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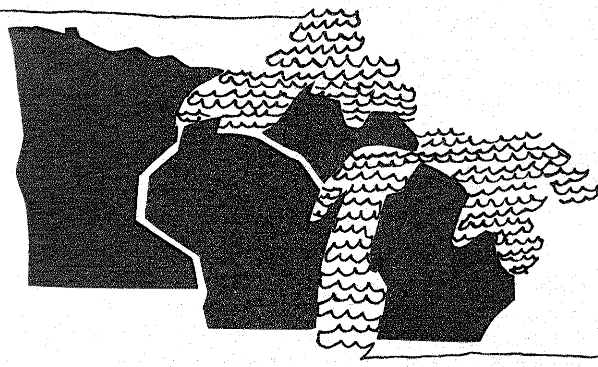
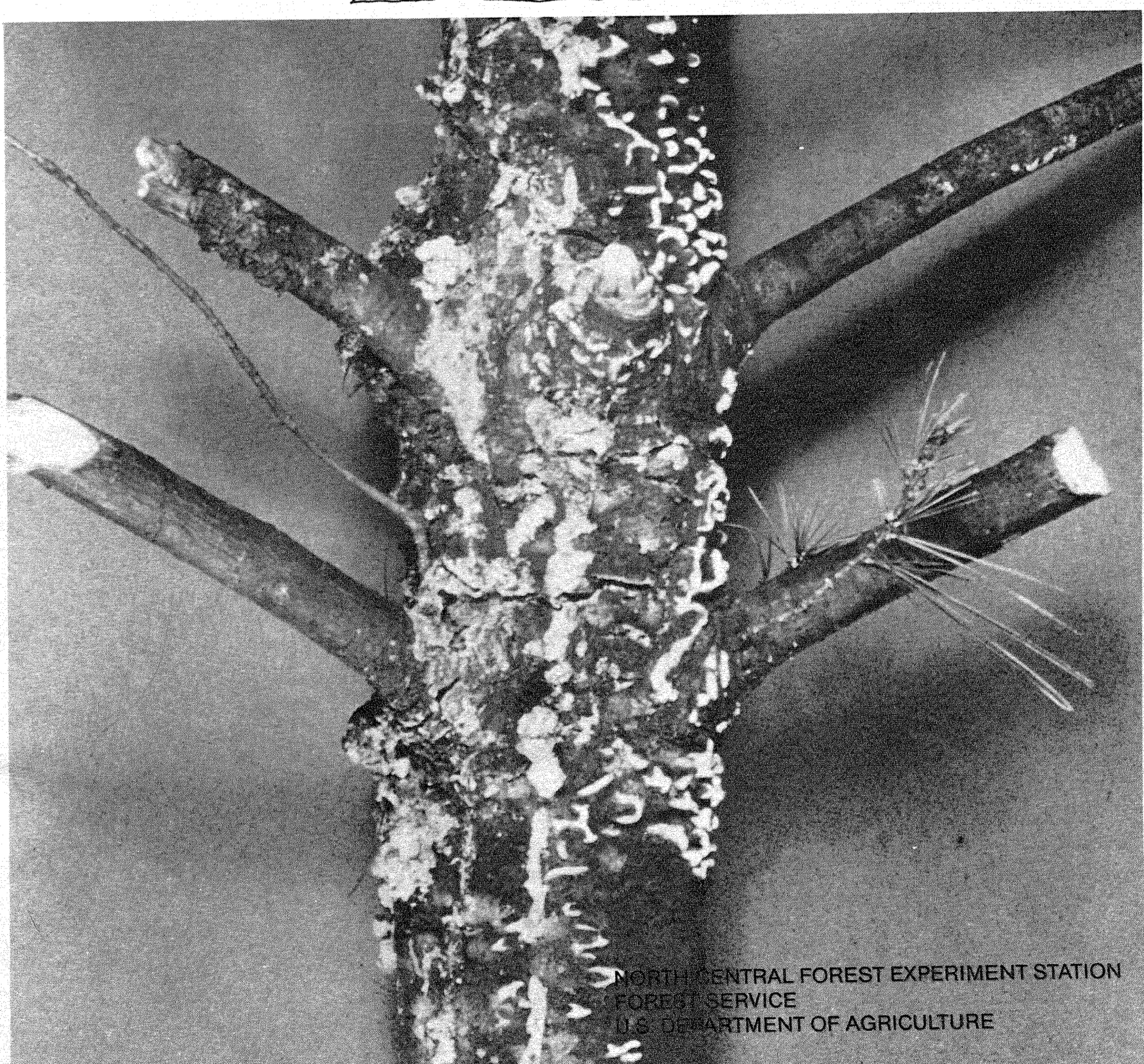


"A SUMMARY OF WHITE PINE BLISTER RUST RESEARCH IN THE LAKE STATES"

RALPH L. ANDERSON



NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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A SUMMARY OF WHITE PINE BLISTER RUST RESEARCH IN THE LAKE STATES

Ralph L. Anderson

For several decades the term "white pine blister rust control" was essentially synonymous with the term "ribes eradication." During that period ribes eradication was a large-scale effort and little attention was given to alternative control methods. No serious questions were raised about the biological effectiveness of ribes eradication for controlling the rust, but some serious doubts were expressed concerning the economic justification for its application in some situations.

Since World War II methods for control of blister rust have undergone many dramatic changes. Major efforts have been directed to several alternative techniques. These include: identification of low-hazard sites, use of systemic fungicides, pathological pruning, and selection and breeding for genetic resistance. Sufficient evidence has also accumulated to question the effectiveness of the ribes eradication control method.

Over the past two decades the North Central Forest Experiment Station has directed major research attention to microclimatic relations and systemic fungicides and has been involved to a lesser extent in the other studies. Research by this Station on white pine blister rust, *Cronartium ribicola* J. C. Fischer ex Rabenh., recently was concluded. No new studies are planned for the immediate future. It is deemed appropriate, therefore, to summarize past white pine blister rust research and the present status of knowledge. That is the purpose of this paper.

MICROCLIMATIC RELATIONS

Infection of white pine by blister rust is favored by extended periods of moderate temperature (below 67° F.) and the presence of free moisture on the needle surfaces (usually dew) during late summer and early fall when teliospores form on ribes leaves. Conversely, when either of these conditions is absent or frequently interrupted by higher temperatures and drying of the needle surfaces, the probability of infection is greatly reduced.

