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## FOREWORD

The Ninth Western-International Forest Disease Work Conference was held at the Cascade Hotel in Banff, Alberta, October 3-6, 1961. Forty-eight members and 9 guests were registered. Sessions were held in the roof-top sun parlor and, although the sun and the surrounding landscape were at times obscured by the elements, the setting was well suited to the consideration of forest topics.

The meetings were opened with welcomes from Frank Hawksworth, the Conference Chairman, and from D. W. McAuley, Administrative Officer of Banff National Park. The Chairman outlined the recent developments on a possible meeting in Mexico City and directed the reading of a letter from J. D. B. Harrison, Deputy Minister of Forestry, Canada, describing the current activities and future plans of the North American Forestry Commission of the F.A.O. The panel presentations were accompanied by animated discussion in the true spirit of W.I.F.D.W.C.

The field trip, rescued from rain by the prescience of the hosts, was held in fine weather, and first hand observation of Atropellis canker, dwarf mistletoe, elk, and Lake Louise was enjoyed by all. Caravans of the W.I.F.D.W.C. Ladies Auxilliary were sighted frequently, attesting to the fact that the wives also found the area enjoyable, both for its scenery and its bargains.

Eighty-six members, guests, and wives attended the banquet on October 4. Preprandial activities were spirited, as usual. After dinner ceremonies were presided over by the award-winning member of the Program Committee, Phil Thomas. Dr. N. H. Grace, Director of Research, Alberta Research Council, gave an entertaining and instructive talk to highlight the evening.

The Ninth W.I.F.D.W.C. was adjourned on the afternoon of October 6. It snowed that night.

### Executive Committee

F. C. Hawksworth, Chairman  
J. R. Parmeter, Secretary-Treasurer

### Program Committee

G. P. Thomas  
J. E. Nighswander  
A. C. Molnar, Chairman

## CHAIRMAN'S WELCOME

Welcome to the Ninth Western International Forest Disease Work Conference. I have looked forward to a Banff meeting for many years, and I'm sure that this meeting will be a memorable occasion for us all. I think that this is the first time that we have had to compete with the World Series, but I'm sure that we'll come out O.K. on that score. I wish to extend a special welcome to the members of the Saskatoon Laboratory, who are our guests at this meeting.

I am sorry to report that Mexico will not be represented at this conference. However, the Mexican Forestry Society, at the request of Sr. Ing. Riquelme Inda, has forwarded a report that will be included in the proceedings of this meeting.

Your Program Committee, consisting of Alex Molnar as Chairman, G. P. Thomas, and J. E. Nighswander and all the members of the Calgary Laboratory, has done an outstanding job in preparing for this conference. Three panels will be presented on topics that your 1960 interim program chairman's report listed as most worthy subjects for discussion. As has been our custom, the panel members will use less than half of the time allotted to each panel so there will be ample opportunity for discussion.

F. G. Hawksworth  
Conference Chairman

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### THE ROLE OF ENVIRONMENTAL AND HOST FACTORS IN CYTOSPORA CANKER OF POPLARS

W. J. Bloomberg

An investigation was made into the factors which were thought to promote Cytospora canker attack on native Populus trichocarpa T. & G. and exotic P. x canadensis Moench poplars in British Columbia. Within the range studied, canker growth varied proportionally with the temperature, and inversely with the shoot moisture content, relative humidity, and soil moisture content. Canker growth was more rapid, although the incidence of cankers was much less, in summer than in winter. Both canker growth and incidence were less in exotic hybrid poplars than in the native species; and both were less in the lower part than in the upper part of the shoot. These findings indicated that the ecological, seasonal, and varietal factors exerted their effects on canker development indirectly by influencing the moisture content of the shoot.

The moisture relations and the anatomy of three poplars were compared to explain their differential resistance to Cytospora canker. Compared with Populus trichocarpa, two P. x canadensis hybrids which were more resistant to the canker, had slower rates of moisture loss and, throughout most of the year, had higher shoot moisture contents. In dormancy, when cankers were more numerous, the shoot moisture content of the three poplars was

considerably lower than in summer. Furthermore, the upper regions of all shoots, which were less resistant to the canker, had lower moisture contents than the lower region. In view of the inverse correlation previously established between shoot moisture content and Cytospora canker development, the superior moisture economies of the hybrids and of the lower shoot region were sufficient to account for their greater resistance to canker spread.

The comparative anatomy of the three poplars suggested that moisture storage, translocation, and retention were greater in the hybrids than in P. trichocarpa; the former had a larger pith, wider vessels, longer phloem rays, larger sieve tube zone, larger fibre zone, thicker periderm and fewer lenticels than the latter. In addition, the comparable bark characteristics suggested that the fungus would penetrate into and spread in the hybrids less easily than in P. trichocarpa, and less easily in the lower than in the upper shoot.

The findings suggest that an effective approach could be developed to selection of canker-resistant poplars according to their anatomical characteristics.

Poplar cuttings were adjusted to three different moisture contents, then wounded by incising or scorching the bark. The three moisture treatments differed significantly in their histological effects on tissues around the scorch wounds. The greatest contrast was in the mode of tannin deposition. Lignification was proportional to the moisture content; however, fewer cells were involved in lignin changes than in tannin deposition. No suberization was observed as a result of wounding.

When wounds were inoculated with Cytospora chrysosperma the growth of canker varied inversely with the number of tanniferous cells, the width of the tanniferous zone, and the number of lignified cells. The correlation with tannin deposition was much stronger than that with lignin. These findings suggested that the correlations previously observed between Cytospora canker growth and moisture content may operate partly through the mechanism of tannin deposition. Implications of these findings are discussed in relation to canker resistance to poplar.

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#### FURTHER STUDIES ON THE ATROPELLIS CANKER DISEASE IN ALBERTA

J. C. Hopkins

This disease occurs in the form of perennial cankers on living stems and branches of lodgepole pine. It has been reported on other pines in some areas, but in Alberta it has been found only on this species and on lodgepole-jack pine hybrids. Inoculations using ascospores and culture mycelium have proven Atropellis piniphila (Weir) Lohman and Cash to be the causal agent. However, the percentage of successful inoculations has been very low.

Stem cankers tend to originate on the stem, at, or close to, branch nodes. This could result from a higher susceptibility at these loci, or, from a

tendency for inoculum to collect there. Examination of small cankers within a dense stand indicated that a very large percentage had originated from stem infections, and none were of undoubted branch or internodal origin. The results obtained from an open stand indicated that, although the majority originated at branch nodes on the stem, many were also derived from branch and internodal infections. Dead branches did not constitute infection courts, and the difference between the two stands was probably partly due to the greater longevity of branches in the open. Examination of very small and incipient cankers also indicated that entry can occur through macroscopically undamaged bark.

Susceptibility of the stem also varies according to the age of the bark concerned. In four stands, random samples were taken to determine the age of the bark concerned at the time of attack. Virtually no cankers developed on bark of less than five years old, and comparatively few on sections of less than ten years old. Most cankers developed on bark which was 10 to 20 or 30 years old, depending on the stand concerned. In three stands, no infections had developed on bark over 35 years old. These results suggest that bark of less than 10 years old is highly resistant and that this early resistance is followed by a period of increased susceptibility and probably, in turn, by a further resistant period. The apparent resistance of the young bark is probably due in part to the greater exposure at the apex of the tree.

The canker develops within the periderm as a more or less hemispherical spot, several millimetres in diameter, and is enclosed by successive layers of wound periderm down to the cambium. At, or just prior to this stage, resin flow commences on the surface of the bark and a resin pocket usually forms within the periderm. Inhibition of cambial activity occurs slightly ahead of the pathogen with the result that a circular gap develops within the current annual ring before the cambium there is invaded. After penetration of the xylem this invasion pattern changes and in place of the more or less equal penetration of tissues, longitudinal streaking develops up and down the stem. The direction of this comparatively rapid growth appears to be determined by the orientation of the long axis of the tracheides since the same type of growth will develop inwards along an embedded branch base.

The invaded wood is characterized by a blue-black discoloration which results largely from pigmentation in the hyphae. A browning of the ray cells in advance of the hyphae also contributes to the discoloration. A reddish to brownish stain in the wood frequently develops at the periphery of the blue-black zone and tends to be most pronounced at the apices of the canker. Sections of cankers and isolation attempts have confirmed that no hyphae occur in this reddish zone.

Plasmolysis, then deplasmolysis, of ray cells from freshly cut sections which had been stained in neutral red or vital red showed that the host cells were killed several millimetres ahead of the pathogen. The reddish zone frequently coincided with this layer of dead ray cells but not invariably so, and dead ray tissue occurred irrespective of whether a red stain was present or not. In fairly vigorous trees, the older cankers are associated with a deep furrow which extends upwards beyond the apices of the canker

in the sapwood. This furrowing beyond the pathogen is caused by a reduction in cambial activity upwards, and to a lesser extent downwards, which results in fewer tracheides being formed in the affected portion of the ring. The tracheides which are produced within this furrowed zone appear to be of normal size and wall thickness.

Canker growth rates were obtained by measurement of the length and circumference of numerous cankers of ages varying from one to over 30 years. Measurements of 224 cankers indicated a longitudinal extension rate per year of 1.85", and an annual circumference growth rate of 0.25".

Girdling of a stem at an internode normally occurs as a result of slow circumference growth. In a small stem, however, girdling may be hastened by penetration through an embedded branch to the pith and out by a similar path to the opposite side. Examination of dead or dying trees in a suppressed stand showed that 39 out of 43 trees had been girdled by A. piniphila. Of the 39 trees, one had been girdled by a combination of three cankers occurring at one level; three had been girdled by a combination of two cankers, and the remaining 35 had been girdled by a single canker. In trees of moderate to high vigour, the normal diameter growth of the host is sufficient to preclude girdling by a single canker and mortality appears to result from a combining of two or more cankers occurring at one level, frequently in the upper bole.

Dye injection was used to determine the influence of cankers on the path of water conduction. A complete ring of dye beneath the canker was required for interpretation of its influence. The method adopted involved containing the dye, acid fuchsin, in an inverted cone frustrum, sealed to the tree with an asphalt compound, and virtually girdling the tree beneath the surface of the dye. A total of 12 trees, including controls were used. The dye was translocated in the outermost rings but ceased just beyond the periphery of each canker at the edge of the resin soaked zone. Multiple cankers on different sides of the tree resulted in movement up the tree in a zig-zag pattern.

Inoculum, consisting of ascospores, are released from late spring or early summer until early or mid-fall during wet conditions. The ascospores begin to be released approximately two hours after wetting the apothecia. No release has been observed in the field resulting from high humidity conditions alone without accompanying rain. An accumulation of mature and semi-mature spores occurs during dry spells with the result that a large volume of inoculum may be released between two and five hours after wetting. A diurnal pattern occurs with spores released during the day and ceasing late at night. Spore release continues for some years following death of the host.

It was concluded from examination of incidence patterns that the ascospores are primarily wind disseminated. The patterns occurred among regeneration plants in a valley with fire residual trees. Many sudden discontinuities of incidence rates occurred concomitantly with changes in slope or aspect. In some locations, plants along one side of a heavy inoculum source were heavily infected while no infections were on another side. Attempts to find the maximum distance of dissemination within the same valley were

directed towards finding the trees farthest from an inoculum source which had a fairly high incidence rate. One plot was found approximately 1000 feet from the closest inoculum source which had infections on 61 trees of the 109 present in the plot.

Within Alberta, the disease is widely distributed at a low incidence rate throughout the lodgepole pine zone, including the isolated area in the Cypress Hills in the southeast of the province and neighbouring Saskatchewan. Within this wide area several high incidence zones occur in which multiple stem cankers are usually present.

It is considered likely that the occurrence and distribution of the high incidence areas is determined largely by the availability of inoculum. In one valley it was possible to trace the origin of infections in regeneration plants to cankers on old fire residual trees. Incidence rates close to 100 occurred in places adjacent to the older trees but decreased at greater distances from the inoculum source. Since lodgepole stands usually originate from fires, and since the fire-residual trees often remain, it seems likely that many high incidence areas, particularly in young stands, originated in this way. In older stands, however, it is possible that sufficient build up of inoculum may have occurred from the existing few cankers which are usually present.

The rate of build up of inoculum varies considerably and appears to be influenced by stand density. Infections on the stems of small suppressed trees form apothecia much sooner than infections on larger trees. Apothecial formation also appears to be hastened by the occurrence of multiple stem cankers, particularly sporulating ones. On a large vigorous host with few cankers, the onset of the reproductive phase may be delayed for over 10 years as compared to others on small suppressed trees. Cankers of between 20 and 30 years old without apothecia have been found.

High incidence rates are frequently found in stands of high density and it is considered likely that microclimatic factors associated with dense stands may be partly responsible. Canker age determinations in two dense stands showed that new infections developed almost every year, whereas data from an open stand showed that very few or no infections occurred in some years and a high proportion of the infections developed in a year with a wet summer.

An additional factor which may be present to influence infection is host resistance. This was detected in one fairly vigorous stand and was manifested in the formation of suppressed cankers, ones which had been partly or completely overgrown by the host. In a sample of 22 trees from this stand, six had only suppressed cankers present with a mean of ten and a range of 4-17. The remaining 16 trees had a mean of 31 stem cankers each and a range of 11-68, with at least two suppressed cankers present in each tree. The ten suppressed cankers present on one of the resistant trees were between 2 and 7 inches long and had therefore become well established before suppression. A further characteristic was the tendency for the suppressed cankers in the 16 trees to occur in groups; one section of the stem could have several suppressed cankers present while another part at a different height would have only cankers of unrestricted growth. The six

resistant trees were all dominants and co-dominants. This suggests that the resistance mechanism may be dependent on a considerable degree of host vigour. However, some of the other trees present, of similar size and age, had numerous cankers of unrestricted growth, which suggests that host vigour alone is not the only factor concerned. The occurrence of a few suppressed cankers on every tree may indicate that the entire host population possesses some degree of potential resistance.

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## ASSOCIATIVE EFFECTS IN CANKER ORGANISMS

A. Funk

In recent years there have been a number of advances in microbiological research which have been successfully applied to various fields of pathology. The study of associative effects between micro-organisms, i.e. symbiosis, synergism and antagonism, as well as successions of fungi, have received much attention in connection with soil-borne pathogens and decay studies. However, they have not been generally applied to the field of canker research.

The conditions on the surface of the bark, and in bark lesions, undoubtedly offer many opportunities for associative effects between micro-organisms. It is common knowledge that these areas are inhabited by a variety of fungi and bacteria, and that the spore inoculum of other fungi, parasitic and saprophytic, is also present in some cases. This condition is not entirely dissimilar to a root surface, which is also surrounded by an assemblage of micro-organisms in various stages of competition or synergism. Possibly there are also stem excretions at certain stages of host development or physiological condition which can affect the constitution of the microflora, in the same way that root excretions in the rhizosphere of some plants affect the microflora of that zone. A crude example is resin exudation, which encourages the resin fungi, such as Retinocyclus; but more subtle and less obvious cases may exist.

Some of the problems and complications, unique to the study of cankers, seem to offer real possibilities for research in this field. In no other class of disease are there so many weak pathogens which give a poorly defined or confused picture of host response. Apart from the physical aspects of the host (bark moisture, etc.,) is it not possible that there may be associative effects operating between the micro-organisms present, which contribute to their virulence? Take for example Pullularia pullulans, which is so frequently isolated from a variety of lesions. Ward (1960) showed that Pullularia is thiamin deficient. This, of course, means that it is unable to grow on a thiamin-free substrate, unless it is in association with an organism which can supply it. However, when we test its pathogenicity, we inoculate a pure culture onto a sterilized surface (a condition under which it cannot even grow), and when nothing happens we say it is non-pathogenic. This may be true, but is it not possible that the supply of the necessary growth factor by another organism could have contributed to its parasitic power?

The fungi that are frequently isolated from cankers along with known pathogens are generally classified as harmless saprophytes or secondary pathogens; this is undoubtedly the case in most instances, but the relationship may bear further investigation if found together consistently. The fungi could then be tested together in culture and possibly in inoculation experiments. This type of investigation may require a little broadening of Koch's postulates.

I would like to present a few of my observations from the Caliciopsis canker of Douglas fir, as evidence that associative effects can exist:

This canker is endemic through much of the range of Douglas fir in B.C.; it is perennial and occurs on trees of all ages, mostly on the smaller branches and the leader. An affected tree usually has a large number of cankers.

I will point out briefly the anatomy of the cankers as a basis for the discussion to follow.

In 1942 when Caliciopsis pseudotsugae was described, Dr. Hansbrough, who made the type collection, suggested that the cankers originated from insect damage to the bark, principally Cicada egg slits. My observations would confirm this, although I have found cankers to be associated most frequently with damage caused by phloem feeders, possibly weevils. The inner bark is eaten away to the cambium; often a few layers of xylem cells are also taken along with it, and the scraping marks are clearly visible on the wood. Feeding appears to take place in the spring, as most damage has been found at the level of the springwood.

In a normal canker, the cambium regenerates across the damaged area, leaving a characteristic brown line in the wood. The age of the canker may be determined by counting the number of rings above the brown line. The fungus seems happy to remain in the superficial layers of phloem parenchyma and the callus tissue which is produced above the scar, and which may reach considerable thickness. There is little or no necrosis.

In making a large number of collections of Caliciopsis cankers, I found that Bacterial galls were frequently associated with them, especially at the coast. In a string of cankers on a leader or a branch, there would occasionally be interspersed 2-3 galls. Usually these galls had more Caliciopsis fruiting bodies than the neighbouring normal cankers--and during this past summer, in some experiments with the spermatia of Caliciopsis, I used galls exclusively to obtain the spermogonia. When these galls were sectioned, they had the typical anatomy of a Caliciopsis canker underneath. There appeared to be a close relationship between the two organisms involved in the diseases, and so it was investigated further in pure culture.

A light streak of Bacterium pseudotsugae was made on sucrose-nitrate agar plates at neutral PH. Then Caliciopsis pseudotsugae was inoculated about  $\frac{1}{8}$  inch from the streak. Plates were left at R. Temp. in the dark. Control plates of Caliciopsis alone were run concurrently. The resultant difference in growth was striking. Growth pattern of the fungus in the test plate was such that it suggested a gradually increasing production of the growth

factor by the Bacterium, i.e., slow at first, and increasing rapidly at the end. Growth in the control plates was almost nil. It thus appears to be a definite synergistic effect of the Bacterium on the fungus. The fungus and bacterium are both superficial in the host, and so are probably in close contact. The fungus probably provides a suitable infection court for the Bacterium.

In all the Caliciopsis cankers which I have observed and cultured, I have never found decay fungi involved, even though suitable infection courts seem to be present at some stage in the development of the canker. Ten common decay fungi were tested in culture for inhibition by Caliciopsis. Of the ten tested, three were definitely inhibited. This slide shows Stereum sanguinolentum inhibited by two species of Caliciopsis. A readily extractable substance has been isolated from liquid cultures of Caliciopsis with commercial solvents which is active against the Stereum, and other fungi as well, in the paper disc technique. This substance is produced in a variety of liquid media, synthetic and natural, which suggests that it is a constitutive response of Caliciopsis, and therefore may be produced in nature as well.

There are some fungi, however, which are able to invade Caliciopsis cankers and replace or crowd out the fungus. One of the most commonly found fungi entering is Dasyscypha pseudotsugae. For a time the fruiting bodies of the two fungi may appear together around the edges of the canker, but eventually Caliciopsis drops out of the picture. The canker that develops in this case is deep and deforming, and enlarges as the tree grows.

Undoubtedly Dasyscypha cankers start in other ways as well, but this power to take over from Caliciopsis may possibly be considered as a case of fungus succession. This has not been investigated in culture.

Although these few examples point to the existence of associative effects in canker fungi, they, of course, do not offer proof of their general importance. It is, however, an angle of approach which may be applied with profit to some problems. Perhaps some of the fungi with a doubtful record of pathogenicity should be re-investigated from this point of view.

As a basis for this type of investigation, the knowledge of the physiology and nutritional requirements of the organisms involved is a prerequisite. Additional knowledge of the production of growth factors or antibiotic substances is also of value. With this information it is possible to choose conditions for experimental associative effects in pure culture. Once proved in pure culture, it is then reasonable to associate them in tests of pathogenicity.

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# DWARFMISTLETOE HOST-PARASITE RELATIONS

Frank G. Hawksworth

Keith has asked me to discuss host-parasite relations in the dwarf-mistletoes, and I should like to do so by considering several aspects of this broad topic. In line with our theme "Where do we go from here", I shall try to emphasize areas needing further study.

