The
effects of pruning young white pine
for
blister rust control

NR 799 Thesis

by

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Abstract

White pine blister rust is the most serious disease causing mortality of 5-needled pines in North America. Control of this fungus disease has for many years involved the eradication of the alternate host Ribes plants from selected white pine stands. Alternative or supplemental control has also involved physical removal of infections since the fungus mycelium is localized rather than systemic within the tree. The mycelium also grows quite slowly, often taking many years to grow from a branch to the bole where damage occurs through killing of the phloem and eventual girdling.

Previous pathological pruning studies have reported only the curative effects of removing blister rust-infected and other lower branches from young white pines. This paired tree study shows that removing all lower branches in addition to the visibly cankered ones results in more benefits than determinable by infection surveys. It removes visible cankers, undetected non-symptomatic infections, and prevents new infections. Three to five years after pruning, 75% of the controls and 95% of the pruned trees remain unaffected by blister rust. New lethal infection is occurring on 3.03 times as many controls as treated trees.

Pruning of all branches from the lower six feet of sapling white pines as soon as the trees reach 12 to 14 feet in height will adequately protect them from blister rust in low and medium climatic hazard zones. Pruning in two steps, beginning when trees are smaller and to a greater height will give better protection and is recommended for the higher hazard areas.

Introduction

Eastern white pine (Pinus strobus L.) is a tree species of northeastern North America well known for its timber, aesthetic and wildlife values. Because of these values and its rapid growth, plus the ease with which it can be propagated, white pine has been widely used in early reforestation efforts both within and beyond its original range.

A major deterrent to the management of both natural and artificially established white pine is the exotic fungus disease, white pine blister rust (Cronartium ribicola Fischer). First introduced into North America about 1900, the disease is now established in all areas where the hosts, five-needled or white pines, (Subgenus Strobus of the Genus Pinus) and a variety of currant and gooseberry shrubs (Ribes spp.) occur. The disease causes serious mortality in pines only where cool, damp late summer weather favors production of sporidia on the Ribes, with subsequent casting, dissemination and germination. These weather conditions occur regularly over most of the northern and higher altitude portions of the range of white pine, and on some southern locations with favorable microclimate. Conditions conducive to infection occur sporadically over the remainder of the white pine's range. Rust losses on the high hazard areas often preclude development of commercial white pine stands unless controls are accomplished. Merchantable trees are killed by the disease but these losses can be reduced by careful marking of infected trees and removal in intermediate cuts. The greatest loss occurs when mortality of established trees prevents white pine from restocking areas naturally. Powers and Stegall (1971) reported observations made in a North Carolina study which continued from 1946 through 1966. After 20 years 41% of all trees over 10 feet high had been killed by rust or had infections which would eventually kill them. In the same period 385 of 622 trees one to 10 feet high which were present on the one acre plot were similarly affected. Blister rust killed 41% of the seedlings present in the area by 1966. An additional 45% of the seedlings were lost to other causes, but many of these also had lethal blister rust infections.

Rusden (1952) reported a loss of 91 stems per acre, or 73.4% of the crop pines over a 20 year period in his Vermont study.

Filler (1933) studied a white pine stand at Waterford, Vermont, in which blister rust was observed causing considerable damage to merchantable trees in 1924, Between 64 and 79% of the basal area and up to 80% of the merchantable pine in the stand were lethally infected before Ribes eradication was completed in 1925. Filler estimated that without Ribes eradication, all white pines in the stand would have been lost.

Other studies, (Filler 1933, Posey and Ford 1924) have shown that infection rate tends to be higher in the lighter stocked stands and in the more dominant crown classes.

Published reports of damage to Lakes States white pine are scarce, but examples of severe damage are common. Many plantations have failed, and natural reproduction has not restocked many suitable areas solely because of blister rust mortality.

Financial losses occur in several ways. Direct loss of trees through mortality is primary. Secondary losses occur when natural restocking is delayed, thus extending the rotation or decreasing the size of the final crop trees. Losses also occur when reduced stocking under utilizes a site, as when blister rust-created openings revert to grass or brush cover. Understocking can also adversely affect quality factors of branchiness, crooking and forking.