For these reasons, small differences in local climate can greatly influence prevalence of infection. The relations between climatic factors and prevalence of blister rust infection were studied by the staff at this Station from 1955 to 1968.[1] The Station received substantial cooperation from the University of Wisconsin and from the Division of Forest Pest Management, State & Private Forestry, USDA Forest Service. Results of these studies have been published by E. P. Van Arsdel and others (Anon. 1957, 1958; Van Arsdel 1954, 1961, 1962, 1964, 1965a, 1965b, 1967, 1968; Van Arsdel and Riker 1962). This research provided new knowledge and concepts that bear directly on effective control practices for blister rust. It also indicated promising approaches for study of other diseases sensitive to climatic conditions, such as *Scleroderris* canker.

Survey data collected by Forest Pest Management personnel and analyzed by King (1958) provided empirical evidence of variation in the hazard of blister rust infection for different areas of the Lake States region. The research on microclimate revealed the specific climatic influences that cause this variation and gave a sophisticated basis for dividing the region into broad blister rust hazard zones.

Hazard zones range from very low in the southern portion of the region to very high in some northern areas, such as the north shore of Lake Superior. In the low-hazard zone the potential for infection is so low that control is not justified. Thus, control programs were abandoned on large acreages that fell in the low-hazard category in the Lake States, Central States, and the Northeast.

As knowledge increased, hazard-zone maps were prepared. The latest version for the Lake States was published by Van Arsdel (1964) (fig. 1). Using similar concepts, Charlton (1963) developed a hazard-zone map for the northeastern States.

The primary objective of the microclimate studies was to determine relations between localized differences in microclimate and prevalence of blister rust infection. To achieve this objective and provide a practical tool for land managers to reduce losses, it was necessary

[1] *These studies were based on an earlier study made by E. P. Van Arsdel in 1951 to 1953 when he was a Research Assistant at the University of Wisconsin.*

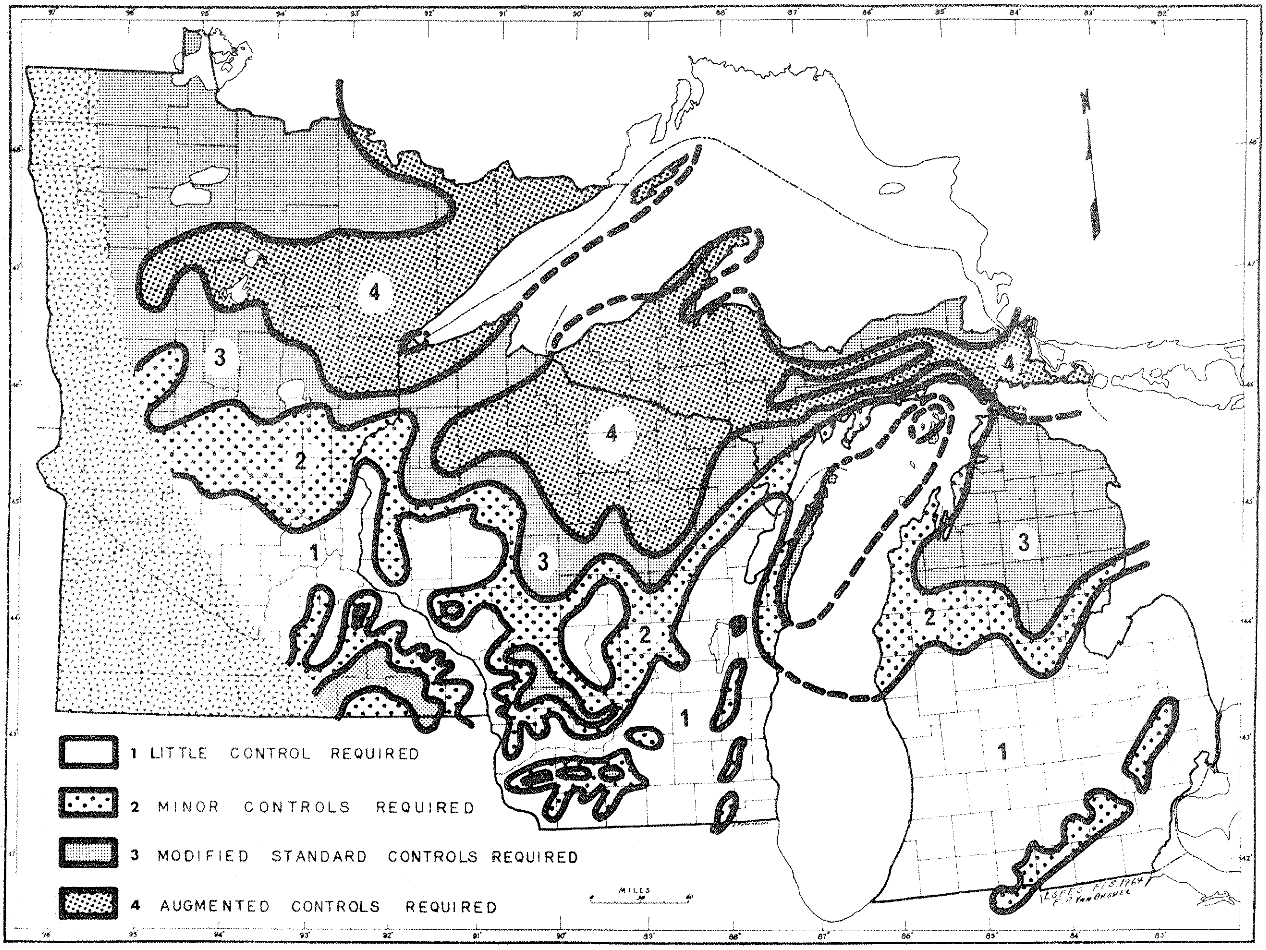

Figure 1.--*Map showing climatic hazard zones for white pine blister rust infection potential, ranging from Zone 1 with low potential to Zone 4 with a very high potential.*

to identify the features of the local environment that influence microclimate and determine how they modify the climatic factors that influence blister rust infection. In much of the Lake States, climatic conditions are marginal for infection and small differences in temperature or in the duration of favorable temperature and moisture conditions greatly influence prevalence of infection. Localized "spots" where infection levels differ from normal for a hazard zone result from microclimate effects, which, in turn, are created by features of the environment that can be recognized and interpreted.