Before discussing host-parasite relations, I'd like to mention what we might call the "pathologist-parasite relationship". That is, the amount of attention that has been paid to the dwarfmistletoes. We are all aware that there has been a great upsurge in interest in the dwarfmistletoes in the last few years, but you may not realize the extent of this increase. The following tabulation shows the number of north American papers on Arceuthobium published annually since the war:

## Number of Publications on Arceuthobium

<u>Year</u>	<u>Annual</u>	<u>5-year average</u>
1946	1	
1947	0	
1948	2	0.8
1949	1	
1950	0	
1951	1	
1952	8	
1953	12	9.4
1954	16	
1955	10	
1956	13	
1957	10	
1958	11	18.2
1959	27	
1960	30	

This shows that there has been a marked upswing in the last two years. This trend is continuing in 1961, as 25 publications have already appeared this year.

This tabulation points out that much of our information on the dwarfmistletoes is recent, but more importantly, it promises that we can expect many more interesting findings in the near future.

## TAXONOMY OF ARCEUTHOBIMUM AND ITS HOSTS

The problem of taxonomic relationships of Arceuthobium and its hosts is very basic and I shall discuss it in some detail. There have been some recent papers on Arceuthobium taxonomy, but I feel that we are still a long way from having a satisfactory treatment of this group. In contrast, some

excellent studies on tree taxonomy have been done recently. Critchfield (1957) has given us a thorough study of Pinus contorta. Studies are in progress on other pines so we may look for equally valuable contributions on them.

The dwarfmistletoe Arceuthobium americanum occurs extensively on two of the four subspecies of Pinus contorta recognized by Critchfield (ssp. murrayana in the Sierras and Cascades and ssp. latifolia throughout the interior of Western Canada and the United States) and, of course, on jack pine. Detailed morphological and cytological studies of the parasite on these three widely scattered hosts certainly seem warranted.

I'd also suggest that workers on tree taxonomy might find important clues to the relations of hosts if they would consider parasitism of Arceuthobium. For example, the range of the scopulorum variety of ponderosa pine in southern Nevada seems to be marked by the occurrence of A. vaginatum. Typical ponderosa pine elsewhere in the state is attacked by A. campylopodum forma campylopodum.

It is with some misgivings that I approach the problem of Arceuthobium taxonomy, as I'm not a taxonomist. However, some comments may be in order. But fear not, I don't intend to describe any new species this morning. First, I'd like to state that I'm alarmed by the tendency in some circles to consider the whole A. campylopodum group as a single, but highly variable, species. I think that this is very misleading, and if we were to follow such a view we would be doing a great disservice to those concerned with mistletoe control. To treat this group as a single species completely ignores the occurrence of host preferences which are obvious to us all. Also, the recent demonstration by Parmeter and Scharpf that the California dwarfmistletoes on red and white fir are distinct suggests that subdivision of the forms, not combination, may eventually be in order.

Lake Gill, in preparing his 1935 monograph, was unable to find consistent morphological differences between eight previously described dwarfmistletoes, so these were designated as host-forms of Arceuthobium campylopodum. That this was not intended to be the final answer is emphasized by Lake's statement that his treatment "should be tolerable as a temporary device pending a complete revision of the genus based on further field and experimental evidence". In the quarter century since the appearance of Lake's monograph, I feel that we have gained much understanding of the relationships of the various forms and I consider that, with some exceptions, the forms of campylopodum are indeed distinct and eventually they should be treated as species.

At present we do not have the knowledge necessary for a revised taxonomy of Arceuthobium. However, I believe that the need for detailed studies of anatomy, morphology, genetics, and cytology of these plants is urgent.

Until we have something better, I think that we should continue using the designations for the forms of A. campylopodum. If, at some future date it is shown that the forms are actually not distinct, it will be a simple matter to relegate them to synonymy. On the other hand, if, as it appears most likely, the forms will be shown to be distinct, literature referring only to

"A. campylopodum" will be of limited value.

Now I'd like to use an example--the western spruce dwarfmistletoe (Arceuthobium campylopodum f. microcarpum)---to show why I feel that the forms of A. campylopodum are distinct. Don Graham and I have recently prepared a manuscript on this topic for Northwest Science.

In Lake's monograph the range of form microcarpum is listed as Arizona, New Mexico, Colorado, California, Idaho, and Montana. Many of the state records were based on single collections. Job Kuijt (1960a), quite rightly I feel, questioned the existence of a biological form that occurred only locally at such widely scattered points. However, I'd like to remind you of the important point, which is often overlooked, that Gill's (1935) records of distribution of the forms of A. campylopodum are based exclusively on host associations. Thus, in this instance, any reports of A. campylopodum on spruce would be listed as form microcarpum.

We have investigated this situation, and have come to the conclusion that form microcarpum is indeed a distinct biological entity, although its range is limited to only two states--Arizona and New Mexico. The other four state records were based on occasional attacks of spruce by other forms or species. The Idaho and Montana reports were apparently larch and Douglas-fir dwarfmistletoes. The California collection on Brewer's spruce appears to be the hemlock dwarfmistletoe. The status of the Colorado report is not certain as the collection has not been located, but the stands in the vicinity of the collection site were recently examined and the lodgepole pine dwarfmistletoe is the only species of Arceuthobium present. Thus the original collection probably was of this species on Engelmann spruce, a host-parasite combination that we have found elsewhere in Colorado.

I feel, therefore, that we have made some sense out of the confusing distribution listed for form microcarpum.

But to return to the taxonomy of the campylopodum group. Are the eight forms really distinct? I can't give a pat answer because I'm not familiar with dwarfmistletoe in some western regions. However, the forms in the Central Rockies and the Southwest are indeed distinct--both morphologically and in their host relationships. Our forms can be readily recognized, regardless of what host they happen to be growing upon. To be sure, the differences in some instances are not marked. But in Arceuthobium, we must constantly remember that we are dealing with a highly parasitic group of plants that has undergone extreme reduction in both its vegetative and floral parts. The scope of possible morphological variation is sharply circumscribed. I also feel that characteristics of living plants will, in many cases, have to be considered in the taxonomic scheme. Some of the diagnostic features of fresh plants are completely obscured in specimens that have reposed for a half a century or so on a herbarium shelf.

I urge you to make and record critical observations on the hosts of the various dwarfmistletoes in your area. This information will be of considerable importance in any revised taxonomic scheme for the dwarfmistletoes.

While in some cases greenhouse or controlled field inoculations will be necessary to determine the host ranges of certain dwarfmistletoes, I think that we can derive even greater benefit by making observations of natural crossovers. After all, we should remember that every year millions of seeds are showered onto susceptible and nonsusceptible trees alike, and all we have to do to cash in on these ready-made experiments is observe the results. Of course, to have meaningful results we must be certain of the identity of the dwarfmistletoe we are dealing with. The easiest way to do this is to limit our observations to areas where only one dwarfmistletoe is present.

In concluding my remarks on taxonomy, I strongly recommend that intensive studies of Arceuthobium, particularly the campylopodum group, be undertaken. In the meantime I urge the continuation of form names. To treat the whole campylopodum complex as a single species, as I feel, about as meaningless as to group all hard pines under a single specific name.

(I only hope that I don't neglect to use the form names in the remainder of my talk).

#### PHYSIOLOGY

Some interesting new information on the physiology of Arceuthobium has appeared recently, and this field will probably provide some real insight into the parasitism of this group of plants.

A paper by Rediske and Shea (1961) in the American Journal of Botany has given us the first concrete information on photosynthesis in Arceuthobium and translocation of carbohydrates. They showed that Arceuthobium does indeed carry on photosynthesis and that photosynthate, particularly sucrose, produced by the parasite is translocated to host tissues. The primary damaging effect of infection is not parasitism per se but rather that infections act as a biological girdle that limits translocation of photosynthate from the host foliage to the tree roots.

Dr. Leonard and Mr. Greenham at the University of California at Davis are delving deeper into the mysteries of translocation of the dwarfmistletoes, and I hope we will learn more of their findings at the conference.

Wagner (1961) has recently reported, in apparent contradiction to earlier reports on various mistletoes, that infection by Arceuthobium campylopodum f. campylopodum on ponderosa and jeffrey pines was inhibited by full sunlight. In the Southwest, we find a similar situation but I don't think that this necessarily negates the familiar axiom that growth of the dwarfmistletoe plants is favored by light. In our studies we suspected that excessive direct sunlight killed the germinating seeds, but that this was not necessarily indicative of the effects of light on established plants. I note that the PSW Station and the University of California Botany Department have embarked on a cooperative study on the light relations of dwarfmistletoes, so we can look to more answers in this field soon.

Another aspect of dwarfmistletoe physiology that I feel would yield some interesting results is the physiology of broom formation. For example,

in southwestern ponderosa pine we find at least 3 distinct types of brooms. It is obvious that the auxin regime of the tree is upset in witches-brooms but we don't know just how. Perhaps experiments using different synthetic auxins along with clipping of branch terminals might show results.

Another profitable undertaking would be studies of the physiological differences between susceptible and resistant hosts. Such studies would be complicated and time consuming, but I think that the rewards would be worth the effort.

#### ECOLOGY

The ecologic aspects of parasitism in the dwarfmistletoes are still a practically unknown field. Although some information has been published on the distribution of these parasites in relation to topography or site, little is known of the basic factors involved.

Daubenmire (1961) has recently reported on the occurrence of Arceuthobium campylopodum f. campylopodum on ponderosa pine habitats in the Inland Empire. Of seven habitat types recognized by Daubenmire, dwarfmistletoe was present on only two: the Pinus ponderosa/Purshia tridentata and Pinus ponderosa/Agropyron spicatum types. These are the two poorest sites in respect to growth of ponderosa pine. These results are similar to those of Dowding (1929) working with Arceuthobium americanum on jack pine in Alberta. Here she found that there were marked differences in the frequency and abundance of the parasite on two jack pine sites, i.e., 33 percent of the plots and 5 percent of the trees were infected in the pine-heath association, while in the pine-moss association, dwarfmistletoe was present on all plots and on 71 percent of the trees.

These studies present some interesting clues to the distribution of Arceuthobium, but I think that caution should be exercised in interpreting such relationships. In stands heavily infected by dwarfmistletoe the high mortality rates and decline of living trees expose the ground to more xerophytic conditions, and such changes can be expected to be reflected in composition of the understory flora. Thus one may not be measuring the site but rather the effects of what opening up the stands by mistletoes has done to the ground cover. Observations suggest that this is the case in infected lodgepole pine stands in the Central Rockies where Vaccinium is much more common under heavily infected stands than under lightly infected or healthy stands on similar sites.

I urge that detailed studies be undertaken on the factors affecting the distribution of Arceuthobium. The need for such information was forcibly brought home to me as a result of some of our inoculation studies on ponderosa pine dwarfmistletoe in northern Arizona. Here ponderosa pine occurs over thousands of square miles of fairly uniform terrain. We had rather innocently assumed that all these stands were susceptible to dwarfmistletoe and that distribution of the parasite was determined primarily by chance of infection and stand history. However, our inoculations gave more than ten times as many infections in an area where mistletoe was present as in a healthy area a mile or so away. We have planted several thousand seeds in the mistletoe-free stand and got so few infections that

I doubt that mistletoe could be established in this stand. We do not know yet why ponderosa pine in two nearby areas varies greatly in susceptibility to dwarfmistletoe, but it emphasizes the great void that exists in our understanding of the ecology of these parasites.

#### MORPHOLOGY

The last year or so has seen the publication of two California studies which are the most detailed studies on the dwarfmistletoe endophytic system that have appeared.

Kuijt's (1960b) exhaustive paper on the "Morphological aspects of parasitism in the dwarf mistletoes" is a monumental achievement, and it will serve as a basis for all subsequent work on morphology and cytology of the endophytic system and on witches' broom formation. Kuijt made detailed studies of the results of infection of several mistletoes on various hosts, particularly A. americanum on lodgepole pine. Kuijt introduces the terms isophasic for those infections where growth of the endophytic system keeps pace with that of the apices of the host (these we have been calling systemic infections) and anisophasic for infections where the endophytic system lags behind that of the host (nonsystemic infection). Job has made a real contribution in his demonstration that in isophasic brooms that ultimate filaments of the endophytic system are present in the apical meristems of the host branches, and that they probably remain there throughout the yearly growth cycle.

Srivastava and Esau (1961) published two papers in the American Journal of Botany on the relations of seven dwarfmistletoes to the xylem tissues of their hosts. Their first paper dealt with anatomy of the sinkers, which they found to be composed of parenchyma cells only, or of parenchyma cells and tracheary elements, including vessels. In all species tracheary cells of the sinkers had direct contacts with the host tracheids of axial and radial systems. They report that centripetal penetration of sinkers may occur to a limited extent, a condition also noted by Kuijt (1960b).

Srivastava and Esau's second paper discusses the effects of dwarfmistletoe on the xylem anatomy of the host. They note that the most pronounced effects are increased size of infected rays. However, axial host tracheids in infected wood differ markedly from that in normal wood. Their striking illustrations of tracheids from normal and infected ponderosa pine wood (showing short, wide, and irregularly shaped tracheids in the latter) suggest that studies on the pulping characteristics of such woods are warranted: Such information would be of immediate practical interest in The Southwest where a large-scale pulp industry, utilizing to a large extent dwarfmistletoe infected ponderosa pine pole timber, has recently been started.

#### CONCLUSIONS

In concluding my remarks, I don't wish to imply that I have covered the field of host-parasite relations, but rather I have mentioned only a few of the many topics relating to this subject. For example, a large area that I haven't touched on is the factors influencing infection. This

whole field of host-parasite relations is so broad, and has so many facets, that it could very well provide ample food for discussion for a separate panel, if not a Work Conference.

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#### BEHAVIOR OF MISTLETOE POPULATIONS

J. R. Parmeter, Jr.

I assume the "where do we go from here?" in the title of today's discussion provides considerable latitude for the exercise of imagination. We obviously do not want to wander back over familiar territory, and to strike out into unfamiliar territory requires that we try to imagine what we will find and of what use our findings will be. The area of population dynamics seems worth exploring.

All biological populations, with the possible exception of man, conform

to certain principles of population dynamics. Thus it is probably safe to say a priori that dwarf mistletoe populations fluctuate in both size and character and that the nature and rate of these fluctuations are governed by the interaction of the parasite, the host, and the surrounding environment. Since spread and damage by dwarf mistletoes in timber stands is related to the size, rate of increase, and character of mistletoe populations, it is important that we understand what these interactions are and how and why they occur.

Several important questions are continually before us. "How much damage will occur if no control is applied in this stand?" "If we treat this stand in a certain manner, will the mistletoe increase or decrease?" "How fast will mistletoe build up if we thin? don't thin? leave the overstory? remove the overstory?" "If this infected, advance reproduction is released, will it produce salable timber before mistletoe damage becomes acute?" The decisions we must make about these and many similar questions depend on our knowledge of mistletoe population dynamics, a knowledge we possess in only the vaguest form at present.

Our knowledge of the behavior of mistletoes as individuals, while incomplete, is growing steadily. We're beginning to get a good idea of what mistletoes can do. But in many ways knowledge that mistletoes can behave in a certain way is just a preliminary to the crucial question: how often and to what extent do they behave in that way? Today I'd like to discuss some how-often-and-to-what- extent questions that have occurred to me and my associates during the course of our work on fir mistletoes, and to suggest how answers to some of these questions might be useful.

Characteristics of Mistletoe Populations - We often speak as if mistletoe populations were homogeneous. They are however made up of individuals of varied type and potential. Before we can approach studies on spread, growth impact, control, and similar problems involving quantitative behavior, we need to know something about the variations within and among populations.

It seems likely, for instance, that damage to host trees is more closely associated with the position of individual infections than it is with the total numbers of infections. Position is quite variable. Infections may be distributed throughout the crown or restricted to the lower crown. They may be on small twigs, on main branches, or on the main stem. In red fir, many of the infections are "midgets" never exceeding an inch in length. Other infections may reach several feet. The proportion of large cankers to small cankers varies among different populations. In considering the impact of mistletoes, which cankers are really damaging? What determines whether a ~~canker~~ will become large or remain small? What governs the proportion of large to small cankers? Can we manipulate stands to decrease the ratio of large to small cankers? Information of this type may be essential to precise estimations of growth impact and to prediction of future damage.

Reproductive capacity is also variable. The proportion of fruiting infections and the amount of seed per infection differs among popu-

lations, as does the position of these infections in the tree and in the stand. What determines the ratio of fruiting to nonfruiting female infections? What determines whether plants will produce few or many seeds? What is the average reproductive span of a mistletoe plant under various stand conditions? Can we reduce the reproductive capacity of a mistletoe population through stand manipulations? Can we index reproductive capacity? If so, can we determine the potential rate of increase on the basis of reproductive capacity? Which cankers are most important in population increase? interior cankers? overhead cankers? nearby cankers? These are all questions that center around the ability of a population to increase and thereby to cause damage. Answers to these questions would aid in the prediction of future increases in mistletoe intensity in given stands.

Longevity and mortality of mistletoe infections are quite different in different stands. The ratio of infection to mortality may have a marked effect on population increase. Can we determine longevity and death rates for various populations? Would such determinations provide a basis for estimating rate of increase and future damage? Can we manipulate a stand to increase the death rate of mistletoe infections? What factors are involved in mistletoe mortality?

The characteristics discussed above are only a few of the possible quantitative measurements that might be indicative of the condition of a population and that might therefore provide a basis for predicting how a given population might behave. To be usable, such information would have to be correlated with observations on actual rates of increase or decrease.

Rates of activity in dwarf mistletoe populations- Measurement of rates of activity poses a difficult problem. In order to determine rates, it is necessary either to observe activity over a period of years or to reconstruct activity in past years. The latter has proved feasible in the case of infested firs. By developing methods for aging cankers, the rate at which new infections have developed and the rate at which the crown has been invaded can be determined with reasonable accuracy. Can we, by reconstructing past behavior, develop methods for predicting future behavior? Can rates of activity be correlated with characteristics of mistletoe populations? Such methods would be of great value in deciding how to treat variously infested stands.

If we can determine the rate at which a mistletoe population advances vertically through the crown of a tree, we might well be able to compare the rate of vertical advance of the mistletoe with the rate of vertical extension of the crown, and thereby predict how much uninfected crown a tree could maintain during a growing cycle. Assuming that growth impact is related, in part at least, to the per cent of the crown infested, we might then be able to predict with some accuracy future losses.

Another important facet of population dynamics involves natural pruning.

Field evidence suggests that the greater numbers of cankers are in the lower portion of the crown. In dense stands, the death of cankers from natural pruning appears to proceed faster than the development of new cankers in the upper crown. Is there an optimum density at which rapid pruning and rapid extension of the crown decrease the mistletoe population and thereby reduce damage? If so, can we determine by population studies the interrelationship of density, growth rate, and mistletoe intensity and damage?

Study of other aspects of population dynamics might yield fruitful results. Knowledge of the pattern and rate of spread from surrounding trees into reproduction in cleared or burned areas might reduce control costs. Are there "key" infections in the reproduction that could be removed without the expense of a complete pruning operation? Observational evidence suggests that the intensification of infections in such reproduction may be due to a few heavily fruiting female plants. Removal of these plants might greatly reduce the rate of intensification at a fraction of the cost of complete control.

Another aspect of population behavior involves levels of infection. Assuming that, in young stands, the greater the initial level of infection, the sooner the mistletoe population will reach critical proportions, then reducing the initial level of infection should prolong the period of host growth before critical damage occurs. With adequate knowledge of rates of increase from given population levels under various conditions, it might be feasible to reduce the initial infection to a tolerable level by partial eradication. Control costs might thereby be reduced substantially without greatly sacrificing effectiveness.

One final aspect is worth consideration. Are there short-term fluctuations we should know about? Is the rate of infection uniform from year to year, or are there good years and bad years? Are there flower failures? pollination failures? fruiting failures? Is seed deposition and retention uniform or do violent storms occasionally remove most of the seeds? Are conditions uniformly favorable to infection, or are conditions sometimes unfavorable? Does host susceptibility vary from year to year?

Answers to these questions may have considerable practical importance. If there are good and bad years for infection, control efforts might well be timed to avoid situations where numerous infections would appear within a year or two after initial sanitation.

The questions outlined here are only a few of the many that might be asked regarding the characteristics and behavior of mistletoe populations. Answers to these and similar questions must in many cases involve long-range studies. In other cases, new methods must be evolved. In any case, the uses to which such information might be put suggest that the results would be well worth the effort.

Ideally we would like to be able to predict from any given host-mistletoe-climate situation the future of a stand under any chosen treatment. While we may never achieve this precision, we can come a lot closer than we are now.

James W. Kimmey

Control of dwarfmistletoes in western coniferous forests by silvicultural means has been advocated by forest pathologists for more than 50 years. Some early forest pathologists, including Weir, Hubert, Meinecke, and Long, reported the severe growth losses caused by these parasites and suggested control through management practices. However, forest managers paid little heed until in recent years, when more intensive management made them aware of the need. Before the 1950 decade only a token effort toward control-- often none at all-- was usually practiced. Such effort ordinarily consisted only of marking heavily infected overstory trees for cutting and did little or no good. In fact, on areas where partial cuts were made, this probably accelerated spread and intensification of dwarfmistletoe in the residual stands.

