columbia expressed a concern that thinning was spreading both *Poria weirii* and *Fomes annosus* in the stands. Both of them recommended that we use borax on all cut stumps in thinning. They have found spores generally in the forest—also infected stumps. Have you had any experience with this, Jim?

Trappe. No. We're talking about two different breeds of cats when we talk about *Fomes annosus* and *Poria weirii*. *Fomes* produces a tremendously heavy spore cast and, when it's fruiting, the spores are all over, flipping through the air, seeking out a freshly cut stump to light upon. Now, if a spore lights upon a freshly cut stump and the conditions are right for germination, the mycelium grows into the wood. If other organisms light on the stump first and colonize it, *Fomes*, because it is a very poor competitor, is crowded out.

We really don't know, at this point, how *Poria* spreads. *Poria* does not produce the heavy spore cast over a good part of the year that *Fomes* does. *Poria* fruiting bodies are brown crusts that form in root crotches or the underside of *Poria*-infected logs. If the weather is a bit too wet, the fruiting bodies develop mold on the surface and the spores can't get out. If conditions are a bit too dry, the fruiting bodies will produce no spores at all. As the fruiting bodies are annual, the prevention of spore production ends it for that year. But it does produce spores—and I would think if one were going to go around producing spores, that one should have a purpose for doing so, and presumably that purpose would be to increase the population of *Poria.*

Fomes spores are very hardy and long-lived and they can be blown apparently for miles, even in rather dry winds, and retain viability.

We have trouble keeping *Poria* spores alive for more than 30 days under what we believe to be ideal conditions of temperature and humidity in the laboratory. Dr. Nelson has a study on infecting stumps with spores, but he has had difficulty getting enough spores from fruiting bodies to attempt to infect stumps. Several years ago, he got very good spore cast from *Poria* fruiting bodies, but then the woods were closed because of fire danger and he couldn't get out and cut trees for about 45 days. By the time he could go back to cut his selected trees, he had zero viability of the spores that were stored in the lab.

Audience. This possibly is why *Poria weirii* hasn't gobbled up the whole Pacific Northwest.

Trappe. Possibly. I might mention that some cursory observations have suggested to us that certain habitats as defined by vegetation (the habitat-typing system) seem to be completely free of *Poria* and other adjacent habitats are riddled with it. This may be a difference of soil or something else. Some habitats are highly susceptible, highly favorable for *Poria* and others are not. What these differences are, we don't know.

Audience. Is *Poria* still considered a species with different genotypes that will not intermingle?

Trappe. Yes, at least this is one way that Dr. Childs has used to determine whether two nearby but not contiguous *Poria* centers were formed by the same original colony. When you grow them in culture, one on one side of the petri plate and the other on the other side, they intermingle and the hyphae fuse if they are the same genotype. If, as often happens, they grow towards each other and then stop—some of these will actually grow back upon themselves rather then grow toward each other—they are two different genotypes.

If Childs had *Poria* pockets separated by some distance, he used this method to determine whether or not they were actually two different centers of infection started by spores of two different genotypes. If they grew together in the culture plate, he interpreted this to mean that he had found an originally large center of infection in the middle of which the *Poria* had died.

Audience. Has anyone identified the antibiotic, or whatever it is that keeps the two colonies from fusing?

Trappe. It would be most interesting and useful to know what it is, but the identification calls for biochemical expertise not now available in our disease research projects.

Audience. How would you treat an area that you know is infected with *Poria weirii?* It is old-growth Douglas-fir in the Cascades in an area that will not grow alder but will grow pine, Douglas-fir, and *Ceanothus.* What would you do?

Trappe. If I could, I would grow pine, because the pines seem by far the most resistant members of the family Pinaceae.

Audience. Would you attempt to grow mixed pine and fir?

Trappe. It would depend on how bad the incidence of *Poria* was. If it was my land, I think I would grow a good merchantable pine species that was resistant to *Poria weirii* and forget the susceptible Douglas-fir for at least a rotation. Of course, alder will grow in surprising places. Bob Tarrant mentioned the only plantation of alder and Douglas-fir that I know of. This is on a site that is not an alder site, and yet the alder has grown rather decently there. At higher elevations we might think of different types of management, perhaps *Ceanothus*. We hope to find out more about that. Three species of alder grow at high elevation, *Alnus rhombifolia, A. tenuifolia,* and *A. sinuata.* These are just shrubs, as a rule, but you might think of using a shrub alder just for its effect on the soil and the *Poria*. Here again, we have management problems of how to do this. If the alder is established first, will it suppress the conifers? These things, of course, can be worked out.

Audience. Is grand fir susceptible?

Trappe. Yes, all the species of *Abies* are, apparently as much or more so than Douglas-fir.

Audience. Have you been able to determine how long *Poria* persists in the field condition, say in the Coast Range?

Trappe. I don't know that anyone has specifically studied the Coast Range. Child's data, mostly from the Cascades, points out that, without question, *Poria* can survive for at least 50 years in some of the areas he has studied. He says he would guess 100 years. In the Coast Range along the coastal fog belt in the spruce-hemlock area, very little *Poria* occurs. Whether it is the soil, the climate, or something else, we don't know. Above the fog belt in the Coast Range, *Poria* is prevalent.