Topography and vegetational cover are important features accounting for local variation in microclimate and hence variation in blister rust prevalence. The effect of topography is most pronounced during the clear, cool, windless nights that also favor dew formation. The coolest air flows downslope and accumulates in depressions forming a microclimatic zone cooler than that found upslope. Also, north-facing slopes are cooler because they are exposed to less intense solar radiation of shorter duration. Therefore, more favorable infection conditions are found in these situations.

Thus, one can assess local topography and predict its effect on the risk of infection. For example, a topographic effect favoring infection at the base of a north slope can be predicted. In such a location there is both accumulation of down-flowing cool air and low exposure to solar radiation. The opposite effect would occur on the upper part of a south-facing slope because of no accumulation of cool air and maximum exposure to solar radiation.

The influence of vegetation on microclimate is more complex than that of topography. Vegetation, for all practical purposes, has the same effect as topographic relief on downslope flow of cool air. Cool air flows down over the tops of a sloping tree canopy in the same manner as it does a hillside. Dense vegetation functions as air dams in essentially the same way as a ridge or cliff, and cool air will flow into and accumulate in an opening in a tree canopy the same as it would in a topographic depression. Another example of this kind of effect would be a dense belt of vegetation running across an otherwise open slope. This belt of vegetation will function as an air dam, and cool air will accumulate on its upslope side in the same manner as it does at the base of a slope.

To interpret other important effects of vegetation, some understanding is required of heat radiation principles, both incoming solar radiation and outgoing heat radiation, or loss of heat, to a clear sky. Incoming solar radiation is partly reflected and partly absorbed by the surface that intercepts the sun's rays. The energy of the absorbed radiation is later emitted as radiant energy. This phenomenon causes a substantial difference in the sunny, daytime environment of an open area exposed to the sun compared to that of a shaded area under a tree crown canopy. In an opening, incoming radiation is intercepted by the ground or low vegetation and maximum temperature buildup is close to the ground. Where a tree canopy is present, radiation is intercepted by the upper crowns and maximum temperature buildup is at that level. Temperature under the crowns is much lower and understory vegetation is not exposed to as high daytime temperature.

However, night temperatures will be lower in openings because of inflowing cool air and, when there is no cloud cover, because of direct exposure of the foliage on small trees to a clear sky; hence, an outward radiation of heat energy. Where there is a crown canopy, cooling by radiation to a clear sky is limited to the upper crown surfaces. Radiation from understory trees is reflected down by the underside of the overstory canopy and a higher night temperature environment is maintained in the understory.

The lowest temperature regime for a 24-hour period occurs in small openings. As used here, a small opening is one in which direct sunlight does not reach the bottom of the opening; i.e., it is shaded by the surrounding tree canopy. In this situation there is no direct input of heat energy but continuous outward radiation of heat; therefore, temperatures are lower both by day and by night.

Vegetation also plays a major microclimatic role in the infection process by influencing dew formation. Dew provides the free moisture that must be present a minimum of several hours for successful germination and penetration of pine needles by blister rust spores. Dew forms on plant surfaces that are cooled when they radiate heat to a clear sky. Thus, in openings, dew forms on the low-lying vegetation including small white pine. If an overstory tree canopy is present, dew forms on the overstory canopy with little or none on understory vegetation. Moreover, dew persists longest in small openings where it is not "burned off" by solar radiation.

In summary, the probability of favorable temperature and moisture conditions persisting long enough for infection to occur is greatest in small openings and least in an understory--primarily because of lack of adequate free moisture on the needles. The probability of favorable conditions for infection in large openings is about average because, although nighttime conditions are very favorable, this favorable period is shortened by the rapid rise in temperature and drying shortly after sunrise.

Detailed information on the influences of topography and vegetational cover on risk of blister rust infection are presented in several publications (Van Arsdel 1961, 1962, 1964, 1965a; Van Arsdel *et al.* 1961).

During the later stages of research on microclimate, much of the effort was shifted to study of local influences on air currents. Air currents transport the rust spores from ribes bushes to white pine (fig. 2). In late summer and early fall, when basidiospores (sporidia)

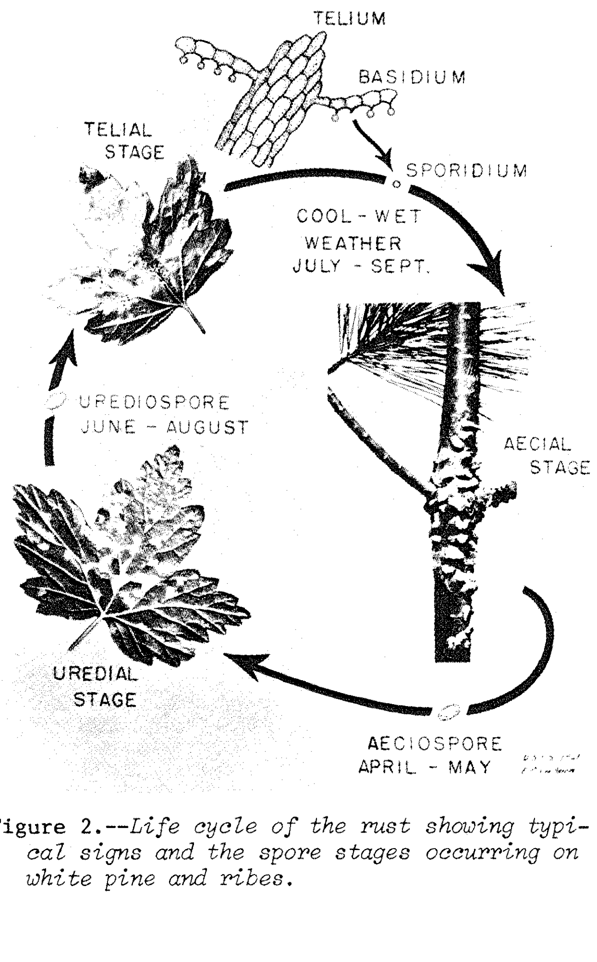

Figure 2.--*Life cycle of the rust showing typical signs and the spore stages occurring on white pine and ribes.*

are available to infect pine, the most favorable temperature and moisture conditions for infection occur during cool, clear, "still-air" periods characterized by heavy dew formation. If there is a wind, dew does not form; hence, even though temperature may be satisfactory, essential moisture is missing. Rainy periods do not appear to be as favorable for infection as might be presumed, because rain tends to wash spores out of the air and off of pine needles. Therefore, low-velocity, local air movements associated with cool, clear conditions are important to effective transport of spores from ribes to pine.