#### WHY NOT PRACTICE CONTROL?

Why have foresters been so slow in taking action to control dwarfmistletoe?

Probably there are several reasons. First, many harvest cuts simply disregarded future stands. Second, foresters were reluctant to believe these parasites caused appreciable damage. Third, they did not know, or take the trouble to find out, how to effect control through silvicultural methods. Fourth, they were not satisfied that control costs were economically justifiable. Fifth, foresters believed that eventually a chemical means of control would be devised and that they could go back later, if necessary, and spray their new stands from aircraft.

Headway is now being made in alleviating these five reasons for not practicing control. Now that forest management is becoming more intensive, nearly all cutting is done with definite plans for future stands on the same area.

Western pathologists, through extensive surveys and intensive research, have accumulated sufficient evidence to convince most foresters of the mortality, growth loss, and other adverse impacts that these parasites cause. From all evidence now available, adverse growth impact caused by dwarfmistletoes is probably 1 billion board feet each year in western coniferous stands. This loss is greater than that from all heart rots in infected stands. As overmature stands are cut, heart rot losses diminish and dwarfmistletoe losses increase unless these parasitic plants are controlled.

Forest managers are gradually becoming aware that silvicultural control is adequately supported by research, is biologically sound, and is not complicated. Dwarfmistletoes are among the forest disease organisms most easy to control because of such biological characteristics as their slow and short-distance spread, their host specificity, and their facultative nature. Adequate instructions and guidelines for control are now avail-

able, and they are adequately supported by research and experience.

Economic justification for control appears now to be the greatest stumbling block to starting control action programs. The 1 billion annual board-foot loss nearly equals one-tenth of present net growth in all western softwood sawtimber. When evaluating this over-all loss one must realize that in the main Douglas-fir region of western Oregon and Washington there is no such loss in Douglas-fir; obviously then, percentage losses in stands where these parasites occur must be much greater. As an example, in Montana, where dwarfmistletoe surveys have been made, present growth impact from these parasites is equal to 23 percent of the net annual growth of Douglas-fir, western larch, and lodgepole pine. Recent growth rate studies by Andrews and Daniels, Gill, Hawksworth, and Pierce indicate that it is logical to estimate that diameter growth on infected stands will be reduced by 50 to 80 percent and height growth by 10 to 40 percent, varying by tree species.

The earlier in life a tree becomes infected, the greater is the growth reduction and the more rapid the damage. After a tree becomes heavily infected, annual new volume growth decreases to a very small percentage of that of normal healthy trees. Besides this great reduction in volume growth, other losses must be considered in economic justification for control: seedling and sapling mortality, weakened seedlings, and production of fewer and poorer seed. Other less tangible losses, such as predisposition to other diseases, to insect attack, and the increased fire hazard caused by both living and dead witches' brooms and dead trees, should also be considered.

I'm sure that economic justification is obvious in many areas. And in any commercial stand, control may be justified if control costs are prorated as they should be, over several succeeding rotations instead of just one. Proper control, especially if complete eradication is accomplished, is effective, not in one rotation only but may continue indefinitely without further costs. I hope that in the present study of growth impact and economic justification for control being conducted at the Pacific Northwest Station, control costs will not be charged to a single crop rotation.

The fifth reason I gave for apathy in silvicultural control was the widespread hopeful assumption that someone would find a chemical means of control. Considerable research toward that goal has so far netted few encouraging results. Most pathologists now realize that a great amount of further research and a long and expensive development program will be needed to ever get a means of chemical control that will be satisfactory under forest conditions. The very characteristics of these parasites that make them so amenable to silvicultural control impede the discovery and development of a means of chemical control. Their facultative nature and their host specificity are enormous hindrances to ever developing a single general chemical that will operate effectively against all dwarfmistletoe species on all host species. Even were such a miracle chemical available, it undoubtedly would only supplement silvicultural control rather than replace it because of the relative control costs. To me it is clear, as it should be to most forest managers, that we cannot

defer control until a suitable chemical treatment is available. Control has been deferred too long now.

### SILVICULTURAL CONTROL

The most practical control of dwarfmistletoe is through silvicultural practices. Control should be carefully considered on every infected area when any type of cut or other silvicultural treatment is made on that area. The best time to control dwarfmistletoe in a stand is when a harvest cut is made. The best type of control is complete eradication of the parasite.

#### Clear Cutting

The best control, under the most economical conditions, is effected at the time of clear cutting. Then all host trees (including seedlings) can be killed, and dwarfmistletoe can be completely eradicated from the cut-over area. New infections in the new stand then can enter only from the borders. If borders for clear-cut blocks are properly selected, much reentry of the parasite can be prevented. If no infected border trees are left, the area may remain free of dwarfmistletoe indefinitely. In some forest types, it is not difficult to select borders free of infected trees. Openings such as streams, lakes, meadows, highways, or other cleared rights-of-way may be free of all trees; other borders may consist of stands of nonsusceptible tree species or uninfected trees of the same species. Clear-cut blocks should be as large as it is practical to make them. When such cutting prevents natural regeneration and planting becomes necessary, unplanted border zones should be left adjoining infected border stands. Or, these borders should be planted to a tree species not susceptible to the dwarfmistletoe concerned.

To control dwarfmistletoe, it is often better to clear cut large areas and plant than to cut small areas in order to get natural regeneration, especially if the naturally regenerated stand will contain dwarfmistletoe infection. Why insist on natural regeneration with dwarfmistletoe infection, as some foresters still do, when planting will be better and cheaper in the long run? Such an area may end up with nothing but costs and lost time. Planting eliminates overstocking and thinning costs; permits uniform spacing, selection of species, control of seed source; and it assures dwarfmistletoe control.

In the Northern Rocky Mountain region the forest managers' biggest problem today is overstocked stands. The over-all growth loss from stand stagnation is probably greater than that from dwarfmistletoes. In the past, many infected trees have been left on so-called clear-cut areas in this region. These were cull trees and other trees unmerchantable because of size (including advanced reproduction), which have supplied abundant sources of infection for the new stands. Many such stands are now so stagnated by dwarfmistletoe, or by overstocking, or by both conditions, that they may never reach sawlog size. If large areas are clear cut, followed by thorough cleaning to kill all residual trees of the infected species, and then planted with the desired species at optimum spacing, maximum production on the area will be assured.

Whenever an infected area is clear cut, complete eradication of the parasites should be striven for. Cleaning out of all residual infection in such areas is the most important step in dwarfmistletoe control in this type of silvicultural cutting. Cleaning may be done by cutting with ax and saw, by poisoning, burning, bulldozing, or by a combination of two or more of these methods. Cleaning clear-cut areas immediately following logging has advantages additional to dwarfmistletoe control. It rids the area of undesirable tree species of advanced reproduction, shrubs, and other unwanted vegetation; and it prepares a desirable seedbed for natural regeneration or seeding or for planting.

#### Other Cutting Methods

Clear cutting is the best silvicultural method of dwarfmistletoe control, but it is not the only one. Control in partial cutting is a less desirable method because it costs more and because it is practically impossible to eradicate the parasite completely. When complete eradication is not attained, control may be satisfactory for one rotation, but the potential for buildup of dwarfmistletoe is still present on the area. This necessitates a continuing control program to keep the dwarfmistletoe at an innocuous level.

In any silvicultural control operation the aim should be to eliminate as much of the dwarfmistletoe as is practicably possible. The nearer complete eradication is attained, the better will be the control. Unless a low level of infection is attained, the control effort is wasted. In fact, infection may be intensified and the condition worsened by insufficient control measures if the operation opens up the infected stand without killing enough of the dwarfmistletoe. The maximum allowable infection that can be tolerated varies with the stand's age, density, and other conditions.

In mixed conifer stands of the West, natural control of dwarfmistletoe has been going on since the parasite's origin. Nature's method of control is stand conversion from susceptible tree species to nonsusceptible species. Host specificity of the dwarfmistletoe species and forms makes this type of control possible. This control process is very slow in nature, but silvicultural treatments to manipulate the tree species in a stand may greatly hasten it; and then it becomes a practical control method. Species conversion is best suited to stands of mixed conifers, where it may be accomplished by cutting to favor the nonsusceptible tree species and encouraging their reproduction on the treated area, or by planting, or by a combination of the two. If this method is employed in pure stands, planting is required.

Eradication of the parasite is not necessary or even desirable when the stand manipulation method of control is used. In fact, dwarfmistletoe infections will aid in the suppression of the susceptible tree species and thereby hasten conversion to the nonsusceptible species.

#### DIRECT CONTROL

Direct control is dwarfmistletoe eradication without any silvicultural

operation. At times such control is desirable and may be economically justifiable when values at stake are exceptionally high, or when potential damage is great and eradication costs are small. Examples of high value where such control might be used are administrative sites such as areas around ranger stations, or on high-use recreational areas such as campgrounds or summerhome sites. An example of great damage potential where control costs are small is an extensive seedling or sapling stand containing only a few small infection centers. When dwarfmistletoe is eradicated in these few centers while the trees are small, costs are low and damage of great potential is prevented. The younger the stand and the smaller the infection centers the greater is the possibility of complete eradication of the parasites. When eradication is complete in the few infection centers, the present young stand will be protected over an extensive area until maturity, as will stands on this area in subsequent rotations.

#### RESEARCH NEEDS

Although past research, experience, and surveys have shown the urgency for control and have supplied practical means of control, more research is needed to supplement present knowledge. There are still some tough problems to be solved, particularly in correcting conditions caused by past apathy in control. Probably the greatest problems exist in the many unmerchantable young stands that are now extensively infected with dwarfmistletoes. How are these young stands to be treated? Detailed information on growth impact under a wide range of stand conditions is needed, and costs of various control procedures in such stands must be determined before the question can be answered. The answer hinges on the economics of the situation. However this question may eventually be answered, it is not likely to change greatly the present recommendations for practical control in merchantable stands.

There are numerous facets of control procedures involving various host and parasite species and forms that need more research and experience before it will be possible to always select the most efficient silvicultural treatments for control. However, enough is now known to design effective control measures in nearly all forms of harvest cutting. Forest managers should not wait for further refinements, but should practice control and keep detailed cost records that will supply much of the needed information to achieve these refinements. Much can be learned by doing.

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#### TAXONOMIC STUDIES ON FUNGI ATTACKING NEEDLES OF PINUS PONDEROSA LAWS, IN ARIZONA AND NEW MEXICO.

P. D. Keener

Studies initiated in 1957 with Grant-in-Aid funds from the Rocky Mountain Forest & Range Experiment Station of the United States Forest Service, show that two distinct classes of pathogens occur in nearly all of the National Forests of the area. Both needle-cast and needle-blight fungi

may appear singly or in combinations on the same trees or single needles. Pathogen complexes were the rule, rather than "mono" infections by one organism.

The most frequently encountered complex consisted of dual infections by Elytroderma deformans (Weir) Darker (a long-recognized needle-cast fungus) and a species formerly designated Phacidium planum J. J. Davis. The latter was also commonly found on single needles infected also by Hypodermella medusa Dearness. In addition to Pinus ponderosa, Phacidium was found on the Coronado National Forest, near Safford, Graham County, in association with Hypodermella arcuata Darker on Pinus strobiformis. The dual infection results in severe necrosis of needles.

Coryneum cinereum Dearness was not as severe in 1960 and 1961 as in previous seasons, although the fungus has extended its range in the North Kaibab and on North Rim of the Grand Canyon, in some of the recreational areas.

The histopathology of fungus-infected needles of Pinus ponderosa was evaluated and in many cases the fungus formerly designated Phacidium planum, when in combinations with Elytroderma, caused complete phloem collapse. The presence of hyphae in the phloem in such needles, and in those infected only by Elytroderma deformans (a rare situation) is in contrast to previous reports as to the actual agency responsible for sieve-tube collapse. Intercellular hyphae is demonstrable between sieve-tube elements if free-hand sections are treated with 0.25% Orseillin BB in 3% acetic acid in proportions of 1 part to 9 parts of lacto-phenol. No heating is required for such preparations.

In addition to the hyphae in the phloem, in cases of Elytroderma-Phacidium infections, mycelial threads of various diameters could be observed in the xylem ray elements and in vessels. In vessels most of the sections showed hyphae in cross-sections. The presence of hyphae in endodermal cells as well as the adjacent transfusion tissues was of interest. It was evident that pits in the former cells (endodermal) often served as modes of passage through and into adjacent cells. This is in contrast to reported activity in Lophodermium. In addition to hyphae of usual diameter, enlarged, brown, thick-walled "chlamydospore-like" cells frequently occupied endodermal cells.

Of interest was the observation of numerous resin ducts instead of the usual 2 to 3 in needles of Pinus ponderosa in trees harboring Phacidium sp., and Coryneum cinereum, either alone or in a complex. In addition, the normally-positioned resin ducts often had so-called cysts in them. This seems to indicate that resin cysts may occur in situations other than the infections by Elytroderma.

In cases in which more than the usual number of resin ducts occurred, some of them were situated inside the endodermal "ring" so that in reality they were in close association with the vascular elements. The normal situation is for these elements to be situated in the needle-mesophyll. Numerous cases of "misplaced resin ducts" were noted. At least one previous report has shown that such an abnormal condition may occur

also in Pinus sp. subjected stress from drought so that these observations may reflect the numerous below normal rain and snow-fall years in the Southwest.

Another pathological phenomenon not observed in non-infected needles was the occurrence of sclerenchyma inside the vascular cylinder in large amounts. These cells did not stain at all, either with Orseillin or Cotton Blue, in fresh materials cut free-hand.

The fungus formerly designated as Phacidium planum J. J. Davis was studied in detail by Dr. Richard Korf, Cornell University, Ithaca, N. Y. as well as Dr. Gremmen in Holland. This pathogen, after study, has been inserted by Dr. Korf in a new Family: Hemiphacidiaceae, and will be designated in Korf's forthcoming monograph as Hemiphacidium planum (J. J. Davis) Korf.

A needle-infecting fungus on Pinus ponderosa in Arizona and New Mexico, causing small, round to irregularly-shaped concolorous "blister-like" areas and present almost universally throughout National Forests in the region, has been found after detailed study to resemble both Hypodermella concolor (Dearness) Darker and H. cerina Darker, with no consistency in appearance. This fungus produces hysterothecial-like locules in needle tissue without any delimiting of the fruiting cavity other than the host cells. It is considered as being a variant of H. cerina and is in need of further study. This species, at least in Arizona, produces its asci and ascospores earlier than most of the described Hypodermella spp., mature structures being commonly found in May.

A recently approved State Research Project at the Arizona Agricultural Experiment Station will permit further studies with respect to needle-cast and needle-blight fungi. On the Prescott National Forest, Pinus edulis Engelm. frequently is attacked by three needle fungi, and these are often present simultaneously. One of these has been identified at National Fungus Collections as Lecanosticta acicola (Thuem.) Syd. (Scirrhia acicola), and requires further study.

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FOREST DISEASES AND THE PROTECTION AND  
MANAGEMENT OF RECREATION AREAS

H. R. Offord

The purpose of this brief report is to stimulate discussion of the interests and responsibilities of forest pathologists in the management of recreation areas. This is a topical item that is rapidly increasing in importance. In California during the past two years Park Service and Forest Service foresters have had occasion to take a close and searching look at tree hazards and public safety. This is one of the more obvious problems on which the advice of pathologists is being sought. There are many other questions about diseases and physiogenic disorders and their significance in relation to planned use of recreation areas that should command our attention. Perhaps it would be appropriate to establish a work committee

of the Conference to stimulate interest in these problems.

Managers of wildland recreation areas are becoming increasingly aware of the need for careful planning to insure maximum use and longevity of desirable plants. (Cliff 1957, Thede 1957, Weyerhaeuser Co. 1961, Nord and Magill 1961, May and Chandler 1956.) Pathologists have long taken a special interest in the impact of diseases, defects, and disorders on the vigor, aesthetics, and life expectancy of trees in high-use areas around buildings and in designated campsites. (Meinecke 1927, 1928, 1932, 1934, 1937.) Federal, State, and industrial foresters generally recognize that the establishment and effective maintenance of campgrounds for continuous use of the public calls for constant vigilance as to the condition of soil and vegetation and prompt use of desirable corrective measures.

Under intensified use normal long-range ecologic trends of vegetation are strongly influenced by compaction of soil by people, animals, and vehicles (National Park Service 1954, Hurd 1961, Lutz 1945), by introduction of pollutants into the soil and the atmosphere, by construction and pavings, and by direct attacks from diseases, insects (Hall 1958), and animals (Halls and Crawford 1960, Hurd 1961). Fortunately the economic considerations that plague the manager of a commercial forest do not restrict the recreation manager quite so sharply. Nevertheless decisions on the planning of campsites and their use must be supported by sound data from economic and biologic research.

In the short time that we will have today for informal discussion on this topic I suspect that top priority will probably be assigned to decay and defect in stem and roots in relation to breakage or windthrow of trees. What is a hazardous tree and how readily can one assign a risk rating? In respect to windthrow where do we draw the line on what constitutes an acceptable risk on anticipated violence of winds? What legal complications, if any, are involved in administrative procedures that seek to establish the likelihood of tree breakage or tree fall? Does the charging of a camping fee, or the posting of rights of entry, modify liability of the landowner in the event of tort claims? These and many other questions have to be answered by wildlands managers; and forest pathologists are clearly in the act. On a trip that Wagener and I recently made to an intensively used recreation area in westside Sierra Nevada of California we saw examples of mortality or damage and defect from: root diseases, stem cankers, insects, excess water, competition, soil impaction by trampling, construction, paving, wind, snow, and waste products from riding stock. Other types of soil and air pollution were probably involved, but they could not be reliably measured or identified.

For the Conference record, may I offer the following outline of the general problem--"forest diseases and the management and protection of recreation areas."

1. Long range research goals
  - a. Impact on vegetation and soils
  - b. Protection of desired vegetation

- c. Reproduction or replacement by artificial or natural means
  - d. Ecologic trends
2. Short term research goals
- a. Safety of people and property
  - b. Pleasure and practical needs of visitor
  - c. Improvement of management and protection techniques
    - Pest control--tree felling or pruning, chemical control
    - Soil amendment--soil aeration
    - Control of pullutants such as smoke, oil, sewage, etc.
    - Construction and paving--physical damage to trees by campers-fire
3. Administration problems
- a. Inspection
  - b. Decisions on action programs
  - c. Tort claims-legal aspects
  - d. Publications--Guidelines (Wagener's report)
  - e. Plans and conferences by agencies concerned

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#### ANTIBIOTIC CONTROL OF WHITE PINE BLISTER RUST

H. J. Hartman

White pine blister rust represents a billion-dollar menace to the western white pine lumber economy of northern Idaho, eastern Washington, and western Montana. There are 2.5 million acres of western white pine in the Inland Empire.

With the discovery and development of systemic, antifungal antibiotics, it is now possible and practical to save white pine from blister rust by periodic application of antibiotics and without eradicating ribes.

The application of antifungal antibiotics for controlling a forest tree disease is a new innovation in forestry. The U. S. Forest Service blister rust control organization in Region 1 pioneered the testing, development and use of systemic antibiotics for the control of white pine blister rust on western white pine.

Beginning in 1949 many toxicant compounds were reviewed. Sixty-six were subjected to foliar spray screening tests. Two antibiotic fungicides, cycloheximide and phytoactin, both from species of Streptomyces were found to kill blister rust infection on western white pine. When properly applied the antibiotics cycloheximide and/or phytoactin are absorbed and translocated throughout the aerial portion in pole-size western white pine killing nearly all potentially-damaging infection. Acti-dione BR (cycloheximide) is used when trees are treated by the basal stem method and phytoactin is used for aerial spraying.

The period of blister rust infection immunity that will result from a single application of an antibiotic is not known. New infection has not been detected on any western white pine treated with antibiotics during the ten years of their use in Region 1.

Bio-assay and paperchromatography results show that cycloheximide persists in the upper and lower needles of pole-size trees for at least 16 months after aerial application and 2 years in treated bark when applied by the basal stem method. However, the antibiotic persistence level required to prevent rust reinfection is not known.

Antibiotic developments are resulting in a continuous fundamental change in blister rust control methods, policies, program planning and control area concept. An important and complex transition from blister rust control through ribes eradication to control by application of antibiotics is being made.

The immediate objective is to treat with antibiotics all potentially commercial stands of western white pine over 10 years of age that, on the basis of long range economic criteria, show a favorable cost-benefit ratio.

The ultimate regional objective is to do all blister rust control work through aerial and hand application of antibiotics. This transition is to be made as rapidly as sound developmental results warrant. It is planned that through forest genetics work, blister rust-resistant western white pine planting stock will be available in large quantity by 1980 or 1985. With this development, antibiotic control work will gradually decrease.