Symptomatology

Blister rust symptoms can be recognized by trained observers as spots of various colors in needles within one to two months after inoculation (McDonald and Hoff 1975). An orange yellow spot about $\frac{1}{4}$ inch in diameter appears at the base of the infected needle 10 to 12 months after inoculation, giving the first indication of infection in the bark. These symptoms are of practical interest mostly to researchers in experimental inoculation work because of the amount of time required to search for them, and the difficulty in thoroughly inspecting any but very small trees.

The cankers increase in size and become more readily identified as the fungus grows in the inner bark. In typical cankers (about 85% according to Phelps and Weber 1969a) the yellowish area enlarges, often becoming swollen, as the fungus mycelium grows within the cambium (Fig. 1). Pycnia develop during a summer season within the marginal bark invaded by the fungus the previous summer, and distinguished the previous summer as a yellowish margin. Pycniospores are contained in a honey-colored liquid

Figure 1. Typical Cronartium ribicola canker on branch of young Pinus strobus. Visible are aecial scars (a); pycnial scars (b); and yellowish discoloration just behind invading mycelium of the fungus (c). Two additional cankers are present in the picture at A and B. The subject canker would probably enter the bole in about 3 years unless pruned off, the one at B within one year, and the canker at A may never enter the bole because branch and infection will probably die first.

which exudes from openings in the bark. The scars of the pycnial exudation and scars resulting from various insects feeding upon pycnia are quite easily identified and are characteristic of blister rust cankers. Cankers reach maturity when blisters push through the bark in the pycnial area the next spring, or about the third or fourth year following needle infection. Each blister or sac, consists of a thin white membrane enclosing a powdery mass of orange-colored aeciospores, which gives the blister a distinctive orange-yellow appearance. The membrane bursts, and the aeciospores are carried away by wind or rain. The small holes or pits left in the bark have ragged edges to which particles of the torn white membrane adhere for a short time. These mature cankers may sporulate each spring or at irregular intervals until the infected tree or branch dies which will also eliminate the parasite. So long as live host tissue remains the fungus mycelium can persist. Live host tissue beyond the canker is not required, as the infection itself appears capable of keeping the intervening cambium alive for some time after all tissue beyond the canker dies (Martin and Gravatt 1942).

A second type (Fig. 2), making up about 10% of infections (Phelps and Weber 1969a) has no marginal coloration on smooth barked trees, even when the canker and tree are young. These cankers have a distinct margin between the brown necrotic face of the canker and the surrounding live green bark. Cankers of this type normally do not sporulate, but sometimes after years of apparent inactivation they produce pycnia and aecia well in advance of the previous symptoms. These cankers then develop and grow normally.

A third type of canker (Fig. 3), has a callus ridge on both sides of the entry branch from which blister rust invaded the bole.

Figure 2. Example of "non-typical" Cronartium ribicola canker on Pinus strobus. A distinct margin is present (a), distal to which the bark is sunken and has no evidence of recent pycnial or aecial activity. Discoloration and pycnial ooze are not evident proximal to the bole.

Cankers on the entry branches appear normal in all respects. The trunk cankers have the appearance of a deep narrow groove in the bole, extending several inches to several feet in length. A small necrotic area is found at the base of the entry branch and

Figure 3. "Non-typical" Cronartium ribicola cankers found occasionally in the bole of infected trees and probably manifesting a resistance mechanism present in some genotypes.

in most instances no other symptoms are visible; externally they appear to be arrested. They have no marginal coloration and do not sporulate. Canker activity and normal symptoms (i.e., discoloration and sporulation) sometimes appear beyond the callus ridge.

Another type of canker is occasionally seen where the branch is considerably swollen at the entry point and which exhibits a roughening and cracking of the bark in the comparatively short canker area. This type canker is thought to be the result of a genetic factor which prevents the rust from surviving in the branch (Hoff et al. 1973).

Pathology

The fungus mycelium grows almost entirely in the cambium. The advancing hyphae are entirely intercellular, producing haustoria which invade host cells well behind the leading elements of the fungus. The invaded cambium is killed, preventing the translocation of photosynthate and nutrients within the infected branch or tree, thus killing those parts of the tree distal to the girdling canker.

The growth rate of cankers varies greatly among individual infections within a size class and even in individual cankers from year to year. Mean annual growth rate towards the bole in one study was 3.1 inches per year in 8 - 13 year old saplings (Phelps and Weber 1969a). Hirt (1939) found a rate of 0.7 to 5.0 cm per year but used smaller trees which generally sustain a slower canker growth rate.