Close correlation was found between prevailing air-movement patterns during periods favorable for infection and the location of areas with high and low levels of blister rust infection. Apparently, local features of topography and vegetation influence the pattern of air currents that transport viable rust basidiospores.

An example of a small-scale effect is a young white pine plantation on a slope above a swamp containing a dense population of ribes (fig. 3). On the lower portion of such a slope, next to the swamp, white pine is lightly infected by rust while pine at the top of the slope, farthest from the swamp, is heavily infected. Studies made when conditions were favorable for infection showed that there is a surface flow of cool air downslope from the plantation out into the swamp. This air diffuses into the tree canopy, forcing air from under the canopy vertically until it meets a temperature inversion layer. The air then flows back toward the upper end of the plantation as a counter current under the inversion layer intersecting the ground surface where rust infection is heaviest (Van Arsdel 1965a, 1965b, 1967).

An example of a large-scale effect is air movement over land and water on nights favorable for infection (fig. 4). The more rapid cooling at night of the air mass over land than over water causes a flow of cool air from land to water. This forces the warmer air over the water upward and then back over the land mass as a countercurrent. In a study adjacent to Lake Michigan this countercurrent came down to the land surface several miles inland. There a much higher concentration of blister rust infection was found than in white pine located elsewhere in

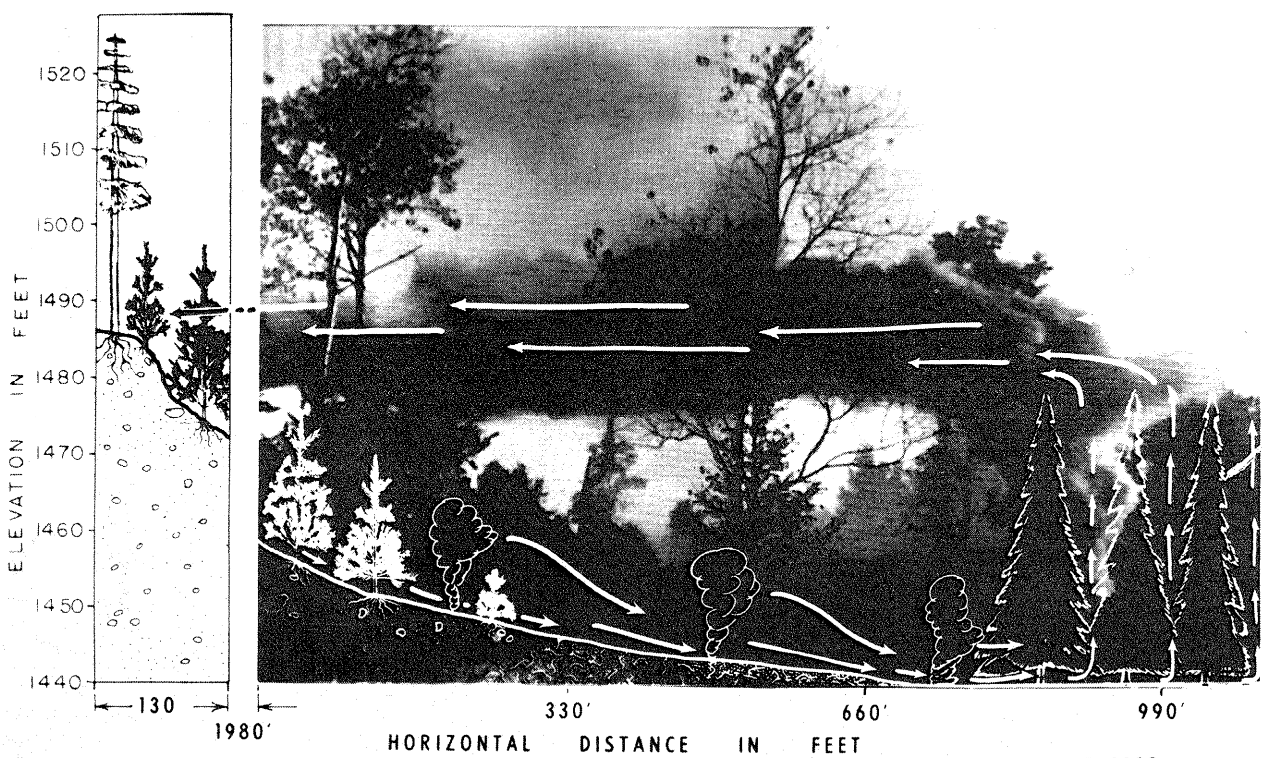

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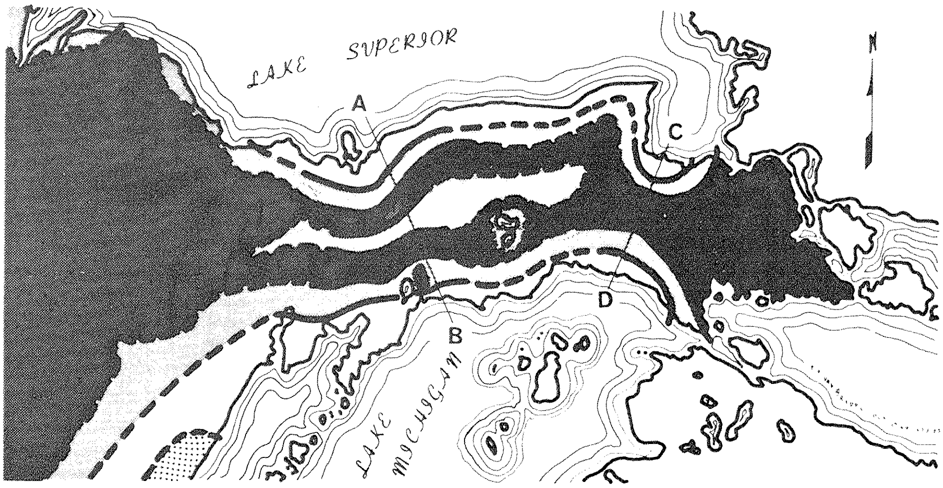
Figure 3.--*Smoke movements show air currents that match the spread of white pine blister rust from swamp ribes to upland white pines in northeastern Wisconsin.*