The initial application of antibiotics in presently established stands 10 years of age should be completed by 1970.

The changes in blister rust control methods resulting from antibiotic control are:

1. In stands over 10 years of age the host is treated instead of eradicating the alternate host. Western white pine can now be grown in close association with ribes.
2. The control area concept has changed from large pathologically-sound control units to individual trees or groups of trees.

The advantages of antibiotic control of white pine blister rust over control through ribes eradication, based on tests and experience gained in treat-

ing with antibiotics over 123,000 acres, are:

1. Generally speaking, antibiotic control, when practicable, is less than one-half as expensive, and final white pine yield per acre will be greatly increased.
2. Antibiotic control is more effective and positive. The degree of salvable stocking present at time of initial antibiotic treatment can be maintained, for the most part, throughout the life of the stand. Under field conditions a single basal stem application will kill all potentially damaging infection on 90 percent of the treated pines. A single aerial application will kill all the potentially damaging infection on 80 to 90 percent of the dominant and codominant white pines. The effectiveness of antibiotics should increase.
3. Most blister rust infected trees can now be saved. Before antibiotics were developed, little or nothing could be done to save infected trees.
4. Through the application of antibiotics, the increase in final white pine yield per acre will be about in direct proportion to the percent of damaging infection in the stand at time of initial antibiotic treatment. Some of the white pine stands that will be brought back into the protection program are now 65 to 98 percent lethally infected. Within blister rust control units, 25 to 55 percent lethal infection is common in stands established prior to 1947.
5. If only a very limited period of blister rust infection immunity results from a single antibiotic application, it is estimated that the average 40-year-old pole stands will require only two or three treatments to reach 100 years of age. Following antibiotic treatment, the pine stand may become reinfected with blister rust. When this reinfection reaches the damaging stage, retreatment will be required. How often retreatment is required will depend mainly on tree size, period of infection immunity, and the rust hazard of the particular locality. Most reproduction and pole stands of western white pine in this region, occurring on high rust hazard areas where no ribes eradication was performed, have already been lost to the rust. Thus, these remaining salvable stands are mainly limited to medium and low rust hazard areas.
6. Antibiotics can be introduced by foliar spray to immunize nursery-grown seedlings from blister rust infection. This will permit early planting of areas requiring artificial regeneration before ribes are removed and before the areas become heavily brushed and sodded. It will also permit the delay of ribes eradication until the most opportune time, and new pine stands can be established 3 to 5 years earlier than is now possible. It is planned that immunized western white pine planting stock will be available in 1963.

It may be possible to immunize such seedlings for a sufficient period of time to economically bring them through to commercial maturity with periodic applications of antibiotics and without any ribes eradication.

7. Antibiotic control of white pine blister rust has the potentiality of successfully protecting any stand unit regardless of size or location. Thus, it affords the opportunity for the private land manager to protect his own individual stand; also small groups of western white pines of high esthetic or recreational value can be saved from the rust.
8. The costly nonwhite-pine-producing protection zones are no longer required where stands are over 10 years of age.
9. If aerial spraying of mature stands with an antibiotic proves effective, 1 to 2 billion board feet of lethally infected 100- to 140-year-old western pine can be treated. This single treatment would afford the orderly harvesting of these presently inaccessible stands plus years of additional increment.
10. Ribes eradication and status check work can now be discontinued in most stands over 10 years of age.

The cost of antibiotic treatment when applied by the basal stem method is 5 cents to 10 cents per tree while application of antibiotics by aircraft ranges from \$10 to \$12 per acre.

To treat the white pine stand on one acre by either the basal stem or aerial method requires only 7 to 8 grams or 1/4 ounce of the basic antibiotic compound. Normally, the 7 to 8 grams of compound required 7 to 10 gallons of carrier to obtain full and effective coverage. The small amount of antibiotic applied emphasizes the importance of proper formulating, mixing and application of the final spray solution.

No harmful side effects of any kind including fish, wildlife, beneficial fungi, and plant growth have been associated with the large-scale field application of antibiotics. Preliminary laboratory and field tests, to detect ill side effects, have been made for all antibiotics being applied in the field.

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## CEOMA EN CUATRO ESPECIES DE PINOS MEXICANOS

Rudolfo Salinas Quinard

### INTRODUCTION

Hasta el momento no se ha tenido oportunidad, al alcance de nuestras posibilidades, de obtener literatura que concierna al problema de las plagas producidas por hongos sobre la vegetación forestal, ya que en nuestro país el mayor número de obras de tal índole se refiere con mayor atención a los aspectos agrícolas y hortícolas que a los forestales propiamente dichos; y en el último caso se extienden principalmente sobre el campo de las investigaciones entomológicas.

Por tal circunstancia, el presente trabajo representa apenas un intento,

una introducción, al problema referido; teniendo por comienzo las tan comunes como desconocidas especies de hongos causantes de las "herrumbres" y que generalmente se designan, sin mayores consideraciones, con el nombre común castellanizado de "CEOMA", derivado del latín, *Caeoma*, que califica el aspecto pulverulento, herrumbroso, de tinte amarillento.

Por un trabajo anterior, presentado por nosotros y titulado "Los Uredinales en los Pinos de Norteamérica" queda completamente establecido que la denominación *CAEOMA* se ajusta únicamente a un tipo o forma de lesiones en las plantas, producidas por diferentes especies de hongos que tienen de común algunas características: en primer lugar, su agrupamiento genérico; por tanto, no se trata de una especie única responsable, ni debe considerarse como tal; siendo bajo este criterio que creemos necesario advertir que en lo sucesivo la denominación susodicha habrá de referirse a un tipo de desarrollo que en un grupo de hongos cuyos ciclos de vida, completos o incompletos, autoicos o heteroicos, presentan las mismas características generales, y en segundo lugar, porque en su diferenciación específica particular, aunque presen tan también cualidades comunes, ofrecen características microscópicas y biológicas particulares en algunos o ciertos de sus elementos; tal por ejemplo, en el aspecto macroscópico, la forma, extensión, arreglo y localización de las lesiones; y en estas, de las estructuras fructificantes o soros (picnidias, aecios a ecidios, uredias, telias y basidios o esporidios); en el microscópico, las características microscópicas que en algunos casos permiten la diferenciación en las diversas especies, por la apreciación de la forma, tamaño, disposición y ornamentaciones de las respectivas esporas (picniosporas o picnidiosporas, teliosporas o teleutosporas y basidiosporas o esporidiosporas); y en el aspecto biológico, la longitud de los ciclos (cortos o largos), la época de aparición de las fases que los constituyen, y principalmente la selectividad de los huéspedes que parasitan, que en ciertos casos llega a limitaciones hasta de localización sobre órganos particulares de los mencionados huéspedes. Esto queda evidenciado por la existencia de formas folícolas, de formas caulícolas, o de formas carpófilas, aún cuando algunas de ellas puedan llegar a superponerse en un mismo huésped, o presentarse en secuencia. En general éste último aspecto, el biológico, es el más útil en los procedimientos de determinación de especies en las royas, teniendo sin embargo como escollo principal sobre todo en nuestro medio, aparte de la imposibilidad de su aislamiento y cultivo en medios sintéticos, el desconocimiento parcial o total de sus huéspedes alternantes, y consecuentemente la ignorancia respecto a alguna o varias de las unidades que constituyen sus ciclos, y las características de ellos.

Así pues, en el presente reporte nos concretamos a mencionar las características de algunas lesiones causadas por royas, en varias muestras llegadas a nuestro alcance, para proseguir el estudio con exploraciones en el campo hasta llegar a determinar los huéspedes alternantes que habrán de dar la clave definitiva para la identificación del agente causal.

#### MATERIAL Y METODOS:

El material empleado en este trabajo está integrado por ramas y conos de pinos enfermos, procedentes de diversas localidades de la República. Se encuentran registrados en nuestra colección bajo la forma siguiente:

- Muestra # 3. Rama de Pino. Etiquetada como Pinus montezumae. Colectada por el Ing. J. M. Gonzalez Carrillo. Procedente del Estado de Oaxaca.
- Muestra # 4. Conos de Pino. Etiquetada como Pinus montezumae. Colectada por el Ing. J. M. Gonzalez Carrillo. Procedente del Estado de Oaxaca.
- Muestra # 6. Ramas y Conos de Pino. Clasificadas por la Srta. Bi. O. Mancera V. como Pinus teocote Schl et Cham. 1831. Procedente de Río Verde, SLP.
- Muestra # 8. Conos de Pino. Etiquetada como Pinus leiophylla. Colectada por el Ing. J. M. Gonzalez Carrillo. Procedente de; Estado de Morelos.
- Muestra # 9. Conos de Pino. Etiquetada como Pinus patula. Colectados por el Prof. J. A. Davila. Procedentes del Estado de Coahuila.

No siendo posible la determinación específica concreta de los agentes etiológicos respectivos, principalmente por las razones de desconocimiento de las condiciones locales particulares de las regiones de que cada espécimen proviene, nuestro trabajo queda, por ende, reducido a las correspondientes descripciones relativas a la morfología macroscópica y a la observación microscópica de cada muestra; incluyendo algunas fotografías y fotomicrografías ilustrativas.

#### DESCRIPCIONES

Muestra # 3.--Es una rama de pino que muestra tumoración o hin chazón globosa, de 12 x 16 cms de diámetro, de tipo cerebriforme, que rodea completamente la rama enferma. La lesión se encuentra profusamente lobada, y con profundas hendiduras separando los lobulos. Su consistencia es lenosa, pero no maciza, ya que interiormente presenta un aspecto esponjoso, cuyas cavidades están abundantemente rellenas de aserrín, producto de las deyecciones de insectos, u ocupados por larvas de ellos. Interiormente no ocupa todo el diámetro correspondiente a la apariencia externa, sino que está formada en una porción anular en forma de banda de aproximadamente 10 cms de anchura. El epidermio de esta tumoración se desprende y levanta en forma de pequeñas escamas, que en algunas partes dejan al descubierto pústulas caprichosamente confluentes en disposición cerebroide, reptante, cerradas o abiertas, mostrando estar formadas por un peridermio blanquecino que encierra un material pulverulento de color amarillo muy claro, casi blanco. Microscópicamente este peridermio está formado por un mosaico de células hialinas o amarillentas, sin disposición regular. Morfológicamente son similares a las que constituyen el contenido pulverulento amarillo, que está formado por células ovoides, periformes, elipsoides, redondeadas, trapezoidales, de husos de extremos apuntados o romos, arriñonadas o triangulares, etc., intensamente tenidas en amarillo; presentan superficialmente un aspecto equinulado (espinoso) que en los bordes y por desplazamiento micrométrico del microscopio manifiestan diminutos diminutos mamelones dispuesto radialmente. Encierran en su interior un

núcleo o vacuola (?) generalmente desplazado a la periferia, y varias inclusiones refringentes. Miden como término medio de 24-32 x 16-24  $\mu$ . y se les puede apreciar una membrana (episporio) de aproximadamente 2-4  $\mu$ . de espesor.

Muestra # 4.--Son conos de pino que se presentan ligeramente hipertrofiados, aunque aún conservan algo de su estructura normal, si bien, las escamas se encuentran difusas, sin contornos definidos; más bien redondeados y tendiendo a adquirir una disposición cerebriforme. Se encuentran totalmente cubiertos por una formación pulverulenta de color blanquecino con manchas amarillo claro, o anaranjadas, o gris verdoso. El epidermio de los conos ha adquirido una consistencia leñosa y presenta coloración café-rojiza mostrando profundas perforaciones redondas posiblemente producidas por insectos barrenadores. El polvillo amarillento está limitado por las escamas epidérmicas del cono no existiendo un peridermio distinto, por lo que la lesión se aproxima al tipo caeoma. La observación microscópica de ese material revela que está constituido por estructuras celulares libres, con la misma morfología que las descritas en el caso de la muestra # 3.

Muestra # 6.--Consiste de ramas y conos de pino que presentan un desarrollo herrumbroso de tipo Caeoma o Peridermium. Las ramas muestran invasión de la porción central de su eje como un polvo de color amarillo claro; y los conos se encuentran cubiertos uno del mismo polvillo amarillento y otro, con discretas pústulas dispersas en toda la superficie; en el primer caso, la estructura original del cono se encuentra adoptando una forma esférica, globosa. Las pústulas se encuentran formándose por debajo de la epidermis y contienen masas pulverulentas de color amarillo limitadas por una cutícula blanquecina, el peridermium, casi perdido. El polvillo está formado por células individuales, de formas diversas, desde la esférica hasta la fusiforme (en forma de husos), que miden de 28-56 x 16 a 20  $\mu$ . con un episporio de espesor de 2  $\mu$ ., abundantemente equinulado (espinoso) en algunas formas, o aparentemente liso en otras y con periferia radialmente estriadas; algunas de estas formas parecen no tener más ornamentación que la periférica radial, y sin excepción presentando una condensación central más oscura y corpúsculos o gotículas refringentes dispuestos periféricamente.

Muestra # 8.-- Consiste de un cono de pino que presenta un desarrollo fungoso de tipo Caeoma, de formación subepidérmica. El cono se encuentra hipertrofiado, habiendo perdido su forma, ya que ha adquirido un aspecto globoso. La epidermis se encuentra levantada formando grandes costras de color rojizo oscuro que dejan en libertad una gran cantidad de polvillo de color amarillo cadmio o naranja, el que está formado por células de episporio arrugado o quinulado, de las formas y dimensiones anotadas en las descripciones anteriores.

Muestra # 9.--La constituyen un cono de pino hipertrofiado. No muestra formación de pústulas, posiblemente por tratarse de un cono muy recientemente infectado, ya que revela una exudación resinosa relativamente abundante. La corteza ha adquirido un aspecto descamado de coloración café-rojiza que contrasta con la del cono joven sano que le acompaña, y que presenta un color de tonalidad café-amarillenta. La estructura normal

del cono ha desaparecido, quedando sustituida por una formación lobulada irregularmente; es de consistencia leñosa maciza, no teniendo más características.

## RESULTADOS

La descripción correspondiente a la Muestra #3, parece corresponde con la relativa a las lesiones de tipo Peridermium en las ramas de los pinos, y la cual posiblemente se identifica con aquellas producidas por Cronartium cerebrum (Peck.) Hedgo. & Long. (= Peridermium cerebroides (?)), conocido en el extranjero como responsable de royas ampulosas de los pinos duros; o bien con Cronartium fusiforme (A. & K) Hedgo. & Hunt., que es una especie muy parecida a la anterior difiriendo de ella en que llega a producir lesiones semejantes aunque en huéspedes diferentes.

La comparación de nuestra descripción para la Muestra #4 con la que se tiene para Cronartium conigenum (Pat) Hedgo. & Hunt. (= Caeoma conigenum) coinciden en casi su totalidad; sin embargo es posible que en este caso se trate también de la especie cerebroides anteriormente citada, ya que procede de la misma localización, aunque si se ignora si ambas muestras o especímenes corresponden al mismo árbol enfermo. No siendo remota la aparición de una infección doble, en ramas y conos, por dos especies distintas de royas, suponemos únicamente la posibilidad de que se trate de una misma especie: Cronartium cerebrum, que tiene la particularidad de atacar tanto a las ramas como a los conos de los pinos; considerando la similitud morfológica de sus esporas y su doble localización, atributo del que Caeoma conigenum carece.

Respecto al espécimen #6, también en su descripción se aproxima a la que corresponde a Cronartium conigenum (Caeoma conigenum). En este caso las esporas son aparentemente lisas, mostrando muy escasas ornamentaciones superficiales, aunque hay células profusamente ornamentadas por estructuras en disposición radial; pero en general presentan morfología muy semejante a la de las especies anteriormente consideradas para los casos 3 y 4.

Por el aspecto macroscópico de la lesión en la Muestra #8, y por la coloración amarillo cadmio que presenta, parece tratarse de una infección de conos causada por Cronartium strobilinum (Arth.) Hedgc. & Hahn. (= Caeoma strobilina). Microscópicamente sus esporas en nada o muy poco difieren de las anteriores descripciones; de aquí que nos guíemos en nuestra apreciación únicamente por el aspecto general de la lesión sin llegar a conclusiones de mayor profundidad.

Finalmente, la Muestra #9 quizá se identifique con una lesión muy reciente causada por la misma especie que en el caso de la Muestra #8; es decir, por Caeoma strobilina.

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SOME OBSERVATIONS ON THE INITIAL INFECTION AND SPREAD OF ROOT  
DISEASES WITH PARTICULAR REFERENCE TO ARMILLARIA MELLEA AND PORIA  
WEIRII

G. W. WALLIS

S. D. Garrett<sup>1</sup> has, as a result of many years of observing root diseases, divided soil fungi into two categories: "the soil-inhabiting fungi, or those which are characterized by an ability to survive indefinitely as soil saprophytes", and "the root inhabiting fungi, or those which are characterized by an expanding parasitic phase on the living host and by a declining saprophytic phase after its death".

It is with the latter group, the root-inhabiting fungi, that we must be mainly concerned when speaking of root diseases in second-growth stands. The intimate association of multitudes of soil-inhabiting fungi with all roots, requires, however, that they too receive their share of recognition in all comprehensive studies of root diseases.

For a fungus to initiate infection and maintain continuous growth within a tree, it must first overcome passive and active host resistance; i.e., the inoculum potential must be sufficient for the fungus to invade progressively a host against the forces opposing infection. Inoculum potential being used here as defined by Garrett<sup>1</sup> "the energy of a fungal parasite available for infection of a host at the surface of the host organ to be infected". The food base is responsible for supplying the energy for the required inoculum potential.

The first distinguishing feature of a root-inhabiting fungus, namely, the ability to survive in dead host tissue, initially invaded when in a living state, requires further examination in light of tree root diseases. The first phase, the ability to survive in dead host tissue, need not be questioned, for it is well known that Armillaria has been isolated from the stumps of most tree species and Poria has been recorded in Douglas fir stumps over a century old. The second phase, the necessity of having the initial invasion of a root-inhabiting fungus occurring when the host is in a living state, however, requires further thought. Garrett<sup>2</sup>, in his latest report on the development of Armillaria rhizomorphs, suggests that the habits of tree root parasites may diverge somewhat from those on herbaceous plants in that the former fungi have the ability to attack lignin and cellulose, a property foreign to most soil-inhabiting fungi. He demonstrated that wood blocks which had been killed by autoclaving were invaded by Armillaria after being incubated in unsterilized soil for several weeks. In our own work with Poria, we have found that Douglas fir heartwood, cut for several months, when placed in contact with inoculum in unsterilized soil in situ, will be invaded by the root parasite ahead of other soil organisms.

The ability of these fungi to invade roots dead for varying periods has not been defined. The answer must await the results of present and future investigations.

The growth of a root parasite from a food base onto a living host, ignoring spores at this juncture, may be assumed to occur in one of two ways: the root may grow in contact with the fungus harboured in the food base, or, by the production of special organs, e.g. hyphal strands or rhizomorphs, the fungus may grow away from the food base through the soil in search of a new nutrient source. Both modes of infection are illustrated in the two fungi being discussed. Poria, I believe, is not able to travel more than

a very few cm through the soil. Therefore, for a tree to become infected with this fungus, a root must grow into contact with viable mycelium in an old root or stump. Growth of Poria in glass tubes through unsterilized soil has been recorded up to two cm in duff in situ from a severely decayed Douglas fir stem section. Until a satisfactory method has been found for the isolation of Poria from soil, it will not be possible to say with certainty that this root-inhabiting fungus does not occur freely in the soil.

Armillaria mellea, as you are all aware, besides spreading by root contact, can, by the aggregation of hyphae into rhizomorphs, grow through the soil for some distance to seek out new host tissue. It is on this point that most controversy and confusion has arisen concerning the parasitology of this fungus. Rhizomorphic strands have been known to grow through the soil for distances in excess of 20 feet. Rhizomorph attachment to a substrate, however, is not synonymous with infection. Wallace<sup>4</sup> found that rhizomorphs grew for great distances through the soil, but doubted that the inoculum potential required for the fungus to invade coffee or tea roots was sufficient once the rhizomorphs had attained a length of more than just a few feet. Garrett<sup>2</sup> found that infection by Armillaria rhizomorphs decreased with increasing distance from the food source. He suggested that the decrease in rate of nutrient translocation would be sufficient to limit initial and sustained infection by rhizomorphs once they had grown beyond a certain length. It appears, at this time, that the size and state of deterioration of the food source, and the length of the rhizomorphic strands are of importance when considering the parasitology of Armillaria. There appears to be little doubt that the fungus can and does invade healthy bark, but the role of the host in confining infection once the fungus has penetrated internal tissues still requires further elucidation.