This growth rate is slow enough to allow removal of cankers before they reach the bole. Some infections which originate well out on branches are killed when the host branch is shaded out. For control operation survey purposes, cankers which are in the bole are called fatal cankers; those branch cankers within 18 inches of the bole are referred to as prunable lethals because they are expected to grow into the bole and eventually kill the tree; those cankers occurring beyond 18 inches from the bole are called non-lethals because they are not expected to survive long enough to infect the bole. That practice is followed in this study.

Secondary fungi are commonly found in bark killed by blister rust. Insects often feed on pycnial ooze and very small areas of neighboring bark, creating characteristic pitted areas on the blister rust cankers. Small rodents, probably mice and squirrels, often feed on the marginal areas of cankers removing much of the infected bark but rarely eliminating all of the fungus mycelium.

The year of inception of blister rust cankers on eastern white pine is determined by dating the annual internodes of the tree, and considering the year of wood formation at the center of the infection as the year of inoculation (Hirt 1939). This method is accurate to within one year only so long as the internodes are recognizable and the branch of canker origin remains on the tree.

Control programs

Earliest efforts to control blister rust in the United States were attempts to completely eradicate the disease by removing the infected pine branches and trees. After realizing this was impossible, most control efforts were aimed at removing the alternate host, Ribes. For many years the standard blister rust control measure in forest stands has been Ribes eradication. Recently, however, alternative control measures have been increasingly advocated (Anderson 1973). There are a number of possible alternatives offering hope in growing healthy white pine on a wider scale. Fungicide treatment to cure infected trees and to prevent infection of seedlings seemed to be very effective in early tests (Moss 1961, Moss et al 1960) but was later proven ineffective (Leaphart and Wicker 1968, Phelps and Weber 1969b). Research in this field is continuing but no specific chemotherapeutant is being field tested at this time.

Inherent resistance to Cronartium infection and genetic control of this character have been demonstrated (Riker et al 1943, Bingham et al 1960). However, resistant stock will probably not be available for planting until 1985 or later (St Amant 1966), and then only in limited amounts because of seed orchard limitations. There is also the probability that different strains of rust which can overcome this resistance will then develop (Anderson 1973, Hoff et al 1976). Selection of sites where rust is inhibited by climatic conditions is a fairly reliable means of control. This method, however, prevents management of white pine on many sites where is has good growth potential. Neither of these methods offer any solution to control of the disease in established stands.

Pathological pruning is one alternative control method which has long been recognized as having value in reducing rust losses (Martin et al 1921). Previous to 1965 canker pruning was performed regularly but on a very small percentage of the total white pine acreage. This work entailed removing visibly cankered branches and fatally infected trees from stands from which Ribes had been removed. No canker pruning work was reported from Wisconsin before 1948, when only one area, in Sawyer County had been pruned by the landowner.

In 1965, the pathological pruning practice evolved into one closely resembling a purely silvicultural operation. All branches, but not more than 40% of the live crown, are pruned from the lower 50% of the bole on selected crop trees. This is done preferably while the branches are still vigorously growing, and is in contrast to the original proceedure of pathological pruning where only the visible infections were removed. All visible infections above the height of complete branch removal have also been pruned in recent operations. Guidelines governing tree size and quality, stand size, and infection percentage were developed so that pathological rather than silvicultural considerations take precedence in selecting stands to be treated (Brown 1972). These guidelines are summarized as follows:

1. Each stand considered for pruning must have at least 200 prunable and non-weeviled white pines per acre.
2. Each white pine stand must be at least five acres in size.
3. Minimum annual lethal infection must be 1%.
4. Infection rate is to be based on the number of infected trees, not on the total number of cankers.

5. Maximum number of crop trees pruned per care will be 200 for natural stands and 350 for plantations.
6. White pine should be pruned to 50% of the total height or nine feet, whichever is less.
7. All limbs with lethal infections above the normal pruning height, that are easily accessible, should be pruned.

In recent pathological pruning projects, fatally infected trees are not removed as they were in past operations.

This modification of the practice was instituted because Stewart's work (1957) indicated that silvicultural-type pruning is more effective than canker pruning alone in areas where *Ribes* eradication has been performed. Weber (1964) demonstrated that silvicultural-type pruning without *Ribes* eradication can be an effective rust control measure even in high hazard areas.