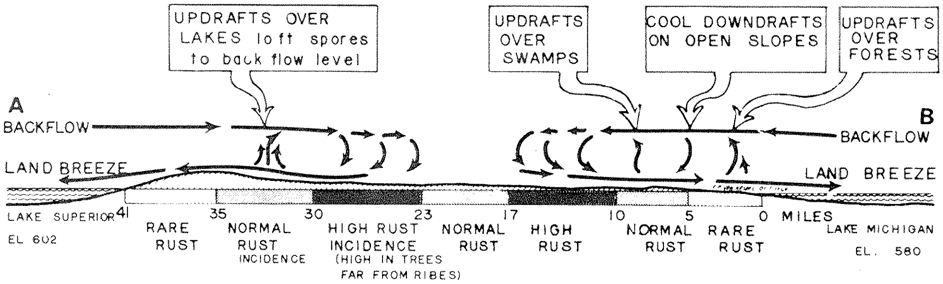


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Figure 4.--*Map (top) shows areas of types of blister rust distribution. Diagram (bottom) shows night land breezes and backflows that give this spread pattern. Shadings for rust spread zones are the same in the chart and map.*

the area. Similar evidence was obtained from observations in other areas with a comparable land-water relation. Evidently, viable basidiospores of blister rust are carried by such air currents for at least a few miles. This possibility is highly significant because control of blister rust by ribes eradication has been based on the assumption that viable basidiospores of the rust can be transported for only a few hundred yards even under the most favorable conditions. Long-distance transport of basidiospores is believed to be a major factor contributing to the failure of ribes eradication to prevent blister rust infection on some very high-hazard sites in the northern part of the region (Van Arsdel 1965a, 1965b, 1967).

Evidence also suggests another air current relation. In the southern parts of the region, in typical low-hazard areas, most infections on pine are within a few feet of the ground. This, in part, is because the microclimate close to the ground is more favorable for successful infection. It is, however, probably also a reflection of successful basidiospore transport being limited to local, close-to-the-ground, air currents. Apparently the fragile basidiospores die when transported at higher levels because of less favorable temperature and moisture conditions.

Generally, as one goes northward the prevalence of blister rust increases and the distribution of rust infection changes. More cankers are found higher on the trees until in some high-hazard zones many blister rust flags are seen in the upper crowns of saw-log trees.

Apparently, the vertical distribution of infections reflects the favorableness of the local climate for infection and indicates the distance viable basidiospores are transported by air currents. This is based on the premise that in high-hazard zones air currents high above the ground favor basidiospore survival and that such air currents move spores for longer distances.

In conclusion, studies show that microclimatic effects caused by features such as topography, water bodies, and vegetation influence prevalence and distribution of blister rust infections. Knowledge of these relations can help minimize losses from the disease by fitting management and control practices to local conditions.

CHEMICAL CONTROL WITH ANTIBIOTICS

During the 1950's antibiotics were tested for control of blister rust in the western white pine region. The results appeared successful, and the blister rust control program was shifted from ribes eradication to application of antibiotics (Moss 1961, Moss *et al.* 1960). This shift was not based solely on the interpretation of the test results but reflected the desperate need for a treatment that would eradicate the many existing infections in white pine (Benedict 1966).

Antibiotics were applied by either of two methods: to individual trees by the basal stem method, in which the antibiotic was mixed in a fuel oil carrier and sprayed onto the lower 6 feet of the bole and the base of branches entering the bole in this zone; or by aerial spraying, usually by helicopter, in which the antibiotic was mixed either in water or in a water-fuel oil emulsion and applied to the foliage.

Either of two antibiotics, Acti-dione (cycloheximide) and phytoactin,[2] was used in basal stem application. Cycloheximide was found to be phytotoxic when applied to pine foliage. Most aerial applications were made with phytoactin, but less phytotoxic derivatives of cycloheximide were also used on a limited scale.

By 1960 several small-scale tests of phytoactin and Acti-dione on eastern white pine (*Pinus strobus* L.) had been established. Results were far from conclusive. Therefore, in 1962 the Station and Region 9, USDA Forest Service, cooperatively initiated large-scale testing of antibiotics for control of white pine blister rust on eastern white pine. The principal objective was to test the efficacy of cycloheximide and phytoactin, using formulations and methods of application developed in the West. By 1965 it was apparent that none of the antibiotic formulations and methods of application were effective. The evaluations were continued for 2 more years to determine if there were any delayed reactions to the treatments, but all results remained negative (Phelps and Weber 1966, 1970b). Powers and Stegall (1965) came to the same conclusion in the Southeast in their evaluation of cycloheximide for control of blister rust on eastern white pine.

[2]*Use of trade names does not constitute endorsement of the products by the USDA Forest Service.*

Concurrent with studies on eastern white pine, a comprehensive evaluation was made in the West on western white pine (*Pinus monticola* Dougl.) (Benedict 1966, Dimond 1966, Ketcham *et al.* 1968). Conclusions were that adequate control was not being obtained, and the large-scale antibiotic control program was abandoned.

Phelps and Weber (1969a, 1970a) also tested a number of solvents and dilutants (other than the standard #2 fuel oil) and a large number of chemicals (other than phytoactin and cycloheximide). None of these were any better than the materials used in the West.

Other methods of applying antibiotics also were tried, such as whole tree drenches (Phelps and Weber 1966, 1970b), various applications to seedlings (Phelps and Weber 1968), and direct treatment of scarified cankers as had been done in some of the early testing in the West (Moss *et al.* 1960). Only one treatment showed promise of being effective in eradicating blister rust cankers: if cankers were thoroughly scarified, including the apparently healthy bark around the canker, and then treated directly with cycloheximide in fuel oil, they usually died (Phelps and Weber 1966, 1970b).