Typical of many root-inhabiting fungi, following introduction onto a new host, both Poria and Armillaria can grow ectotrophically along the bark surface as well as internally within the tissues. The rate at which this root surface growth advances ahead of tissue infection is a further factor governing the success of continued fungal invasion. Poria spreads over the surface of roots in a dense mat, often fan-like at the advancing margin. This surface mycelium may reach distances of 3-5 feet in advance of the last point of tissue infection, depending upon the root size. The mycelium invades healthy bark, usually resulting in a number of points of wood infection between the advancing ectotrophic margin and the main body of tissue invasion. These advanced points of infection develop and eventually girdle the root, killing the distal portion. In this manner the death of the root and the tree is greatly hastened beyond that which would have occurred had the mycelium been confined to wood only. Host resistance, having minimal, if any, effect on surface growth of mycelium, can do little to suppress its development. Also, since surface mycelium grows rapidly across roots of the same and adjacent trees where they are in contact, grafting not being required, the rate of spread of the disease is further increased.

Armillaria rhizomorphs also frequently spread along the surface of roots, penetrating healthy bark well in advance of the major body of wood infection. A number of workers are of the opinion that the initial invasion will succeed only in those hosts which are growing under adverse environment conditions.

Others, however, have stated that, given conditions suitable for the development of the fungus, Armillaria will act as a virulent primary pathogen--showing no respect for host vigour. A detailed study of host-parasite relationships, using controlled inoculations, will be required before many of the conflicting reports on the habits of Armillaria can be disentangled.

Besides the local vegetative spread of root disease fungi, there also remains the possibility that more distant spread may arise from infection by spores. The infection of freshly cut stumps by spores of Fomes annosus is probably the most outstanding example of the intensification of a root rot in this manner. The infection of healthy roots of trees by spores has not been observed. Attempts to infect stem sections and stumps with basidiospores of Armillaria and Poria have not proven successful to date.

Past studies with both Armillaria and Poria, as well as other root-decaying fungi, have shown that an intensive study of environmental-fungus relationships is required for many of the major tree root diseases. Rishbeth<sup>3</sup> has shown that the growth of Fomes annosus along the surface of the bark of Scots pine roots is closely correlated with soil reaction. On acid sites, possibly because of the presence of antagonistic soil-inhabiting fungi, surface growth is sparse to absent. No record of the growth of Armillaria and Poria in relation to soil reaction were found by the author in a search of the literature.

A number of workers have observed that Armillaria appears to cause extensive damage in young stands, trees appearing to become more resistant with age. Poria, on the other hand, becomes prominent only after the stand is 15-25 years of age. Intensive investigations, using controlled infection points, are necessary to establish the relationship between infection and host age.

These are but a few of the many problems still facing those concerned with root diseases, as will become evident throughout today. The neglect of the field of root parasites, until comparatively recent years, and the threat to future plantations, requires that we divert more of our attention to the often long-term and rather tedious work required for a detailed analysis of these problems.

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STUDIES OF SOIL MICROORGANISMS AS RELATED TO ROOT ROT

Ernest Wright

As forest pathologists, we are interested in determining whether there are any detectable differences in the quantity, the kind, or the activities of soil microorganisms in root-rot-infested soil as compared to root-rot-free areas. If there are identifiable differences, then it might be possible to alter the soil by chemical or other amendments to such an extent as to change favorably the micropopulation of the soil and thereby lessen losses from root rot. Such control is largely hypothetical, because we have very little direct evidence in forestry to support such theorizing.

The population of the rhizosphere is decidedly different from the adjacent soil, as has been shown by Starkey (8), Lochhead et al (5), and others. Since there are decided differences in the micropopulation of root surfaces as compared to the surrounding soil, the soil processes also must be considerably different (3). Wilson (10) found that the production of carbon dioxide by rhizosphere soil was much greater than that of the control soil, and this difference was increased greatly by the addition of root extracts. Also, he found higher concentrations of soluble nitrogen in the form of ammonia, amides, and amino acids. These and many similar references indicate that studies of the microflora of forest soils may give some definite clues to the control of root rot in much the same manner as has been developed for agricultural crops. Of course, the solution is infinitely more complicated when applied to forestry practices. For example, Bjorkman (1) concluded from his studies of Polyporus annosus Fr. that the possibility of combating this root rot biologically cannot be considered especially great, but that investigations ought to be continued with regard to the practical importance of the problem. Wallis (9) indicated that soil microorganisms are probably not the primary factor which inhibits Fomes annosus spores from infecting uninjured pine roots. For one- or two-year-old agricultural crops, there is increased likelihood of changing physiological reactions of the plant and thus lead to greater or lesser resistance to infection by root rots. However, it is equally impossible to neglect the factor of host resistance in forestry when considering the environment in relation to plant disease (2), and, since we are discussing root rots, we are concerned primarily with the soil. The purpose of this paper is not to discuss the literature on control of root rot. This has been done by Garrett and others far more concisely than can be done here. To discuss in some detail the methods of study applicable to root rot seems desirable in the hope fruitful ideas may develop.

Methods of Study

The type of root rot under investigation will, of course, have an important

bearing on the method of study adopted. The root rots I have studied were adaptable to dilution-plate studies because they either spread freely through the soil and over the underground organs of the host plants, or spread along the outside of the host roots (subsequently invading and rotting the root tissue within).

In the first category, *Rhizoctonia* damping off and root rot of broadleaf seedlings was studied. In this instance, fungi counted in dilution plates were more numerous in soil containing diseased seedlings than in plates from the check soil. *Rhizoctonia*, however, rarely appeared in dilution-plate cultures. A wider variety of fungi, including *Rhizoctonia*, was noted in the same soil by use of a modified Cholodny slide technique (11). The latter method, however, was not quantitative. After a considerable number of individual trials, neither method was deemed reliable enough to predict the probable extent of seasonal losses from root rot in new seedbeds.

In the study of *Fusarium* root rot, *Trichoderma*, *Penicillium*, and *Streptomyces* were found antagonistic in varying degrees to the *Fusarium* in vitro. However, when these organisms were inoculated into the soil of unsterilized seedbeds, either singly or in combination, they failed to reduce losses from root rot. The most satisfactory result was obtained when all three organisms were used as inoculum, although the losses were not significantly less than in the untreated check soil. These tests are mentioned here to illustrate again that an apparently promising lead under laboratory conditions is likely to be of little or no benefit in field trials and that the microbiological approach is extremely complex.

In studying *Phymatotrichum omnivorum* (Shear) Duggar, the so-called Texas or cotton root rot, no attempt was made in my studies to relate the type or abundance of soil microorganisms to the virulence of this fungus. Indicator plants were found to be the most reliable guide to the presence or absence of this root rot (7) in unplanted areas. However, Mitchell et al (6) showed that decomposition of organic matter increased microbial activity in *Phymatotrichum*-infected soil, which resulted in decreased virulence of the root-rot fungus on cotton. This very striking control of cotton root rot obtained in field trials over a period of 13 years by the use of organic manures was attributed by King (4) to the action of antagonistic soil microorganisms. Later, this was partially verified by use of Cholodny slides.

*Phymatotrichum* root rot, like *Poria weirii* Murr, spreads primarily by contact of roots, and, consequently, some of the techniques used in studying the former may prove applicable to the latter.

The microbiological studies of *Poria weirii* that we have made to date are extremely limited. The Cholodny slide technique was not used, primarily because it wasn't considered applicable. Two series of soil-dilution plates have been made. Both gave interesting results, but the findings so far are not considered conclusive.

Methods of obtaining soil samples for the studies, however, may interest you. In the first series, the soil was obtained by inserting a soil tube

parallel to the outside of diseased roots after a foot of the surface soil had been washed away. The samples were taken at a depth of one to two feet. Several soil borings were taken in this manner from separate trees. Soil cores from individual trees were composited in sterile soil cans. The soil borer was sterilized for each root area sampled. Soil obtained in this manner was mixed and sieved for standard dilution-plate counts. On the basis of this study, conclusion was that the differences noted may have been influenced by variations in depth of sampling, as well as the presence or absence of Poria weirii.

The second test consisted of selecting five trees dying from P. weirii and five apparently healthy trees in the same stand. The trees were felled and the cut stumps examined at ground level. Isolations were made from each P. weirii-infected tree for verification.

From six to eight samples of soil were extracted with a sterilized tube 1-1/2 feet from each stump in a circle around it. Samples were taken to a depth of six inches and one foot in each boring. These were composited separately in sterile cans and taken to the laboratory, where soil samples in each can were mixed thoroughly and sieved as before in preparing them for soil-dilution plates. After sampling, the soil was hand-excavated away from the stump to a depth of two feet, and the roots were cut into with an axe to verify that those trees used as checks were actually free of P. weirii, at least in the area sampled. Significant differences in soil microorganisms were obtained. This test needs to be repeated for several additional areas to substantiate the results from these quintuple samples.

Limited progress has been made in the study of soil microorganisms as related to root rot of forest trees, but a start has been made. Whether the obscure reactions involved are due to synergism, antagonism, competition for available nutrients, minute changes in pH, CO<sub>2</sub>, or edaphic conditions, or a combination of one or many of these, remains to be determined. The fact appears clear, however, that microbiological studies of soil as related to root rots of forest trees are extremely complicated, even more so than was realized; nevertheless, they should be continued with increased vigor.

Suggestions and comments will be appreciated. Before we have these, however, I would like to call on Earl Nelson to explain his studies of Poria weirii at Black Rock.

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#### FACTORS PREDISPOSING ROOTS TO INFECTION

R. D. Whitney

Root infection implies the entry and establishment of fungi in roots. The present discussion will be concerned mainly with those fungi that decompose woody tissues in tree roots. The data were obtained during root disease investigations of white spruce in Saskatchewan and Manitoba from 1951 to the present, and from experiments conducted in the Forest Pathology Laboratories at Saskatoon and at Queen's University.

Predisposition involves the conditioning or exposing of host tissues to infection by organisms that are presumably present and ready to attack. However, it is pertinent in a discussion of this subject to consider forces acting on the potential pathogen as well. Two classes of predisposing factors will be dealt with. One is mechanical injury to the host caused by a variety of agents; the other is environmental conditions that influence both the host and the potential pathogen.

## Mechanical Injury<sup>1</sup>

Mechanical injury as used here denotes bark or wood disruption that results in susceptible tissues being exposed. This injury is caused by external agents or forces.

Hylobius Wounding. Root injury caused by Hylobius sp., a root boring weevil, has been found in several coniferous species. Warren and Whitney (1951) found root wounds caused by Hylobius warreni and H. pinicola highly correlated with the occurrence of root rot in white spruce regeneration in Manitoba. Smerlis (1957) found a similar relationship with Hylobius sp. in young balsam fir in Quebec. Reid (1952) found Hylobius sp. wounding in lodgepole pine roots in Alberta, and Warren has recently found fairly heavy wounding in jack pine in Northern Manitoba. Wounding by Hylobius also occurs in numerous other conifers including eastern larch, black and Norway spruce; and scots, red, eastern, and western white pine (Warren, 1956a). The pine root collar weevil (Hylobius radicis Buchanan) causes extensive damage in jack and scots pine and lesser damage in several other pines (Schmiege, 1959).

The examination of 1170 diseased roots on 495 living white spruce in Manitoba and Saskatchewan revealed that girdling and non-girdling Hylobius wounds were responsible for the entry of fungi in 27.2 per cent of these diseased roots (Table I). The larvae tunnel in the bark to the depth of the cambium, or sometimes slightly into the wood, and cause abundant resinosis. Tunneling is mainly around the base of roots, and roots smaller than one inch in diameter are commonly girdled and killed. Roots less than one-eighth inch in diameter may be chewed off completely. Where larvae have been active during several years, the damaged part of the root may be heavily encased in a mass of resin-soaked duff and frass containing abundant remains of pupal cells. When these masses are removed, a girdled branch root is usually found. In small girdled white spruce roots less than one-half inch in diameter, accompanying wood stain or decay in the parent root can usually be traced to the girdled root. Entry of fungi does not always appear to be directly through the wound, but is often through a more distal part.

Non-girdling wounds usually occur in larger roots and in the root collar region. They vary in size from a single tunnel to areas of riddled bark several inches across. Although these wounds are very resinous, and tend to heal over, they usually become infected before healing is complete.

On a tree basis, root rot was highly correlated ( $r = 0.7504$ ) with insect wounding of both types. The most advanced stage of decay (indicating the probable region first attacked by fungi) was always in the most heavily wounded part of the root system; in roots with moderate wounding the rot could be traced definitely to the wound.

Root Compression. Compression caused by growth expansion against stones or

1. Most of the figures and tables have been published in the Forestry Chronicle, 37(4): 401-411., 1961, and are therefore omitted here in order to conserve space.

other roots, kills the protective bark layer. Root wood is thus exposed to infection, particularly when compression is against an infected root.

Redmond (1957) found wounds on the under side of roots, apparently caused by stone bruising, important entrance courts for fungi in balsam fir. He even found stones completely embedded in wood in the vicinity of root crotches. Domanski and Dzieciolowski (1959) found Polyporus tomentosus root rot associated with deformed roots of scots pine on stony and impermeable soils in Poland.

In white spruce in Saskatchewan and Manitoba compression wounds were entrance points in 4.7 per cent of 1170 diseased roots. White spruce roots were frequently deformed by growth against roots of the same or other species, especially aspen, which composes a considerable portion of many spruce stands. Deformities of this kind were most important for entry of fungi in older stands in conjunction with Hylobius wounds.

It may be concluded that factors contributing to root compression such as shallow or stony soils, and dense stands with many roots in a single narrow horizon, are factors predisposing roots to infection.

Root Grafts. Root grafts, though not mechanical wounds, are considered here because their relationships with root infection are similar to those of root compression. Root grafts provide ideal entrance courts when one root of a grafted pair is diseased. Redmond (1957) found decay (presumably in both grafted roots) in all of the occasional root grafts in balsam fir. Root grafts are abundant in douglas fir and are important avenues of spread of Poria weirii (Buckland, Molnar, and Wallis, 1954). Very few root grafts were found in white spruce in Saskatchewan and Manitoba, and all of these were sound. Possibly grafts are more important in older stands than those examined.

Dead Root Ends. Redmond (1957) found that 85 to 90 per cent of the rootlets were dead on spruce budworm defoliated balsam fir, but he was able to correlate only about 3% of the current root rot infections with previous budworm defoliation. Phytophthora cinnamomi Rands infects rootlets of Pinus echinata growing under adverse soil conditions resulting in dead root ends, and eventually in death of the tree (Campbell, 1951).

Broken root ends in roots one-quarter inch or less in diameter were common in some localities in Saskatchewan and Manitoba. These roots usually had died back for a short distance above the point of breakage, and new rootlets branched off at the lower end of the living part. Stains, some of which were incipient decay, extended from the dead root ends into the living root. Dead root ends, one-eighth inch or less in diameter, were often completely grown over by callus tissue, leaving the dead infected wood embedded in sound living tissue. Broken roots of this nature could result from stress during severe windstorms, as suggested by Redmond (1957), or possibly from chewing by insects or small burrowing animals such as mice and shrews.

Animal trampling. Roots near the soil surface are commonly wounded by the trampling of deer and elk, especially where trails are made by these

animals. Such wounds were always infected in the present study, and accounted for 1.5 per cent of the diseased roots.

Root canker wounds. This term designates a type of healed or nearly healed wound of unknown cause, the swollen callus of which is covered by a thin layer of living inner bark and a thickened outer layer of rough, fissured, dead bark. A black non-sporulating fungus was consistently isolated from the margin of the dead bark and from pink stains which extended into the wood from the healed wound. The relationship between the black fungus and the lesions is not known. These lesions were abundant in very stony areas and could possibly have been initiated by stone bruising. Extensive decay in some roots appeared to have entered through these lesions, but usually the stain was limited to a local area near the wound.

#### ENVIRONMENTAL CONDITIONS

Excessive Moisture. High water tables following periods of heavy or prolonged precipitation on poorly drained areas result in root mortality and outright death of many tree species (Boyce, 1948). Newhook (1959) found high soil moisture favored root rot with which Phytophthora cinnamomi was associated in four year old potted Pinus radiata. He found a similar correlation between high soil moisture and disease in trees 30-40 years old. P. cinnamomi parasitizes the roots of Pinus echinata to a much greater extent on heavy clay soils with poor internal drainage than on well drained sandy soils (Campbell, Copeland, and Hepting, 1953). Similarly, Etheridge (1956) found a higher incidence of root rot infections on "moist" compared to "dry" sites in subalpine spruce in Alberta. The relationship was not clear cut, however, because the trees on moist sites also had faster growth.

On poorly drained sites in Saskatchewan and Manitoba, many fine rootlets and larger roots up to about one inch in diameter of white spruce were dead, apparently as a result of excessive soil moisture. Soil around the dead roots was saturated, and water rose to 11 inches from the soil surface in holes from which stumps were removed. The extremities of moisture-killed roots were saturated and were usually stained grey. No fungi could be isolated from this part of the roots; however, Armillaria mellea was isolated from the non-saturated and adjacent living parts of the root. Moisture-killed roots provided infection courts for root-rotting fungi at Candle Lake and Reserve; none were found at Hiding Mountain, presumably because of better soil drainage.

Soil Temperature. The optimum temperature for growth of a root pathogen is not necessarily the best temperature for infection. Rennerfelt and Paris (1953) found Fomes annocus withstood competition from Trichoderma viride only at temperatures below 12°C. while its optimum growth occurs at 22°C. (Rishbeth, 1951).

To investigate the ability of P. tomentosus to compete with fungi from dead rootlets at lower temperatures, isolates were grown at various temperatures on malt extract agar. The rootlet fungi were mostly hyphomycetes which do not cause destructive decay in roots. The latter fungi were placed into two growth-rate groups. Both groups grew faster over much of the range and had higher optimum temperatures than P. tomentosus, but the latter grew faster than group "b" and almost as fast as group "a" at 5°C.

At this temperature P. tomentosus grew at about one-third its optimum rate while the group of fast-growing fungi from rootlets grew at about one-twelfth its optimum rate. This indicates that at the low soil temperatures prevailing during the growing season at Candle Lake, P. tomentosus may have competitive advantage over some of the fungi which were isolated from small roots.

Soil Reaction. Root-rotting fungi that require a woody substrate for growth and do not grow through the soil can hardly be directly affected by soil reaction. However, most of them have appreciable growth on the root surface and those that do not, may be in contact with root surface conditions at least briefly while spreading from root to root.

Alkaline soils favor Fomes annosus infection of pine (Rishbeth 1951). F. annosus, which usually grows extensively over the root surface prior to infection, is antagonised by Trichoderma viride on acid but not alkaline sites.

Stand-opening disease caused by the parasitism of Polyporus tomentosus on white spruce, has been found only on acid sites (van Groenewoud, 1956). Studies on this pathogen (Whitney, 1960) have shown that it spreads by root contact but grows very little on unsterilized root surfaces. P. tomentosus does not grow on standard media with a pH higher than 6.8 and inability to grow on alkaline media may explain its absence on alkaline sites. No specific antagonists from root surfaces or alkaline sites have been found.

The possibility that high pH might restrict the growth of P. tomentosus in uninfected roots or uninfected tissues in diseased roots was investigated. The pH of bark and wood of uninfected roots and of infected and healthy parts in diseased roots was determined. Samples from the various parts were cut into two mm. squares, and soaked in distilled water for 24 hours. A Beckman model N pH meter, with microelectrodes, was used in making pH determinations.

Results of 292 determinations from 56 roots show that the pH of sound bark and wood in both healthy and diseased roots was within the pH range of P. tomentosus on artificial media. The upper limit of the pH range of healthy bark and wood in sound roots was slightly higher than that of the corresponding healthy tissues in diseased roots; however, the small differences obtained could have been due to the diffusion of metabolites from diseased tissues. The pH of diseased roots was considerably lower than that of healthy roots, the lowest pH values occurring in the most advanced stage of decay. This indicates that the fungus reduces the pH of infected roots as it tends to do with artificial media. From these results it is concluded that the rate of growth of the fungus in roots is not governed by pH.

Host Vigor. Etheridge (1956), referring to stem and root rot together suggested that faster-growing subalpine spruce were more prone to infection than slower-growing trees. Wallis (1961) found the growth of F. annosus mycelium was significantly higher in roots of suppressed compared to dominant Scots pine trees. Percentage infection, however, was about the same on severed roots of suppressed dominant trees. It is widely held that Armillaria mellea attacks suppressed and otherwise weakened trees to

a greater extent than dominant and healthy trees (Boyce, 1948; Day, 1927). However, Christensen (1938) has found infection to be common in apparently healthy trees. It may be that infection is as common in healthy trees, but the spread of the fungus and the development of disease following infection does not occur.