Even though the fact that pruning has value in reducing blister rust mortality has been accepted, several important questions have not been resolved. First, and most important, the infection preventative benefit of pruning has been suggested but never demonstrated (Putnam 1956, Stewart 1957, Van Arsdel 1964, Anderson 1973). Weber's study near Bloomville, Wisconsin (1964a) did not permit a comprehensive analysis because the 2 year repruning schedule did not allow development of visible canker symptoms before removal of lower branches. Most infections present were removed before they could be seen. There is no record of any follow-up on Putnam's suggestion that the pruning plot near Walker, Minnesota, by J. N. Licke, be re-examined to determine rust preventative benefits of pruning juvenile white pine. Stewart investigated factors affecting local control of blister rust in northern Minnesota. His main concern was to determine reasons for the apparent failure of <u>Ribes</u> eradication to control the disease in a few instances. He also reported on pruning done at different intensity levels which showed that silvicultural-type pruning was more effective than canker pruning alone. He did not report any preventative benefits, and apparently did not attempt an evaluation of this.

Other important questions concern the duration of rust control and the related height of pruning required. Anderson (1973) raised the question of rust infections occurring above the normal pruning height, negating the effects of pruning. Weber (1964b) surmised that pruning may only temporarily save trees, and that many would later become infected above the pruning height. Some lethal infections have occurred on his Bloomville plot above the 4 foot average height to which he pruned (Lehrer 1971, 1975). An additional indication that pathological pruning may be of limited value has been the occurrence of blister rust infections in the upper crowns of white pines throughout the high hazard areas of the northern Lakes States (Van Arsdel 1965). Despite this evidence, most workers indicate the majority of infections occur on branches quite close to the ground, and that pathological pruning can be a valuable control measure, either alone or supplementing other methods (Phelps and Weber 1969a, Van Arsdel 1961, Weber 1964b). Thus the major questions remaining are: (1) to what degree does pathological pruning have preventative benefits? (2) how high should trees be pruned for optimum pathological benefit? and (3) are benefits from pruning temporary or long term.

This report involves a study begun in 1970 to monitor the results of pathological pruning as now practiced, in an attempt to answer the above listed questions.

Method of Study

The ideal test of plant disease control methods under field conditions compares growing stock of equal infection capacity under uniform infection exposure conditions. Results become more pronounced and can be obtained more quickly as infection intensity increases. Ideally the only difference between treated and control stock is the treatment. Plantations with tree heights of 6' to 18' provide uniform test and control materials conforming to the size of trees treated in rust control projects. However, young white pine plantings in the high hazard areas of northern Wisconsin are very scarce due to high blister rust and white pine weevil (Pissodes strobi Peck) damage potential which causes land managers to avoid the species. Most of the known plantations of suitable size have too little rust due to natural Ribes scarcity or past eradication efforts, to provide a meaningful test, or have such high rust losses that too few trees remain to test the long term effects of pruning. This has necessitated a method which allows for study in young natural stands as well as in the few plantations available. The study technique chosen involves the comparison of paired individual trees of similar size and vigor, one pruned and one unpruned. Each pair comprises a test plot. This approach was used because of the difficulty in setting up comparable multi-tree rows or blocks of treated versus control trees.

Guidelines were established to assure uniformity within plots and to insure that environmental factors which cause variations in rust hazard are minimized.

Guidelines

1. Within each plot, trees must be within 15% of each other in crown size, thus both trees should have a similar amount of needle surface for spore reception. When establishing plots, crown height, width and density were objectively rated, because of the difficulty in measuring needle surface.
2. Within each plot, trees must be of similar vigor to assure that pruned and control trees provide a growth medium for infections which is comparable. Tree age and size, and internode length provided the criteria for rating this factor.
3. Paired trees must have equal exposure to help insure equality as a spore target and germination site. This involves associated overstory and understory vegetation which can intercept spores, and can also affect temperature and moisture conditions. Variations in microclimate and spore transport as affected by topography (Van Arsdel 1962) are minimized by this requirement.
4. Paired trees should be within 25 feet of each other to minimize varying distances to nearby Ribes and to avoid the possible occurrence of varying air movement patterns which could cause different exposure to basidiospores (Van Arsdel 1965).