This method is not considered practical operationally. The action obtained is not a systemic action but rather chemical excision; i.e., the chemical is sufficiently phytotoxic so that the large quantity absorbed by scarified bark kills the host tissue occupied by the rust, and the rust, being an obligate parasite, is also killed. Even fuel oil alone has some suppressing effect on the rust when applied with scarification. To kill the canker the chemical must be applied directly to each potentially lethal blister rust infection on a tree, because the chemical is not effectively translocated from the site of application to a site of infection. Furthermore, scarification of the canker and surrounding area must be thorough. This is time consuming and difficult to achieve. Also, inasmuch as scarification must extend a few inches beyond the margins of the cankers, the bark must be killed over a large portion of the tree's circumference at the point of infection. The same type of control can be achieved by mechanical excision of the canker and immediately surrounding bark tissues (Martin and Gravatt 1954, Stewart 1957).

Much was gained from the studies on antibiotics although an effective systemic treatment was not found. The natural characteristics of blister rust cankers were found to vary greatly. Large deviations from the "classic textbook" (fig. 5) description have been described by Phelps and Weber (1969b). Misinterpretation of such natural variations contributed to early conclusions that the antibiotics were effective.

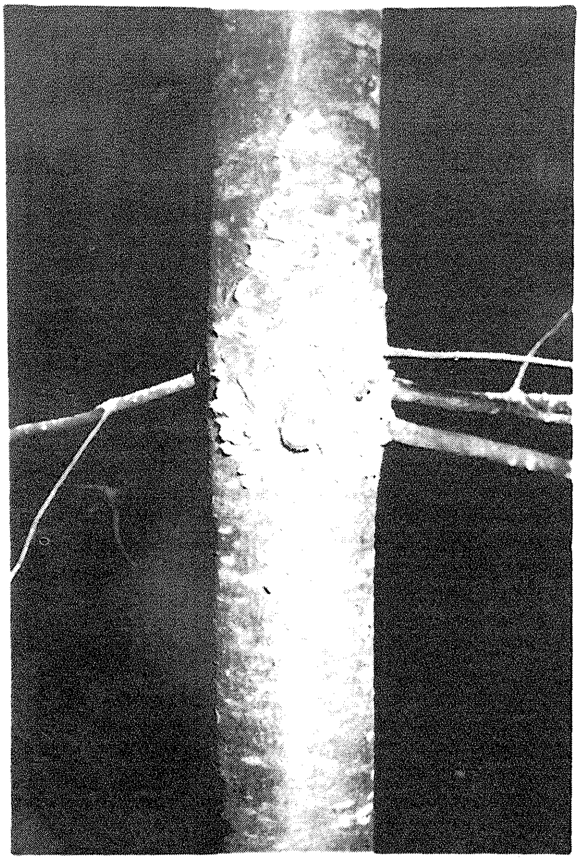

Figure 5.--*A typical white pine blister rust canker photographed in late spring when aecia are present. More often than not this portion of a canker will have been chewed by rodents and a heavy pitch flow will occur.*

Characteristics considered evidence of antibiotic action were found to be normal when many untreated check cankers were included in subsequent experiments.

No effective systemic fungicide treatment is known for white pine blister rust. Such a system would be unique in that it would eradicate infection on all parts of a tree. Regardless of the control methods used as a standard practice, a good systemic fungicide would be valuable for special uses such as cleaning up an area before establishing a preventive control practice or to clean up a new wave of infection in an area normally not hit hard.

Although cycloheximide and phytoactin are ineffective, it should not be construed that other systemic fungicides would not be. Antibiotics are used effectively for some plant diseases. Although no systemic action against blister rust was obtained with cycloheximide and phytoactin, bioassay analysis showed that these antibiotics are absorbed and translocated throughout white pine trees (Phelps and Leaphart 1968, Phelps and Weber 1967). The shortcoming was that these specific chemicals--at least in the quantities absorbed and translocated--were not active against the pathogen when they reached the site of infection. Further efforts to find the right chemical and the optimum conditions for absorption and translocation are needed.

PRUNING AS A CONTROL METHOD

Pruning shows some promise as a blister rust control technique (Martin and Gravatt 1954, Stewart 1957). It has been used to some extent in recent control programs. Blister rust infection occurs by invasion of the pine needles and then advances into the bark tissues. So, except on small seedlings, most infections initiate on branches. Pruning can therefore control infection in two ways: (1) cutting off an infected branch before the rust has advanced from the branch into the main stem eliminates the infection with no damage to the tree; (2) cutting off the lower branches eliminates the needle-bearing surface of the tree that is closest to the ground and the most vulnerable to infection.

During the early 1960's some small-scale studies of pruning as a blister rust control method in a high-hazard area demonstrated that pruning substantially reduces blister rust losses (Weber 1964). Several factors, however, limit the practical use of this technique.

Young eastern white pine is most susceptible to infection and mortality. If the objective is to protect most of the white pine natural regeneration or plantation stock established on an area, pruning must begin much earlier than for other silvicultural objectives. Also, trees must be pruned often enough to keep the lower third of the bole free of branches.

Severe white pine weevil infestation also can complicate the situation: investment in rust control is not practical unless the weevil is also controlled.

The distribution of blister rust infections on trees poses another problem. In rust-hazard zones where most infections occur near the ground, pruning is a good means of eliminating potentially lethal infections. But where infection occurs in the upper crowns of larger trees, pruning is impractical. Unless the rotation is short, many pruned trees would probably be killed later by infections originating too high on the tree to be pruned out.

SELECTION AND BREEDING FOR RESISTANCE

The North Central Forest Experiment Station has done little research on genetic resistance to white pine blister rust. However, progress is being made on this problem by others. Much of this work is pertinent to Lake States white pine and, in view of the importance of this approach to control of blister rust, merits summarizing.

Since World War II much effort has been devoted to development of genetic resistance to white pine blister rust by selection and breeding. Major efforts are being made on all three commercial white pines; i.e., eastern white pine (*Pinus strobus* L.), western white pine, and sugar pine (*Pinus lambertiana* Dougl.).

Genetic resistance to blister rust is present in all three species, and some of the resistant individuals do transmit a degree of resistance to their progeny (Bingham *et al.* 1969, Kinloch *et al.* 1970, Patton and Riker 1966). This prompted initiation of a large-scale program by Region 9, USDA Forest Service, to develop rust-resistant seed orchards for eastern white pine. Several hundred potential parent trees have been selected and are being tested for ability to transmit resistance. Trees known to be resistant are also being propagated by grafting to create first-generation seed orchards.