To investigate the possible effect of host vigor on infection and resultant root rot of P. tomentosus, observations were made on root systems of heavily shaded suppressed trees in an area where stand-openings were common. If host vigor was important in predisposing trees to infection and disease development, a higher percentage of the suppressed trees would probably be diseased. Two transects 300 feet long and 12 feet wide were made, on which the root systems of all trees were examined. Only those trees that were in stand-openings were diseased, and trees of all crown classes were equally affected. From this result it is evident that low host vigor, as indicated by suppression, is not an important predisposing factor of infection and disease development. The absence of P. tomentosus root rot between stand-openings suggests that effective inoculum was lacking, and the slow growth of the fungus, which apparently is restricted to roots, may be a more important limiting factor than host vigor.

Fast-growing trees were evidently as susceptible to infection by P. tomentosus as those with slower growth. Growth measurements of thirteen diseased and three healthy trees on each of four plots were made from increment cores obtained at breast height. Annual rings were measured in tenths of mm. with the aid of a stereomicroscope.

The radial increment of trees with 100 per cent of the roots dead (recently killed trees), began to decrease from 5 to 15 years prior to death. All roots on these trees were decayed with P. tomentosus. Since the fungus grew at an average rate of less than two inches per year in inoculated roots, a period considerably in excess of 15 years after infection would be required for complete invasion of roots and tree death. These results indicate that infection took place before the period of growth "slow down" that preceded death, and that it is not only weakened or declining trees that are attacked by P. tomentosus.

Soil Impermeability. Day (1951) was able to correlate depth of rooting in various coniferous species with the occurrence of root and butt rot in Britain. He considered that restriction in root development caused by soil compactness or poor drainage resulted in root rot in the trees. Paine (1960), however, found that shallow rooting and low soil nutrients resulted in outright death of white spruce without the occurrence of root rot. van Groenewoud (1956) found the B-Horizon very compact on areas of root disease in white spruce and the inability of roots to penetrate the soil may be a factor predisposing this species to Polyporus tomentosus. When roots can not penetrate the B-Horizon they become concentrated in the A-Horizon and excessive competition for moisture, nutrients, and space takes place. The resultant concentrations of roots in a comparatively shallow space produces a more or less continuous substrate suitable for P. tomentosus, the vegetative growth of which is apparently confined to roots. Other factors bearing directly on the fungus, however, are also operative in this disease.

Some relationships on predisposition of roots to infection, such as scots pine on alkaline soils being much more susceptible to Fomes annosus than on acid soils, are becoming well established. Also, it is fairly clear that mechanical injuries, such as Hylobius and compression wounds, increase infection by exposing wood and dead bark. However, the basic and undoubtedly complex ecological relationships of most tree root-rotting fungi are little understood and the knowledge we claim to have is built up from association of factors only, rather than from experimental evidence.

At least two major obstacles have hindered intensive ecological investigations of root fungi. They are inability to determine presence or absence of the organisms in soil, and inability to inoculate roots with a satisfactory degree of success. Some advances have recently been accomplished with the second of these by Wallis (1961) who found that the use of hardwood inoculum blocks greatly increased the percentage infection with Fomes annosus in scots pine.

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## ROOT ROT DAMAGE AND THE CONTROL OF FORESTERS

T. W. Childs

In a small town in southeastern United States, in the center of the village square, stands a monument to the cotton boll weevil. This pest reduced the local cash crop by hundreds of bales annually. It was so destructive, in fact, that farmers were compelled to diversify their agriculture. As a result, soils are slowly recovering from past abuse. Local economy is more prosperous. Hence the erection of this monument by a grateful citizenry.

Just how damaging was the weevil? Disease damage is generally assumed to be the total decrease in yield of useful products that is associated with activity of a pathogen. This seems reasonable enough, but the weevil statue makes us stop and think. Was the weevil's effect on cotton yield a proper measure of its damage? Perhaps some of our other pests also deserve an occasional entry on the credit side of the ledger.

In evaluating damage, we take pains to distinguish between primary and secondary parasitism, to give due consideration to the physical environment's effects on such things as tree vigor (whatever that may be), and to allow for the fact that yield is not a straight-line function of stocking. We accumulate data from long-term plot studies and, in the meantime, try to get interim results by complex calculations and extrapolations. Such activities are no doubt worth while, as intellectual exercises if for nothing else.

But in our preoccupation with details of an exceedingly difficult problem we are inclined to forget the primary objective of forestry, and the concept of damage that harmonizes with that objective. Let's take an example, and look at one or two of the basic relationships that we should consider before trying to compute the damage that it causes.

Poria weirii root rot is unquestionably a damaging disease. Strong circumstantial evidence indicates that its persistence and local spread are favored on areas continuously occupied by successive stands of Douglas-fir, and that it gradually disappears when Douglas-fir succession is interrupted for considerable periods by other vegetation. This in turn suggests that we might profitably refrain from planting Douglas-fir, almost before the slashfire is cold, on areas where Poria is much more than ordinarily

abundant. We say, however-- and I have heard these very words-- "We can't afford that. We can't afford not to keep our land fully stocked all the time."

This attitude is based on several assumptions. First, that despite its costs and other disadvantages, planting immediately after logging is good business because it presumably gains a few years on the next rotation. Second, that plantings on badly infected areas will somehow escape serious damage by *Poria*. I'll not attempt to demolish these two assumptions here, although I'll gladly undertake the job in private. We need merely view them with skepticism until such time as they are confirmed or discredited by economic analysis and by a few more decades of records from *Poria* plots.

The next assumption, a multiple one, is usually made more or less unconsciously. This assumption is that natural Douglas-fir stands characteristically are pure, fully stocked, and regenerated immediately after the destruction of their predecessors; and that, since Nature's ways are best, continuous full stocking is synonymous with maximum productivity. With certain qualifications we might accept the bit about Nature's ways, but none of the rest of this corresponds very closely to the facts.

You who have head-chained in fir know how seldom are crown canopies continuous enough to discourage vine maple, and how often you find individuals and groups of scrub hardwoods. "Sidehill" alder is so common that it is generally considered a nuisance. Walter Meyer (*Jour. Agr. Res.* 41:635-665, 1930) states that in immature stands 9.5 percent--almost one-tenth-- of the average acre is in small "holes." His figures include gullies and rock outcrops, but do not include breaks in the Douglas-fir cover more than 2 chains across. When we say that Douglas-fir stands are pure and fully stocked, all we really mean is that they are a little more so than are stands of most other species.

The myth of immediate regeneration can be exploded even more easily. It probably originated like this: All the firs in a stand are about the same size; therefore, they are all the same age; therefore they must have started right after the old stand was destroyed. There isn't much wrong with this except poor observation, worse reasoning, and an erroneous conclusion. (In passing, note that we unconsciously use this assumption-- that natural regeneration is immediate and complete even over thousand-acre burns--as a step in the support of our contention that 60-acre settings must be immediately planted because natural reforestation will be slow and incomplete.)

Anyone who has watched the process of natural reforestation, or mentally reconstructed it on big old burns, knows how irregular it usually is and how long it often takes. Such observations are confirmed by data. In Boyce's study of heart rot (described in U. S. Dept. Agr. Tech. Bul. 286, 1932), age at ground level was determined for all trees of merchantable size on 38 plots where the trees had been felled during ordinary old-growth logging operations. Average plot area was 2.05 acres and average number of sawtimber Douglas-firs per plot was 71. On the average plot, the quartile range of Douglas-fir ages was 30 years and the range of extremes was 172 years.

When we lump together all these facts--delayed regeneration, persistence of openings and groups of hardwoods, light forest cover over brush, together with premature opening of stands by pests or wind--then it is apparent that the average acre within the Douglas-fir type falls far short of being fully stocked with Douglas-fir at all times.

Then, if we continue to assume that Nature's ways are best, we are forced to conclude that Douglas-fir stocking should be intermittent or only partial if we are to obtain full productivity. We must remember that this is still only an assumption, but it agrees with what we know about plant communities in general, and is not as far-fetched as it may seem at first glance. We might even dignify it by calling it a theory. Assumption or theory, it deserves serious consideration. Its bearing on such important things as recreation and water yields is outside the scope of this discussion, but it cannot be ignored in our deliberations on damage by disease.

There's an old saying that one-crop farming makes a rich father but a poor son. When we strive for continuous full stocking of conifers, we may not only be wasting effort that could better be devoted to other purposes--we may actually be reducing yields and impairing the productivity of our land resource. In most Douglas-fir localities you don't have to look very hard or long to find symptoms of nitrogen deficiency, yet such symptoms are rare in close association with alder. Perhaps an intermixture or short rotation of alder may increase total Douglas-fir production by increasing soil nitrogen. Even the despised and cursed vine maple almost certainly improves the structure of the soil, if not its fertility.

According to our new assumption, a Poria weirii infection center is evidence that plant succession there has not followed the usual pattern, and that, exclusive of the effects of the disease, conditions for Douglas-fir growth there are consequently inferior to those in superficially similar but uninfected parts of the stand. Poria damage, then, is not equivalent to the differences in yield observed between infected and uninfected plots. This is a comforting thought. I've been bothered because I couldn't think of a good way to measure disease damage, and it's consoling to realize that maybe there isn't any such thing.

I am also supposed to discuss root-rot control. No one can reasonably deny that root rots cause real damage and must be controlled. But give a moment's thought to the damage that foresters themselves may be causing by uncritical acceptance of conclusions that seem too obvious to be questioned. We pride ourselves on membership in a young and alert profession, and in many instances we are finding and adopting better methods. In far too many instances, however, the only thing that keeps us from practicing our grandfather's mistakes is that there wasn't any North American forestry in Grandad's day.

After profound meditation on this subject, I am inclined to assign a secondary priority to root-rot control, and top priority to control of foresters. Present company not excepted. As foresters, we should have one objective and one only--to get the maximum yield of useful products, tangible and intangible, from forest land. Such things as continuous full

stocking, fire protection, or even root-rot control, are not necessarily means to that end. When we fail to discriminate between real and substituted objectives we are likely to find ourselves in the front rank of pests that reduce forest productivity.

When, for example, we take continuous full stocking as our goal, we forget that this substitute goal may not even be compatible with our real one. The dry-land wheat farmer can crop his land each year for an annual yield of 8 or 10 bushels per acre, or he can summer-fallow for a biennial yield of 30 bushels. Nature has her own ways of giving the land a rest, although she's a slovenly old girl and puts a little brush-fallow here and a little there instead of in neatly outlined 320-acre blocks.

I have belabored this continuous full stocking idea partly because it's far enough from my field so that I am not unduly cramped by a knowledge of the facts. Then, too, it's always easier to see the mote in your brother's eye than the beam in your own. Mostly, however, I am interested in stocking because of its influence on my favorite disease, and because it provides an excellent illustration of why foresters must be controlled. And I repeat: by foresters, I mean us. The forest manager is not without responsibility in such matters, but he is essentially a believer, a man of faith. He has to be, or he'd never get anything done. It is the researcher who is above all responsible for maintaining an open, or what is even better, a chronically suspicious mind, for careful scrutiny of all assumptions (especially the obvious), and for constant insistence upon the necessity for facts as bases for conclusions and action programs.

It might be going too far to assume that a Poria weirii infection center is attributable solely to Nature's mishandling of that particular part of the stand, and that the fungus, by opening the canopy and introducing a rotation of vine maple or alder, has had a net effect that is actually beneficial. Nevertheless, by making us consider its basic ecological relationships, Poria forces us to give some thought to fundamentals of forest culture which we cannot afford to ignore. In that way, at least, Poria and its fellow pests are as beneficent as the boll weevil, and are equally deserving of our gratitude.

I do not urge the erection of a statue to Poria weirii. (A small plaque, perhaps, with a basidium rampant, setal hyphae in orle, and of course a bend sinister.) Looking into the future, I foresee the 509th Western International Forest Disease Work Conference, held here in Banff in the year 2461. Word comes from the Poria Weirii National Monument that the last survivor of that species has just died from an overdose of strontium fallout. The assembled thousands of researchers, including as usual a maximum of two from each of the participating United States laboratories, stand with bowed heads for a moment of silence in memory of that friend of mankind, who compelled us to master Nature's primary lessons before attempting to create silvicultural masterpieces.

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## LIMITATIONS WITHIN THE ROOTING ZONE AS A CAUSE OF ROOT DISEASE

R. G. McMin

Day, in a series of papers (1938, 1949, 1950, 1951, 1953, 1957, 1959a, 1959b, and 1960), has developed the proposition that deficiencies within the rooting zone provide:

"the initiating or foundation factor in the development of disease, in the later stages of which parasites or pests play a more or less important part..."

In his paper "The imperfection of the environment and its importance in the management of forests", Day (1950) states:

"Forestry in... Britain tends inevitably to be relegated to the less fertile soils. The factors which determine fertility are those which relate to the nutrient status of the soil, space available for permanent root development, and variation in water and oxygen content: low fertility means in practice, a deficiency in one or more of these things. Because of this, curves of abnormal shape, indicating the presence of root disease, are common in British forestry, and whenever root disease occurs... the possibility and importance of... fundamental edaphic deficiency has to be considered."

In Day's paper, four curves are used to exemplify different situations. The first curve is derived from yield table data for Height Quality Class I for Sitka spruce in Britain. A fairly rapid increase in rate occurs up to the "grand period" of growth which is then followed by a gradual tapering off. The second curve shows the increment rate of trees growing in sand of only moderate nutrient status, underlain by gravel which has a stream at some depth as water table. Day considers that the slow initial growth reflects the relatively poor nutrient status of the surface soil and its poor water retentive capacity. The subsequent increase in rate is thought to result from the vertical roots having reached the water table. Maintenance of a moderately good rate for many years subsequently (the trees were 80 years old at the time of examination) is considered to be attributable to trees having an adequate volume of soil for rooting and a sustained supply of water. The third curve shows growth in a moderately fertile gravelly loam overlying, at 18", a badly drained sandy clay. At first growth was good, comparable with the first curve. With increase in the size of the trees, roots entered the clay layer, it being the normal habit of Sitka spruce (and of most other tree species) to increase rooting depth with increasing size of crown and bole. This is where trouble is thought to begin. The gradual decline in increment which followed the initial good growth is thought to coincide with the entrance of roots into the fissured clay subsoil. That roots in such locations are subject to die-back is well established, whether decline originates through lack of adequate aeration or through the activity of pathogens such as the Phytophthora root rots. The maintenance of the large crown necessary for height increment to be sustained in a large tree (there being a large amount of metabolizing tissue to maintain) is con-

sidered to be dependent on the continued functioning of the deep root system. Surface soils simply do not contain large enough moisture reserves to carry large trees through periods of low rainfall when subsurface irrigation is absent.

The fourth curve shows increments in Sitka spruce planted in fertile but shallow (about 9") peat overlying badly drained sandy clay. The initial poor increment is thought to coincide with the period when root development was restricted by competition from the ground cover present when the area was afforested. Later as tree crowns closed, this vegetation was shaded out and a relatively high increment was attained reflecting the fertility of the peat layer. The subsequent catastrophic decline in growth rate is thought to follow a drought which killed the absorbing rootlets confined in the shallow peat layer because deep rooting was prevented in the underlying ill drained clay. The slight upturn in rate present in the last few years shown is likely to correspond to the regeneration of some absorbing rootlets.

Similar fluctuation in growth increment during the "grand period" are shown by Day (1953) in his paper "The growth of Sitka spruce on shallow soils in relation to root disease and windthrow." The inference is made that trees which have grown to relatively large sizes but whose roots are restricted to shallow soils are "out on a limb". When periods of drought occur, trees lacking roots in subsurface soil horizons are unable to draw on moisture reserves in the lower soil profile. Growth rates eventually decline and some trees may die.

These illustrations seem quite plausible, as do the suggestion that gum veins which occurred in eucalypts in Cyprus (1959b), and the top dying of black pine on the same Island (Day 1960) were associated with droughty sites.

Other implications in these papers are more contentious:

"Examples of soil conditions which act as foundation factors in initiating root diseases are frequently observed. The most common in Britain are provided by sites on which root disease develops of which butt-rot caused by such fungi as Fomes annosus, Sparassis crispa or Polyporus schweinitzii is a sign. Field experience shows that, although there may be some real degree of parasitism with fungi of this type, which on occasion results in the death of trees (Risbeth 1948), it is, at least in Britain, always possible to find evidence of restriction in supply of the fundamental needs of the tree for root development and maintenance..." (Day 1950, p. 312).

In response to this viewpoint, some comments by Peace on another report by Day (1951) are pertinent:

"Day is certainly putting forward a perfectly valid idea, and there is no doubt that free rooting depth is a matter of great importance, in regard to both rate of growth and health. I consider, however, that he ascribes undue influence to this one aspect of the relation of the tree to its environment..."

There are certain difficulties in explaining it (the dying of Sitka spruce) entirely on a basis of restricted rooting. Often it occurs in groups, and the groups tend to extend radially. This is more suggestive of a pathogen spreading from a central infection. Usually one or two roots die completely before any of the others are obviously affected. If the disease is due solely to inadequacy of rooting space, one would expect the root system to deteriorate as a whole. If one tree is left isolated as a result of the disease it usually fails to benefit from the increased rooting space provided by the death of its neighbours. There is no evidence that the disease is associated with underthinning, though one would expect this to be the case if rooting space were the sole cause. I would certainly not deny that rooting depth may well play a part in this disease, but I feel that the behaviour of the disease is not consistent with this as the sole explanation... It would be interesting to know how often the conditions Day associated with root disease occur in plantations where growth is reasonably rapid and the trees healthy. More investigations of healthy sites seem required before such a definite correlation of restricted rooting with ill health can be established."

Although Day in his paper on the growth of spruce on shallow soils (1953) states that:

"The examination was made to ascertain what factors other than parasitic infestations or infections were acting to cause the thinning of crowns, the death of trees, and the susceptibility to windthrow..."

and elsewhere Day (1950) refers to the action of outright parasites, one may be excused, in the face of such statements as that previously quoted (it is always possible to find evidence of restriction of supply), in concurring with Peace in thinking that Day ascribes undue influence to rooting depth. However, in response to Peace, it may be stated that it is just as possible to imagine that pathogens are spreading in weakened hosts from a central infection as it is to think that a root disease is spreading in trees which are perfectly healthy. Day (1953) refers specifically to evident thinning in the upper crown. This is suggestive of systemic debility, for if only a few roots are affected and the majority are still quite healthy, could it not be expected that the apical portion of the crown would continue activity and recession would be through a reduction in size originating in the oldest, lower portion? Peace also comments that usually one or two roots die completely before any others are obviously affected. If by "obviously affected" is meant that the remainder are not lacking a healthy complement of absorbing rootlets, then it would seem that a virulent pathogen is involved. If a vigorous tree with a full complement of absorbing rootlets suffers from a root parasite, then that parasite is pretty powerful. Such would seem to be the case with Poria weirii in coastal Douglas fir, where contact is "the kiss of death" even to a 25-year-old tree with an annual increment rate of 2 to 3 feet.

Day (1950) emphasizes that:

"It has to be remembered that space for growth of the root (systems)

is as much a need as anything else...

"Other things being satisfactory, the root (system) will remain adequately healthy when the rooting space is large enough to permit the growth in size which is normal for the species, the variations in water and oxygen supply are never unduly large and nutrient deficiencies never acute. The size of the tree is then determined, according to the species, by the amount of water and food materials available. The alternative proposition is that rooting space ceases to be adequate at some point in the development of the tree, which will, at this point, attempt to continue to grow so that it may assume the size and shape which is normal to it, considering the limiting factors... such as waterlogging or compaction will be responsible for this; then because a tree root is necessarily limited in horizontal spread and cannot compensate in that way for limitation in depth, quite apart from the inherent tendency to extend in depth, the growth of the tree will necessarily become restricted. Also because in this case, limitation of root development is obtained by cutting back of growth which is attempted, as when a root dies through having grown into soil which is frequently waterlogged, root disease... will occur."

We have then the proposition that when a tree which has been growing satisfactorily, reaches the limit of size permitted by the rooting space available on that site, root disease, that is the death of roots, whether pathogenic or non-pathogenic, will inevitably develop. When roots are pushed into horizons in which they cannot survive or roots are confined within a rooting zone which dries out, photosynthesis is reduced and the ability of roots to form protective cork layers or pitch is impaired and roots are vulnerable to pathogens. If such circumstances are severe or repeated, the tree becomes debilitated and the stage is set for infestations or infection. Day (1959) quotes the interesting case of a thinning experiment involving Sitka spruce in Nystrup (Denmark). The trees were growing in shallow sand overlaying chalky boulder clay which permitted only limited development of absorbing rootlets. Following the drought of 1947, the first treatment most severely affected by bark beetles was that which has been thinned most heavily and had shown the greatest crown and diameter development. The contention is that these trees which had been stimulated to faster growth by thinning had reached the maximum size for the site. The smaller trees of lightly thinned or unthinned stands were not yet at a size which made them as vulnerable to environmental reverses. There is in this case a similarity to the situation in some pole blight affected white pine stands. Initial rapid growth may merely speed the tree to the limit of the site's capacity, so that the bigger they are, the sooner they fall.