Genetic resistance is regarded as the most desirable form of disease prevention because progeny from resistant parents can be outplanted with no further need for rust control. Cost is limited to that needed to develop adequate parent material and resistant progeny beyond the cost of other means of regeneration.

The most serious potential problem in using genetic resistance is pathogenic races of the pathogen. Most genetic resistance that has been developed in economic plants is of the "vertical" or "differential" type (Van der Plank 1968, 1969) and is specific for certain races of a pathogen. When a new crop variety was developed, genetic resistance was built in for those races prevailing in the regions where the variety was to be used. When such a variety is put into production, other races of the pathogen develop. Eventually a new crop variety incorporating resistance to these "new races" must be created to replace the one previously used. A new variety of annual agricultural plants can be developed and put into large-scale production within a few years; it takes much longer for trees. The problem of races could best be overcome by developing "horizontal" or "uniform" resistance (Van der Plank 1968, 1969), i.e., nonrace specific resistance, but plant breeders have had less success in creating this type of resistance.

Bingham *et al.* (1971) demonstrated that there are pathogenic races of white pine blister rust. What effect will this have on rust resistant white pine? Instead of an annual crop exposed to a season's infection, a white pine crop is exposed for several decades during which rust races could develop through many changes. If a new race appeared that infected previously resistant selections of pine, a long period would be required to develop new selections resistant to the new race.

The potential of the blister rust race problem is very real. It is not certain, however, that resistant white pine will fall victim to devastating rust race changes. Plant pathologists and plant geneticists in agriculture are working toward developing disease-resistant varieties that should not be so vulnerable to new races of pathogens. Until horizontal resistance can be developed an alternative is to develop several lines of white pine differing from each other in the genetic basis of resistance and plant them in mixtures. Thus, only a portion of the trees in any given stand should be vulnerable to any "new race" that might develop. This is the short-term approach to blister rust resistance; in the long run, it is hoped that more reliance can be placed on developing horizontal resistance.

A factor that might influence the race problem on white pine is the stage in the rust's life cycle that infects white pine. Agricultural crops affected by serious rust race problems are infected by stages of the rust's life cycle in which each pathogen cell has a 2N chromosome number and is capable of propagating itself vegetatively on that host indefinitely without going through the sexual stage and the attendant recombination of genes. This means that once a given genotype has appeared, it can persist with that specific genetic constitution for as long as susceptible hosts are available.

White pine, on the other hand, is infected by the 1N chromosome number stage in the blister rust's life cycle. This stage is not capable of vegetative propagation and is produced by the telial stage on the ribes host. In the telial stage, the rust undergoes combination and segregation of genes. This means that massive populations of a single 1N genotype by vegetative propagation, such as occurs in 2N stages of the many rusts on agricultural crops, cannot develop. Although this indicates that the genetic constitution and propagation of a pathogenic race of blister rust on white pine is different, the end result for practical purposes could be about the same.

Because the white pine blister rust fungus does contain genetic diversity for pathogenicity on white pine, some trees resistant to only some of the possible "races" of rust probably would eventually become infected. If such trees were extensively planted, this could create a "breeding ground" for less prevalent genotypes to which they were susceptible. Even though lack of vegetative propagation of a pathogenic genotype would preclude rapid buildup, there would be active selection for the alleles of those genes controlling pathogenicity that permitted infection of the available host material. This means there would be a gradual buildup of those alleles permitting infection of the "resistant white pines" that had been widely planted. However, this trend could be diminished because the rust has to also live on another host, ribes. Usually, a race that has great virulence on one host is less aggressive on alternate hosts and so does not increase as rapidly.

Probably this process would be much slower than that typical for buildup of a 2N race. But when one considers the much greater length of a white pine rotation as compared to agricultural crops and the time required to create new resistant selections to replace those attacked, it would appear that the race buildup situation could be more serious for pine than for an annual crop.

This suggests that in blister rust resistance development programs, economically acceptable low levels of infection on "resistant" trees should not be ignored. At least some such infections could indicate presence of rare alleles for pathogenicity in the rust population. These could build up on "resistant" tree populations if there were no block to their spread and intensification, such as low aggressiveness on ribes hosts.

In limited research on this problem, evidence was found of pathogenic races for the 2N stage on ribes (Anderson and French 1955) (fig. 6). This proved genetic variability but most certainly did not prove that the rust varies in pathogenicity in the 1N stage on pine. As mentioned earlier, this question has now been resolved by others (Bingham *et al.* 1971).

The evidence for races on ribes could have more practical significance than we assumed at the time this work was done. The evidence indicates that the rust's virulence or aggressiveness does vary on the ribes host, which in turn can influence the populations of various rust races available to infect pine. Although progress on development of genetic resistance has been made, it will be many years before plantations of resistant trees contribute much to the eastern white pine resource. Most of our eastern white pines and their natural progeny will be subject to blister rust damage for a long time unless other controls are effectively applied in the interim. This emphasizes the desirability of not putting all research and development effort on genetic resistance.

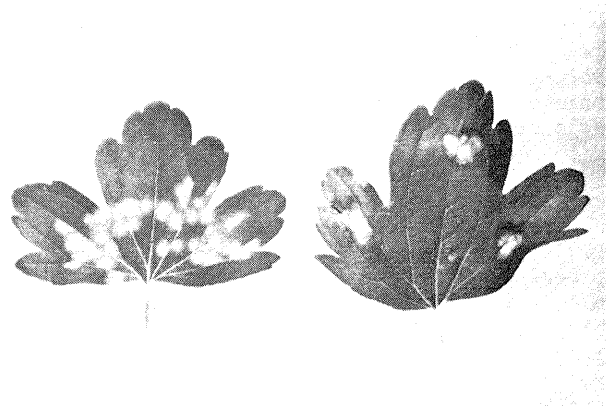

Figure 6.--*Two ribes leaves from a single clone inoculated at the same time with different sources of white pine blister rust urediospores and then incubated in the same way. The genetic difference between the two rust collections is demonstrated by the difference in the characteristics of individual pustules on the two leaves, not by the difference in number of infections.*

CONTROL BY RIBES ERADICATION

Control of white pine blister rust by eradication of ribes was first applied in 1909. It gradually expanded to become the largest tree disease control program ever undertaken. Until the early 1950's it was *the* blister rust control method, and ribes eradication became essentially synonymous with blister rust control. Since the early 1950's it has been largely replaced by other methods.