During the development of an even-aged stand, the dominants initially have an advantage in competition because trees in the subordinate canopies are so shaded that their photosynthesis rate is low and root development consequently is restricted. No one is surprised when suppressed trees succumb to root disease. As the crowns of dominants increase in size, a commensurate increase in the volume of absorbing rootlets must take place. Day (1957) postulates that when the limit of the site is reached, the trees

of the dominant canopy lose their competitive advantage because they are then vulnerable to any periodic fluctuation in supply. Death of some roots occurs and crown volume must be reduced to a level corresponding to conditions of minimum supply.

A further thesis, not one specifically advanced by Day, but one which seems pertinent to his view on forest hygiene, may also be advanced. It is probably more than a coincidence that many of the exotic species selected for use in north temperate forests because of their highly productive growth rates, are intolerant pioneer species. Such trees are usually quite exacting in their growth requirements: they are the emergents of stand or they fail. Sitka spruce, around which much of Day's argument centres, has tremendous growth rates given adequate soil moisture and nutrients, but as Day (1957) observed, it is overtopped and suppressed by more shade tolerant species such as hemlock and cedar when site conditions do not meet the exacting requirements of Sitka spruce. It seems possible that an inherent capacity for rapid growth is incompatible with an ability to release once the youthful stage or grand period of growth is over. Perhaps trees which have gone through this period are in a particular physiological stage of development and may to some extent be in an over extended morphological condition. Hemlock, on the other hand, is remarkable for its ability to endure suppression and subsequently to show release when the formerly dominant canopy breaks down. By release is meant the ability to form new roots and shoots after a period of slow growth brought about either by shade or other adverse environmental conditions. It is possible that the concept of vulnerability at a size dictated by the limit of rooting space applies particularly to pioneer species such as Sitka spruce, to white pine, Douglas fir or larch in the Interior Hemlock Zone (Krajina 1959), to ponderosa pine in the Interior Douglas fir Zone or to the southern pines where tolerant hardwoods are climax. Climax species, on the other hand, such as hemlock, Abies grandis, A. amabilis, A. lasiocarpa, or Douglas fir in its own zone, which seem to have the ability to gear growth rates down to virtually nothing, are possibly not as vulnerable. Additionally, longevity in climax species may also be associated with a difference in response to the activity of pathogens. In some cases it would seem that a pathogen which may affect a tolerant species merely as a butt rot (e.g., Poria weirii in red cedar) may act as a lethal root rot in an intolerant species (Douglas fir).

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THE PROBLEM OF ISOLATING AND IDENTIFYING  
ROOT DISEASE ORGANISMS

Otis C. Maloy, Jr.

Almost a century has elapsed since three of the most durable technological developments in the history of plant pathology took place in the laboratory of Robert Koch. The first was the utilization of agar as a substrate for the cultivation of microorganisms. The second was the development of the petri dish, and the third was the establishment of the 4 rules of proof for demonstrating the pathogenicity of a microbe. The application of these developments has changed very little since they were first employed although the inadequacies of standard agar media and plating methods, and the difficulty of applying Koch's postulates to root diseases have long been evident.

Root diseases of forest trees are of great consequence, but because more etiological work has been carried out on root diseases of agricultural crops, many of the examples cited in this paper have been gleaned from work with non-forest plants. One has only to peruse a check list of plant diseases to see that some common root disease organisms attack a wide range of hosts, and much of the information obtained in studies of root diseases of beans, peas, wheat, corn, potatoes, onions, and the like may have some application to root diseases of forest species.

Root diseases may be induced by a number of causes: bacteria (crown gall),

fungi (club root, various root rots, vascular wilts), nematodes (root knot), viruses (net necrosis of potatoes), and nutritional (black spot of beets). Even crop residues have been suggested as a primary cause of root rots (7). However, the great majority of the known root diseases of forest trees are caused by fungi and this paper will be concerned largely with this group of organisms.

In a study of root disease the first difficulty to overcome is that of recognizing an abnormal condition as a root disorder. Often above-ground symptoms do not develop until the roots are well decayed and at this stage saprobes predominate in the microbial population on and in infected tissue.

Examination of plant root systems constitutes a second problem. Plant roots are not easily observed in an undisturbed condition because of difficulty in separating the roots from the surrounding soil. Root observation boxes (11) have been used to study undisturbed root systems of small plants. Various root washing procedures have been employed (19,25), but no doubt many of the fine roots are lost. The use of ultrasonic equipment such as that now used in industry for cleaning electronic circuits and the like may provide a means of separating roots from soil with minimum damage to the roots. However, the study of intact tree root systems is virtually precluded because of their enormity.

Even if the roots can be exposed the isolation of a specific organism may be difficult. Some organisms are able, under certain conditions, to attack living plant roots and these are considered primary parasites. Others, called secondary parasites, invade living roots only after another agent has opened a path for invasion. In addition, the soil abounds with a variety of saprophytic microorganisms capable of invading dead or dying plant material. Often both primary and secondary parasites occur together to cause what is called a disease complex. A few organisms causing root diseases have not been cultivated on non-living media and are considered obligate parasites. The isolation of root disease and soil fungi has been reviewed recently by Warcup (30) and many specific techniques may be found in his paper.

The ease of isolation of an organism is usually directly related to its saprophytic ability and there have been cases where ease of isolation of an organism has led to erroneous conclusions. An example of this is pink root of onions caused by Pyrenochaeta terrestris. Initially a Fusarium was consistently isolated from diseased roots and considered to be the cause of the disease (29). What person working with root diseases has not been able to isolate a Fusarium from diseased roots with at least some consistency?

Microscopic examination of diseased roots may reveal a microbial population different from that determined by plating procedures. In a study of microbial associations in bean root rot (17) Thielaviopsis basicola was observed by direct examination on 15 percent of the roots examined but this fungus comprised less than 1 percent of the fungal isolates obtained from roots placed on water agar or on potato dextrose agar. In the same study, mycelium that was otherwise unidentifiable was observed microscopically in two-thirds of the roots studied. Of the fungi isolated on agar media only

three genera--Thielaviopsis, Alteraria, and Rhizoctonia--could be definitely identified by microscopic examination of the roots. These findings are in complete agreement with Garrett's statement (14) that "with the plate count method one identifies what one cannot see (i.e., in situ), whereas with the direct method one sees what one cannot identify."

While potato dextrose agar will no doubt continue to be the standby of the plant pathology laboratory, more and more selective media are coming into use. These can be classified into 2 groups and are used alone or in combination. The first includes "baits" which are organic substrates favoring the development of one or only a few organisms. Apples (6), lemons (16), and avocados (32) have been used to trap various Phytophthora species; Thielaviopsis basicola can be isolated without difficulty on carrot disks (31); and Rhizoctonia solani was isolated easily from buckwheat stems buried in infested soil (23). Rishbeth (26) employed freshly cut pine stems to detect the presence of Fomes annosus and Peniophora gigantea. Fleshy roots have been used to detect the crown gall bacterium, Agrobacterium tumefaciens, and the hairy root bacterium, Agrobacterium rhizogenes (1, 2).

The second group of selective media are those to which a material has been added which inhibits the growth of organisms other than the one being sought. Russell (27) isolated Fomes annosus on malt extract agar containing O-phenyl-phenol and a medium containing ethyl alcohol has been used to isolate Verticillium from the soil (21). Many microbial metabolic products, primarily antibiotics, have been used to prepare semi-selective media. Parmeter and Hood (24) recently reported that cultural filtrates of a specific organism will enhance the isolation of that organism when added to a medium.

Even though the isolation of a specific root disease organism is possible, we are still faced with the question, "Are pure cultures of organisms desirable in studying the etiology of root diseases?" Fawcett (12) thought not and advanced the argument that pathologists should do more work with mixtures of organisms. More and more evidence is accumulating that combinations of bacteria, fungi and nematodes are responsible for various soil-borne diseases. One of the members of the complex no doubt usually precedes the others and should be considered the primary pathogen even though the complete symptom picture does not develop as a result of inoculation with this organism alone. Therefore, Koch's postulates are not satisfied, if only a single organism is employed.

Once an organism is isolated in pure culture and its pathogenicity demonstrated there remains the problem of correctly identifying the organism. Identification of obligate parasites obviously must be by direct examination, but for non-obligate parasites not producing fruiting structures on their normal substrata, identification is usually based on the morphologic structures produced in culture. Many root disease fungi, especially basidiomycetes, when cultivated on agar media produce only conidial stages or sterile mycelium. Terms such as Mycelia Sterilia, Mycelium radialis atrovirens, vesicular arbuscular endophytes, unidentified mycelium, brown sterile mycelium, and so forth (15) are frequently employed to describe sterile cultures.

Several methods have been described for producing sporophores of basidiomycetes. These are all basically the same and employ a sterile wood substrate supplied with a nutrient medium and held in a moist atmosphere (4). Snyder and Hansen (28) have also stressed the importance of natural media and environmental conditions for the production of fruiting structures of certain deuteromycetes.

Identification of pathogenic fungi may be considered from two points of view: the morphologic and the physiologic. Morphological characteristics that are easily recognized, well-defined, and not subject to pronounced change due to environment or genetic variation have preference but often the pathologist is dealing with either the conidial or sterile stage of a fungus. These stages frequently are difficult to categorize on accepted morphologic features. Then identification is usually based on the host species attacked.

Several physiological approaches, such as nutritional or substrate grouping (3, 13), inhibitory effects of chemicals (9), serology (8), hyphal fusion (5), and interfertility or sterility (20), have been tried but these techniques usually have not provided the consistent results required for acceptance. However, these procedures do in some instances provide valuable supplements in the cultural identification of fungi.

In the absence of sporophores, keys such as those prepared by Davidson, et al (10) and Nobles (22) are invaluable tools for identifying fungi in culture. Certain fungi have specific identifying features such as the oedocephaloid conidiophores of Fomes annosus, the rhizomorphs of Armillaria mellea and some other root disease fungi, and the sclerotia of Sclerotium rolfsii, Rhizoctonia solani, and Phymatotrichum omnivorum.

Despite these difficulties a name can usually be found for the fungus in question, but the problems of validity, acceptance and synonymy remain. The genus Fusarium exemplifies this problem. American pathologists use Wollenweber and Reinking's system. The same is true for some higher fungi, for example, most species referred to as Agaricus in America are placed in Psalliota in Europe.

The connection between the imperfect stage of a fungus and the perfect stage also may be a source of confusion. Again the form genus Fusarium is an example. Four ascomycetous genera, Hypomyces, Gibberella, Nectria and Calonectria, represent perfect stages of various Fusaria. Species of the form genus Rhizoctonia may fall into two basidiomycetous genera, Pellicularia and Helicobasidium. Some, such as Rhizoctonia bataticola, produce a pycnidial stage which in this case has the name Macrophomina phaseoli.

Similarity of names may lead to confusion. This is demonstrated by the incorrect interchangeable use of the names of the imperfect fungus, Thielaviopsis basicola, and the ascomycete, Thielavia basicola. Although there is no genetic relationship between these two fungi, there frequently is a biological relationship. They are commonly associated in nature and it has been shown that cultural extracts of Thielaviopsis will stimulate cleistothecial production by Thielavia (18).

Host specificity raises another question in regard to identifying root disease fungi. Should the different host isolates of fungi with wide host ranges, such as Armillaria mellea, Phymatotrichum omnivorum, Verticillium albo-atrum, and so on, be considered identical or do they differ sufficiently in their physiology, i.e., in their ability to attack different species, to be differentiated from one another at the sub-species level? More cross inoculation studies will have to be conducted to answer these questions.

The problem of isolating and identifying root disease organisms actually consists of a series of problems which can be summarized as follows:

- (1) Recognizing and associating foliar symptoms with root disorders.
- (2) Exposing root systems for examination and isolation.
- (3) Isolating a primary pathogen.
- (4) Proving the pathogenicity of that organism.
- (5) Determining the role of mixtures of organisms in the etiology of root diseases.
- (6) Identifying, in culture, the organism isolated.
- (7) Producing fruiting structures of the fungus isolated to aid in its identification.
- (8) Avoiding the pitfalls surrounding synonymy, validity, and similarity of names.
- (9) Determining the host specificity of an organism.

Perhaps the greatest need for future work on root disease fungi lies in the development of specific trapping techniques for the various fungi involved and the construction of keys based on those characteristics, both morphologic and physiologic, exhibited in culture.

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APPENDIX I

ACTIVE PROJECTS - NEW

(Project leaders' affiliations and addresses are given in the membership List, Appendix (VIII))

D. Root and Soil Diseases or Relationships

61-D-1 Nursery and reforestation diseases (Robert V. Bega and R. S. Smith)

Objective: To determine field survival of sugar pine and Douglas-fir grown in nursery beds fumigated with different chemicals.

61-D-2 Fomes annosus (Robert V. Bega and R. S. Smith)

Objective: To determine efficacy of soil fumigation as a control measure in high value areas. To develop reliable inoculation techniques. To study the genetic variability of the fungus.

61-D-3 Soil microbiology with special reference to forest and nursery root diseases (K. C. Lu).

Objective: To determine the kinds and numbers of micro-organisms present in the soil under various conditions, and the relationship between these micro-organisms and root pathogens.

F. Stem Diseases- Malformations, witches' brooms dwarfmistletoe, etc.

61-F-1 Eradication and thinning studies for dwarfmistletoe control in infected stands of western larch, Douglas-fir, and lodgepole pine (E. F. Wicker)

Objectives: To investigate the effects of direct eradication, and silvicultural operations for dwarfmistletoe control, on impact of tree growth, and intensification and spread of the pathogens.

G. Stem Diseases-Stains and Decays

61-G-1 Growth characteristics of heart rots (Lee A. Paine)

Objectives: To investigate the growth rate and other characteristics of isolates of Fomes pini from Douglas-fir and white fir on the same site. Growth characteristics will be compared over the temperature range of 14.5° to 28.5° C. over a period of 60 days.

61-G-2 Decay of hemlock in the Kitwanga Area of British Columbia. (J. E. Browne)

61-G-3 Study of decay in commercial conifers of the western white pine type (O. K. Miller)

Objectives: (1) To identify the causal fungi of major importance and determine their relative importance; (2) To determine the external indicators of decay, and to assess their value in estimating cull in standing trees.

61-G-4 The Indian-Paint Fungus in Northern Idaho (Arthur D. Partridge)

Objectives: The principal objective is to study this fungus and its effects under various physical and physiological conditions. An attempt has been made to interrelate laboratory and field work to facilitate fulfilling this objective. Lesser objectives include mapping the occurrence and intensity of decay, correlating indications with cull, and finding corrective management practices.

#### H. Stem Diseases- Rusts and Cankers

61-H-1 Streamlining pollination and progeny-test methods in breeding for blister rust resistance in western white pine (R. T. Bingham)

Objectives: To test the efficacy and reliability of four-tree pollen mixes and ten-tree pollen mixes used in topcross tests for detecting general combining ability for rust resistance vs. that of our standard top-cross test involving four single-crosses with individual test-tree pollens. Controlled pollination and progeny test work and costs can be cut to one-third if individual tree incompatibilities, pollen germination differences, etc., do not interfere with mixed-pollen tests.

61-H-2 Breeding and selection for climatic adaptation in interspecies hybrids, toward accumulation of a pool of rust-resistance genes from other white pines of the world (R. T. Bingham)

Objectives: As some insurance against development of new physiologic races of the blister rust fungus, to accumulate a reservoir of resistance genes in the form of locally-adapted interspecies hybrids which, if needed, will be ready for immediate use.

61-H-3 Life cycle of spruce broom rust (R. S. Peterson)

Objective: To examine aspects such as cross-fertilization by insects, infection requirements, incubation period, mycelial extent.

#### K. Miscellaneous Studies.

61-K-1 Physiological action of antibiotics in tree disease control (E. A. Schwingamer)

**Objectives:** This project is still in the analysis stage and studies have not yet been set up. The over-all objective is to make basic studies the results of which will be useful in developing antibiotic control of various tree diseases.

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## APPENDIX II

### TERMINATED PROJECTS

54-D-1 Survey of Phytophthora lateralis. (John Hunt)

57-F-9 Comparative anatomical study of conducting tissue of Arceuthobium-infected and noninfected conifers (PSW Forest and Range Expt. Stn. contract research with Univ. of Calif. at Davis--L. Srivastava and Dr. Katherine Esau).

Publication: Relation of dwarfmistletoe (Arceuthobium) to the xylem tissue of conifers. I. Anatomy of parasite sinkers and their connection with host xylem. Amer. J. Bot. 48(2): 159-167. II. Effect of the parasite on the xylem anatomy of the host. Amer. J. Bot. 48 (3): 209-215.

57-G-5 Temperature-growth rates of Echinodontium tinctorium in vitro (L. A. Paine).

Publication: Growth studies of regional isolates of Echinodontium tinctorium, the Indian paint fungus (Lee A. Paine and William G. O'Regan). Accepted for publication by the Canadian Journal of Botany.

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## APPENDIX III

### NEW OR MODIFIED TECHNIQUES

#### THE USE OF THERMOCOUPLES FOR THE DETERMINATION OF WOOD TEMPERATURES

A. A. Loman

Thirty-gauge copper-constantan thermocouple wires connected with a potentiometer were used to measure interior temperatures of lodgepole pine logging residue at various levels. The thermocouple wires were placed in the wood and remained there for the duration of the temperature determinations. The manner of inserting thermocouple wires to predetermined levels within the wood was a modification of methods proposed by Russel Eggerts (Jour. Agr. Res. 72(11) June 1946). The potentiometer with a 2.5 feet 24-gauge copper-constantan lead wire could be carried from place to place.

Holes were drilled into the wood with a 5/16 inch wood auger bit into

which 1/4 inch polyethylene tubing could be inserted. The polyethylene tubing was cut in predetermined lengths, and holes were cut in its wall at known distances from one end. A thermocouple wire was inserted through each of the holes and threaded to one end of the tube, where they were carefully labelled. Three inches of thermocouple wire were allowed to protrude from the hole to eliminate thermal conduction to or from the "hot junction", the cotton sleeving was removed, and the insulating material was carefully scraped off with a knife. The copper and constantan wires were tightly wound together. This portion was then wound in a groove cut around the tube and coated with "seal all" to keep the wires in place.

The ends of the thermocouples were prepared for connection with the lead wires as follows: one inch of cotton sleeving was removed from the ends, and approximately 1/3 inch of insulating material was scraped off the wires which were separated by blocks of wood measuring 3/4 by 1/2 by 1/8 inches.

The lead wire ends were attached to a clothespin in such a way that a firm connection could be obtained between the copper and between the constantan components of both lead and thermocouple wires.

#### ELECTRICAL APPARATUS FOR DETERMINING INJURY AND DEATH IN TISSUES(C.A. Greenham)

The apparatus demonstrated comprises a wide-range A.C. bridge, operating at 1 Kc/s ("Low Frequency"), 10 Kc/s, and 1 Mc/s ("High Frequency"). The apparatus measures the plant tissue in terms of Resistance and Capacity in parallel. It is usually convenient to make contact with the tissue to be measured by means of needle tips.

Often a tissue may be characterized solely in terms of resistance measurements, particularly  $R_{LF}$  (resistance at 1 Kc/S). Living tissue has a high value for  $R_{LF}$ . Usually  $R_{LF}$  decreases with increasing injury, though it may increase if the tissue loses water or electrolytes. On the other hand  $R_{HF}$  is low in living tissue, and approaches the value for  $R_{LF}$  with increasing injury. At death  $R_{HF} = R_{LF}$ , though the ration  $R_{LF}/R_{HF}$  at death can be between 1.1 to say 1.6 when metallic needle tips are used.

Some research applications of the instrument are:

1. Determining the lowest point of dead tissue in the roots of sprayed plants, in terms of both  $R_{LF}$  and  $R_{LF}/R_{HF}$ .
2. Determining the response of the potato tuber on invasion by a "virulent" and "avirulent" strain of Phytophthora infestans (here the reciprocal of  $R_{LF}$  was used).
3. Diagnosing the presence of blackheart in intact pineapples, in terms of  $R_{LF}/R_{HF}$  (unpublished work in collaboration with the Queensland Department of Agriculture).
4. Discriminating between healthy and virus-infected clones of potatoes (here both resistance and capacity measurements were used at 10 Kc/s).
5. Determining cold-hardiness of ecotypes of alfalfa and white clover.

6. Studying the inheritance of cold hardiness in alfalfa.

Further details of the instrument and of published papers describing the investigations above will be found in the following:

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APPENDIX IV

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APPENDIX V

MINUTES OF THE BUSINESS MEETING

The business meeting was called to order by Chairman Hawksworth at 3:06 p.m., October 5, 1961.

Secretaries' report. Jim Kimney moved that the minutes of the previous meeting, as written in the "Proceedings of the Eighth WIFOWC, be approved. The motion was seconded by Keith Shea and passed by voice vote.

Treasurers' report. The Secretary-Treasurer gave the following report:

	<u>Credits</u>	<u>Debits</u>
Balance from 1960	\$ 36.06	
Interest	.27	
Receipts		
Canadian money	241.00	
U. S. money	200.00	
Exchange at 2 3/8%	4.60	
Banquet (with trimmings)		\$353.00
Receipt book and name tags		9.75
Bus rental for field trip		50.00
Coffee		3.00
Expenses of Dr. Grace		17.00
	<u>\$481.93</u>	<u>\$432.75</u>
Balance on hand	\$ 49.18	

Harold Offord moved that the report be accepted. Acceptance was approved by voice vote.

Report of the Interim Program Chairman. The Interim Program Chairman, Don Graham, read the report included in Appendix VI. Chairman Hawksworth congratulated the Interim Program Chairman on a job well done.

Mistletoe Committee report. The report of the Mistletoe Committee (Appendix VII), having been given to the members at the beginning of the conference, was approved without discussion. Committee chairman Shea pointed out that the chairmanship of the Mistletoe Committee was due for rotation. He forthwith appointed Frank Hawksworth as new chairman.

Old business. The 9 policy amendments introduced at Centralia were re-introduced for consideration. The Chairman indicated that the members had elected by letter ballot to consider the motions in open session at the Banff meeting. Brief discussion of the value of these motions in preventing undesirable expansion and the possible detrimental effects they might have in creating an overly formal and inflexible "constitution" followed. Art Parker then moved that the motions be tabled. The motion to table was seconded by several members and carried by voice vote.

New business. Keith Shea asked if Lake Gill's 1955 report on chemical control of dwarfmistletoes should be brought up to date? Some members felt that revision was unnecessary; others suggested inclusion of antibiotics tested on any disease, or the inclusion of all chemicals

and antibiotics tested on all diseases. Following the general discussion, C. Gordon moved that the Chairman appoint one of the members to compile a list of chemicals and antibiotics that have been tested on any forest disease within the W.I.F.D.W.C. area- this list, with brief indication of results of the tests, to be included in the Proceedings. Childs seconded the motion and it was carried by voice vote.

Selection of site for the Tenth W.I.D.W.C.- Art Parker invited the group to meet at Victoria. Paul Keener extended an invitation to meet in Tuscon. Harold Offord made the annual invitation to meet in Berkeley, stressing the numerous advantages and pleasures that would accrue to the membership by holding the meetings in the magnificent and always exciting state of California. Shea moved that the invitations be closed. The motion was seconded by Miller. No vote was taken and no further invitations were extended. Wallis mentioned that Tuscon and Berkeley were considered to be fringe areas. The chair called for a show of hands. Victoria was chosen over Tuscon by an impressive margin and over Berkeley by a ridiculous landslide.

A brief discussion of the meeting date followed. The general trend of opinion, as sensed by the Secretary, was that a meeting soon after the close of the field season was preferable to a later meeting.

#### Election of Officers.

Chairman: Dick Parmeter was nominated by Wallis. While the Secretary was trying to object, the nominations were closed and Parmeter was elected.

Secretary-Treasurer: Gardner Shaw was nominated by Parker. Offord moved that the nominations be closed. The "aye" votes obscured Childs' second of the motion.

Historian: Nominations were opened for the new office of Historian. Ray Foster was nominated by Roff. With customary celerity, a move by Miller to close the nominations, second by Shea, and a unanimous voice vote in the affirmative were made simultaneously.

Adjournment: The meeting was adjourned by tacit agreement at 4:16p.m.

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## APPENDIX VI

### SUMMARY OF SUGGESTIONS FOR CONSIDERATION BY 1962 PROGRAM COMMITTEE

1. Nursery diseases, soil fungi, soil fumigation. Effects of continuous use of chemicals on same sites (nurseries).
2. Pathological problems in natural regeneration and plantations. Need to follow the tree beyond nursery.
3. Thorough and complete treatment of mycorrhiza.
4. Use and progress of antibiotics and other systemic materials in control of forest diseases.
5. Physiology of parasitism of diseases. Predisposal of trees by physio-

logical factors (or other factors) before an infectious disease can become established.

6. Treatment of problems involved and pitfalls to avoid in measuring growth impact of forest diseases (especially dfm.).
7. A session on how we can get better cooperation between personnel working on same or related projects. Also needless repetition. Importance of two workers getting together in early planning stage.
8. Air pollution and atmospheric conditions, what is known and chances for increases in problems of this nature in the future.
9. Methods and techniques of culturing, isolation inoculation that are not in the "book". Also such things as handling of diseased material, disease herbariums, field plot techniques and collection of field data.
10. Special methods and techniques of decay studies and successional studies of the rots and decays.
11. Part of program should be planned around meeting place.
12. Elytroderma studies (anatomical picture).
13. Specific treatment of rust diseases.
14. Need for bringing in specialists from outside (physiologist, ecologist, etc.) whenever appropriate.
15. Recent findings in morphology of certain species of fungi that may affect taxonomical classification.
16. New developments and problems in root diseases. (well covered at 1961 meeting)
17. Less "piece meal" treatment of a broad subject. Discuss a specific part of a broad subject and bleed that part dry.
18. More emphasis on: how what we know can be applied to some degrees of control even then we don't have the final answer.
19. Ecological factors in relation to disease occurrence, incidence and in prediction of chances of a lethal disease becoming established.
20. A panel suggested on:  
What is the most important tree disease in Western North America? Why? What research has been done and/or is being done? What is possibility of control.
21. Current work on and recent developments:
  - a. A mellea
  - b. Echinodontium tinctorium
  - c. Elytroderma

- d. Rust diseases
- e. Root rots

22. Culture media:  
stimulators and inhibitors

23. The most frequent answer I received was :  
Well, gee whiz, I haven't really given it much thought.

Many individuals talked in generalities so a great deal of reading between the lines is needed.

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#### APPENDIX VII

#### COMMITTEE REPORT ON STATUS AND NEEDS OF RESEARCH ON DWARFMISTLETOES.

J. E. BIER,<sup>1</sup> F. G. HAWKSWORTH, J. R. PARMETER,

and K. R. SHEA (Chairman).

#### Highlights of 1961 Research

##### I. Intensification and Spread.

- a. Fifty-four previously known areas of dwarfmistletoe infection on lodgepole pine were investigated to determine their extent and the intensity of infection. The survey showed that 61 per cent were heavily infected, and that 85 per cent of these were stands less than 80 years had peculiar stand histories which explained the early development of heavy infection. The estimated area of these 54 stands is 43 square miles. (Baranyay, Calgary.)
- b. Two experimental flights were made to determine the effectiveness of aircraft in mistletoe surveys. In lodgepole pine stands approximately 80 years of age, witches' brooms were visible from 300-500 feet above ground. In stands over 100 years old the more severe brooming was visible from as high as 600-800 feet. In jack pine stands where brooms are more evident, infected areas were readily visible from heights of 800-1000 feet. During this last flight an infected area, approximately 65 miles long and 8 miles wide, was found in northeastern Alberta.

The results showed that aerial surveys are suitable at elevations up to 1000 feet for the detection of heavily infected old stands or groups of trees, but are unlikely to be effective for infected young stands. (Baranyay, Calgary.)

- c. Field work was completed on the study of losses resulting from

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1. J. A. Baranyay kindly substituted for Dr. Bier in preparing this report.

growth reduction and mortality in lodgepole pine stands infected by dwarfmistletoe. Results have not been completely analyzed (Baranyay, Calgary.)

- d. Canker dissection studies on red fir and white fir were initiated in 1961. Preliminary results indicate that the year of infection, the age of wood at time of infection, the age of cankers, and the pattern of infection can be determined within reasonable limits. These data permit partial reconstruction of the infection history of trees growing under various conditions. (Parmeter, Univ. of Calif., Berkeley, and Scharf, PSW)
- e. Continued studies on deposition and retention of seeds on red firs and white firs suggested that retention of seeds in exposed areas was less than that on trees under sheltered circumstances. (Scharpf, PSW, and Parmeter, Univ. of Calif., Berkeley)
- f. Field work was completed on a cooperative study between the Rocky Mountain and Intermountain Stations to determine (1) the distance of spread and degree of infection in lodgepole pine reproduction from infected border stands and from infected individual trees or groups of overstory trees and (2) the minimum age at which lodgepole reproduction will become infected. Data and samples were taken on 40 study areas in the Rocky Mountain Station territory and on 39 study areas in the Intermountain Station territory. The results suggest that mistletoe behavior in the two regions is very similar. The average proportion of trees visibly infected in stands 5, 10, 15, 20 and 25 years old was 0, 1, 6, 17 and 33 per cent, respectively. The average maximum distance of infection into reproduction was 26 feet from the infected residual stand. Dissections of the oldest infections on the plots showed that 14 per cent of the stands were infected before they were 4 years old and 85 percent were infected before the stands were 11 years old. (Graham INT and Hawksworth RM).
- g. Re-examinations were made on the permanent ponderosa pine dwarfmistletoe silvicultural control plots at Grand Canyon and Fort Valley Experimental Forests, Arizona and on the Mescalero Apache Reservation, New Mexico. (Lightle RM).
- h. Data have been obtained on the effects of dwarfmistletoe on growth and Mortality in 29 Colorado lodgepole pine stands ranging from 50 to 150 years old. The following tabulation shows the per cent reduction in stands infected for various lengths of time:

	Length of Time Infected (Years)		
	<u>20</u>	<u>40</u>	<u>60</u>
Height of dominants and codominants	14	28	42
D.B.H. of dominants and codominants	14	28	42
Merchantable cubic-foot volume	26	74	100

Thus, in stands infected for 60 years the height and D. B. H. of the dominants and codominants were 42 per cent less than that in nearby uninfected stands. Growth reduction and mortality due to mistletoe had reduced the merchantable volume to zero. (Hawksworth and Hinds RM).

- i. Data from a 1/50-acre, temporary plot in a 60-year-old stand are summarized in the PNW 1960 Annual Report. Both average number of infections per tree and percentage of trees infected increased more rapidly in the larger trees-- those ordinarily constitute the future crop. Additional plots are planned. (Childs- PNW).

## II. Biological and Chemical Control.

- a. Greenhouse trials have provided 4 promising selective herbicides (2 each for ponderosa pine and Douglas-fir) for field testing. Dormant and late summer field applications were made to the tree bole and foliage, and to mistletoe shoots on ponderosa pine and to the bole and foliage of Douglas-fir. Systemic properties were demonstrated in Douglas-fir, but not in pine. Results to date in the greenhouse and field indicate these materials have considerable promise. (Shea and Rediske, Weyerhaeuser Co.)

- b. The 1959 herbicide tests on dwarfmistletoe in California look much the same as they did a year ago. (See Eighth Proceedings, 1960, p. 96). Many of the sprayed dwarfmistletoe plants are still "dead". Very few trees were killed, but few, if any, sizable trees were cleaned of all dwarfmistletoe without severe damage to the trees. (Quick, PSW).

- c. Concentrations of herbicides in the 1960 tests (100 tests, 893 trees) in general were increased. (None of the 1959 tests were notably successful as systemic treatments). A good many of the trees treated in 1960 were damaged or killed. It now appears that the margin of safety between destruction of the parasite and severe damage to the host (pines and firs) is too narrow, in the case of basal-stem treatment with the 2,4-phenoxy compounds, to be usable. The same appears to be true also of MCPA. (Quick, PSW)

- d. In 1961, 39 tests (496) trees were initiated with a variety of herbicidal chemicals. (Tests with 2,4,5-TA, 2,4,5-TP, and 2,4,5-TB were emphasized. The diluent carrier in most cases was stove oil; in one set of tests it was water with added agricultural spray oil. Some of each test batch was sprayed directly on dwarfmistletoe plants, and some was used as basal-stem spray of infested trees. One test area each was located on the Sierra National Forest, the Stanislaus National Forest, and the Lassen National Forest. (Quick, PSW)

- e. Widespread dying of the dwarfmistletoe on digger pine on Mt. Diablo State Park, California, was noticed in the summer of 1961. Buds and shoots in all stages of development were killed. Extensive necrosis of the endophytic system was observed in some in-

fections. No apparent damage of the host tissue was observed. Pronounced resin flow generally occurred from around the base of the shoots of the parasite. Infected dwarfmistletoe plants will be checked for recovery. No causal organism has been associated with the disease. Symptoms suggest it may be caused by a fungus similar to that which causes the resin disease of A. americanum, (Scharpf, PSW, and Parmeter, UC, Berkeley)

- f. Lodgepole pines infected with Arceuthobium americanum were treated (stem injections) with antifungal antibiotics. No results at this time. (Mielke, INT).

### III. Silvicultural Control.

- a. Re-examinations of silvicultural control plots reported in 1957 have shown gradual reduction in stem and branch infections following yearly treatments. Some latent infections have appeared 4 years after treatment. Three-year diameter increment on thinned and treated plots has been over twice as great as that of trees in unthinned check plots (Shea, Weyerhaeuser).

### IV. Host- Parasite Relations.

- a. The study of the effects of dwarfmistletoe on the water economy of western hemlock was completed. No significant differences were found either between samples with or without aerial plants, or between samples taken from branches above and below the infections. Dwarfmistletoe did not affect the water economy of those portions of branches that had not been invaded by the endophytic system. The relative turgidities of bark within the swollen portion of infected branches showed significant variation. The moisture content of the bark was higher at both tips of the swellings than in the bark of the uninvaded portions of each branch. The moisture content was lowest in the middle of the infected area which is the oldest infected portion of the swelling. A similar pattern was found on young (8 years-old) and old (15 years-old) branch infections although the turgidity values of young infections were above the critical 80 per cent. According to Bier's findings these results indicate that branches with older infections would be more predisposed to fungus infections than branches with young infections. (Baranyay, Calgary).
- b. Canker dissection studies on red firs and white firs indicated that cankers were quite variable. Those cankers that developed on small branchlets remained "midgets" that seldom attained an inch in length. Such cankers were never found with more than a few fruits. Thus these "midget" cankers appeared to contribute little to either damage or spread. Larger cankers developed on main branch axes or on the bole. These cankers supported large clumps of fruiting shoots. Preliminary observations suggested that long-lived cankers developed near branch bases after branches were several years old. (Parmeter, Univ. of Calif., Berkeley, and Scharpf, PSW).

- c. Inoculation studies confirmed the existence of two forms on fir, one restricted to red fir and one to white fir. Preliminary observations suggest that the form attacking ponderosa pine is distinct from that attacking digger pine. (Parmeter, Univ. of Calif., Berkeley, and Scharpf, PSW).
- d. A study of the extension of the endophytic system of the dwarfmistletoes on digger pine has shown that: (1) the longitudinal extension of the system can be determined quite accurately by measuring the length of branch swelling; (2) the system extends about the same in both directions; (3) annual extension varied considerably among infections; (4) the systems showed nearly the same amount of extension during the dormant season (October-March) as they did during the period of active host growth (April-September). (Scharpf, PSW, and Parmeter, Univ. of California, Berkeley)
- e. Results of seeding tests made in 1935 with Arceuthobium campylopodum on ponderosa and Jeffrey pine in northern California have recently been compiled and analyzed. No direct relationship was found between the amount of estimated light received and the growth vigor of shoots of dwarfmistletoe on ponderosa pine nor between light received and the establishment of new infections of the parasite. The results suggest that the effects of light on dwarfmistletoe need reassessment. (Wagener, PSW).
- f. The results of translocation studies of natural substances may be summarized as follows: (1) labeled materials did not translocate into infected branches (except at the commencement of growth in the late spring), unless the fir needles were first removed from the portion of the "translocate" went into the mistletoe. (2) Covering the aerial system with aluminum foil or removing it entirely did not influence the translocation of materials into the endophytic system. (3) Although the intensity of translocation varied at different times of the year, the pattern was not markedly different. The endophytic system was a "sink" at all times, while the aerial system of the mistletoe was a strong sink only during the active growing season (June and August treatments) and not during October, January, and May. (4) The mistletoe was a sink even when the fir branch was detached from the host or if it was girdled. The results as explained were obtained from autoradiographs. However, actual activity in various sections have been determined and support all conclusions drawn from the autoradiographs.

Individual shoots of the dwarfmistletoe were found to carry on photosynthesis. Carbon fixation was 4 to 20 times greater in the light than it was in the dark. However, food manufacture by the mistletoe represents only a very small part of its need, or use.

The above results were obtained with the dwarfmistletoe (Arceuthobium campylopodum) on white fir (Abies concolor) on an Experimental Forest of the Pacific Southwest Forest and Range Experiment Station, Strawberry, Tuolumne County, California. The work has been expanded to include a survey of translocation relationships on

several other species of conifers having the same species of dwarfmistletoe; also, A. americanum on lodgepole pine, to have a comparison of this work with that which has already been conducted by Dr. Shea and Dr. Rediske, conducted under controlled conditions. Further, several species of Phorodendron have been studied growing on conifers and walnut and oak. No results on these other species are available at present, except for the results appreciable transfer of food materials between host and parasite in this case; this is in marked contrast with the results with Arceuthobium. Whether this observation will be supported by the other work remains to be determined. (O. A. Leonard, R. J. Hull and C. G. Greenham, Botany Dept., Univ., Calif., Davis).

A few preliminary analyses of data from the impact study were made. Results to date suggest that mistletoe doesn't have much effect in densely overstocked stands, probably because competition does not permit mistletoe to assert and effect. Additional permanent plots to yield data on mistletoe effects on growth are continuing to be established. (Childs-PNW).

Results on the mature-stand study are summarized in the PNW 1960 annual report. Mortality is greatly increased by moderate to severe infections. Uninfected trees on infected plots were the same height as trees of the same diameter on uninfected plots, but were highly significantly taller than their infected neighbors. (Childs-PNW).

#### V. Life History, Taxonomy, and Morphology.

- a. Removal of germinated seeds of the red fir form of dwarfmistletoe from host branches at regular intervals showed that infection may take place as early as August of the year following seed dispersal, or approximately 6 months after germinations. These tests were repeated in the greenhouse with the dwarfmistletoe on digger pine. Similar results were obtained. (Scharpf, PSW, and Parmeter, Univ. of Calif., Berkeley).
- b. Field observations have shown that the period and duration of flowering and seed dispersal vary considerably among the several forms of A. campylopodum. The high altitude forms are the first to flower and disseminate seed but are shorter in the duration of these processes. Low altitude forms have a longer growing season and have a later and longer period of flowering and seed discharge. Due to the different periods of flowering, it is possible that cross pollination may not occur among most forms of A. campylopodum. (Scharpf, PSW, and Parmeter, Univ. of Calif., Berkeley).
- c. Studies were completed on the relation of dwarfmistletoe to the xylem tissue of conifers including (1) the anatomy of parasite sinkers and their connection with host xylem and (2) the effect of the parasite on the xylem anatomy of the host. Changes in the xylem anatomy induced by dwarfmistletoe infection were studied in

seven coniferous species of California. (Srivastava and Esau, Univ. of Calif., Davis).

Needed Research and Studies not yet Reported on.

I. Intensification and spread:

- a. Possible use of aerial photography in detecting lodgepole pine dwarfmistletoe.

Objectives: (1) to explore whether aerial photography will enable the detection of infected areas, define the limits of infected areas and differentiate between different degrees of damage, (2) to explore the suitable scale at which to take photographs and type of film.

Literature references indicate that air photos taken to proper specifications and at suitable times of the year will permit the differentiation of diseased and healthy trees or group of trees. To aid in the development of techniques for taking such photographs, it is possible that spectrophotometric analyses of light reflection from specimens of diseased and healthy trees would prove useful in predicting the photographic tones or colour that would have to be registered. (Baranyay, Calgary).

- b. A plot study of the effects of various degrees of dwarfmistletoe eradication combined with various degrees of silvicultural thinnings on the intensification, spread, and adverse tree growth impact in a mixed stand of western larch, Douglas-fir, and lodgepole pine is in the planning stage. Study will be established in June-July, 1962. (Wicker, INT).

II. Biological and chemical control.  
(no reports).

III. Silvicultural Control  
(no reports).

IV. Host-Parasite Relations  
(no reports).

V. Life History, Taxonomy, and Morphology.

- a. Research is needed to establish the influence of environmental factors on seed development of A. americanum. Field observations in Alberta indicate large variations in the number of mature seed produced in different areas. (Nighswander, Calgary).
- b. We are concerned at the moment mainly with obtaining suitable collections and developing techniques for future cytological studies. One of the initial problems that has arisen has been contamination in germinating seed. This has been largely overcome in initial tests through the use of 0.5 and 1.0 per cent Orthocide captan

and with Ceresan. The procedure has been to soak the seed in distilled water for one hour, followed by immersion in the fungicide for one hour, followed by a rinse in distilled water for five minutes, and followed by planting in PDA at normal room temperatures. Further tests are planned this fall. (Foster, Victoria).

9/28/61