Until about 1960 ribes eradication was assumed to be an effective control. Questions often were raised about the economic justification for applying the method in many specific situations, but no one seriously questioned its biological effectiveness. It was assumed that if the local population of ribes were removed, white pine would not become infected.

Within the past few years, however, the effectiveness of ribes eradication has been challenged. Several individuals began to doubt its universal effectiveness both on the basis of research results (such as evidence for long-distance dissemination) and because of high infection rates in some areas essentially devoid of ribes either naturally or by eradication. These doubts culminated in a large-scale evaluation survey on the effectiveness of ribes eradication in the western white pine type. It was concluded that ribes eradication did not reduce the infection rate to acceptable levels. As a consequence, the ribes eradication program was abandoned in the western white pine type (Ketcham *et al.* 1968). Results of the study were consistent for all areas sampled, suggesting that the general climate for the western white pine region is sufficiently favorable for blister rust infection to give rise to unacceptable rates of infection.

Our research on microclimatic relations suggests a different situation in the eastern white pine region. Here we have a range of broad-hazard zones plus local effects caused by microclimate variations. In the low-hazard zone, the general prevalence of rust infection is so low that control is not needed. The real question on effectiveness of ribes eradication applies only to the high- and intermediate-hazard zones. On some sites in the high-hazard zone there is strong circumstantial evidence for long-distance dissemination of viable blister rust sporidia, suggesting that ribes eradication would not be effective.

The most likely area in which ribes eradication might provide practical control is the intermediate-hazard zones, on sites where evidence suggests that dissemination is more local. Local microclimate effects also influence the situation. Until more evidence is available, it is difficult to speculate as to the total area involved where infection levels are high enough to justify control.

The evidence for lack of effectiveness of ribes eradication raises an interesting question: how could such a massive control operation be applied for several decades before serious questions were raised concerning its biological soundness? Two important factors may have created this situation. First, initial tests of ribes eradication likely were made in areas where effective spore dissemination was local. If so, the error was in making a broad generalization based on a few nonrepresentative examples. Errors in generalizing from a few specific examples certainly are not unique, but this may be a classic example with far-reaching consequences. These studies and decisions were made before foresters and related professionals had acquired adequate comprehension of statistical methods or an appreciation for the complex variations in the ecology of habitats.

Second, the postcontrol evaluation system involved re-examination from time to time of areas from which ribes had been eradicated. If infections that had originated since eradication of the ribes were found, it was assumed that regrowth of ribes or missed ribes provided the necessary alternate host material. In most cases, ribes were found and the area was scheduled for a rework. Although control personnel were perplexed by some situations where new infection was occurring without any evident local ribes, no systematic assessment of this phenomena was made in the eastern white pine region.

The width of the protective zone from which ribes were eradicated around white pine stands was modified from time to time. Apparently these modifications were made without benefit of carefully designed tests. In some cases the protective zone was modified to provide as much protection as possible with limited available funds. In others, transfer of "practical experience" in one hazard zone to another may have been involved.

We now know from microclimate studies that the width as well as shape of protective zones could be important and vary with locality, depending upon the direction of the airflow patterns and distance of effective dissemination.

CONCLUSIONS

What can or should be done about the white pine blister rust problem in the Lake States? A final conclusion is not possible because of uncertainty about the effectiveness of ribes eradication in some situations. However, the following conclusions concerning control of the disease appear relevant:

1. On most sites in the low-rust-hazard zone, white pine blister rust does not cause serious losses and can be largely ignored. Fear of blister rust has had a much more serious impact on the growing of white pine than have losses from the disease. White pine should be considered a desirable species in this zone, although the white pine weevil can cause considerable damage. In general, white pine grows well in this area and alternative species on many sites are low- or intermediate-quality hardwoods. An additional argument for favoring white pine in this zone is that elm and oak, two of the more common alternative species, are suffering severe losses from Dutch elm disease and oak wilt. Oak wilt is most serious in Wisconsin and Minnesota.

2. In the intermediate-rust-hazard zones, blister rust losses can be appreciably reduced. Sites characterized by a microclimate favorable for rust infection should be avoided and an overstory should be maintained over juvenile white pine. In areas where most rust infections are close to the ground and economics permit, pruning will greatly reduce rust losses and upgrade tree quality.

3. In the high-hazard zone there doubtless also are some areas where methods recommended for intermediate-hazard zones would be reasonably effective. However, there are many areas--especially those where long-distance dissemination occurs--where it appears that losses would not be reduced to an acceptable level by any of the methods available at this time. Generally, white pine should not be planted on these areas.

The great diversity of rust infection hazard between and within climatic zones, because of microclimatic variations, indicates the danger of making broad, rule-of-thumb generalizations for a specific control technique over large regions. Each local situation must be evaluated, the amount and distribution of infection observed, and local experience with a control method evaluated. Then, tailormake any control program to the local situation.

Much research effort has been directed to the white pine blister rust problem and much progress has been made. Nevertheless, it is evident that more research effort is needed for satisfactory resolution of the problem. The following are regarded as the most important problems needing attention:

1. In areas where rust losses are serious genetic resistance must be developed that will endure, at least long enough to permit trees to grow to merchantable size. Development of the best possible genetic resistance to blister rust will require continuing research.

2. An effective antibiotic control for white pine blister rust would be desirable. Even if economic and other factors precluded its general and widespread use, it would have great utility for use on high-value stands and trees. Examples are some recreational areas and where an unusually severe wave of infection caused by abnormally favorable infection weather hits an otherwise low-hazard area. It also could be used to preserve desirable genetic material until such time as it could be incorporated in trees with stable resistance to blister rust.

3. The role of ribes eradication in controlling blister rust in eastern white pine must be resolved.

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Summarizes white pine blister rust research in the Lake States and present status of knowledge. Important microclimatic relations are described. Antibiotics are not effective, whereas pruning provides some control. Genetic resistance shows much promise but may be complicated by pathogenic races. The effectiveness of ribes eradication is open to question.

OXFORD: 443.3--172.8 CRO(77). KEY WORDS: *Cronartium ribicola*, *Pinus strobus*, microclimate, antibiotics, pruning, genetic resistance, ribes eradication.

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PESTICIDE PRECAUTIONARY STATEMENT

NORTH CENTRAL FOREST EXPERIMENT STATION

50 YEARS

1923 1973