5. Either tree or neither tree in a pair could have a prunable blister rust infection, although neither could have an infection already in the bole.

It is impossible to exercise any control over genetically controlled susceptibility of trees in the study. Because natural occurrence of resistant individuals is on the order of one in 10,000 trees (Bingham et al 1972), this factor is considered not important in the study. Selection of areas on which pairs were chosen was also governed by guidelines as follows.

1. Areas must have at least 10 acres of white pine to facilitate location of sufficient test material.
2. Pine on the areas chosen must have a current rust incidence of 1% per year so that enough infection occurs to show significant differences between treatment and controls.
3. Areas must have enough suitable material to provide 50 or more pairs.
4. The areas must have young vigorous white pines of 6' to 18' total height with green branches on the lower bole.
5. The area should not have had a recent Ribes eradication so that the infection rate would continue at a high level to allow a test of preventative effects.

The areas chosen for this study are located and described in Appendix I.

Data gathering procedure

Transects were laid out in cardinal directions and marked.

Along these transect lines paired tree plots were established. The transects provided a systematic sample and an organized system for data gathering. They will also facilitate re-reading in future years. Transects are separated by a one-half chain buffer strip in which no pruning has been performed. When two comparable trees which satisfied the guidelines were located along the transect (Fig. 4), the one occurring closest to the

Figure 4. Trees of comparable size and vigor which were selected for a study plot of the basis of guidlines which assure that each has similar exposure to inoculation.

starting point for that transect was selected as the treatment tree. Height and infection data were then recorded for both trees; the pruning was performed, and the trees marked (Fig. 5).

Figure 5. Paired tree study plot immediately after pruning and marking of the study trees.

Pairs were identified with numbers painted on the bole, and with numbered aluminum tags wired loosely to the trees. The tags were attached to a branch which would have been in the lowest remaining whorl if the control tree had been pruned, and to a branch in the lowest remaining whorl on the pruned trees. Blister rust cankers were also paint marked to facilitate relocating them and to save time in future examinations.

Data sheets (Appendix II) include all pertinent stand and individual tree information. Data gathered and recorded for each pruned tree include total and pruned height, and the distance and direction to the paired control tree. Total and prunable height was recorded for control trees. Height of occurrence, distance from the bole, and year of formation of canker-bearing wood were recorded for each blister rust canker on infected trees. Provision was made on the forms for recording subsequent data at 3 year intervals.

Tree and pruning heights were estimated to the nearest foot, height of canker occurrence was estimated to the nearest 0.5 foot, and the distance from the leading edge of cankers to the bole was measured to the nearest inch in most cases. In the few instances where the visible symptoms of pruned cankers were less than 2 inches from the bole, the distance was measured to the nearest tenth of an inch and noted so that subsequent observations would indicate the effectiveness of pruning with such short distances between visible symptoms and the bole.

All live infections were recorded, but only those occurring within 18 inches of the bole were considered lethal. All the computations were based on the number of infected trees rather than on the total number of cankers. Infections occurring after pruning were all recorded on the data sheets, but were not counted as causing mortality if the tree had a prior lethal infection. Some infections present at the time of pruning were not observed until a later examination, because field diagnostic symptoms such as yellowish discoloration, swelling or constriction, and pycnial or aecial sporulation had not yet developed. These are called non-symptomatic infections in the remainder of this report. They are included with the other pre-pruning infections in the determination of curative results.

Treatment

The pruning operation followed accepted silvicultural practice in that limbs were pruned flush with the trunk, tearing of the bark was avoided, and live crown removal was kept at 35-40%. Pruning to 50% of the total height would, in some cases, have removed more than 40% of the live crown, so, percent of live crown removal was the criterion used to determine pruning height. No extra effort was made to excise possibly infected bark from branch collars as described by Martin and Gravatt (1942) and as performed by Stewart (1957). Branches pruned from the treated trees were not removed from the ground at the tree base, except to allow examination to determine that all lower branches were severed from the tree.

Hand pruning clippers, loping shears, and pruning saws with a 4 foot handle were used as needed to perform the pruning. Associated vegetation which interfered with the pruning treatment was not removed. Two maps were prepared for each area.

One, at a scale of 1:20,000 locates the study area, and another at 1:5,000 locates the transects within the area (Appendix III).

Results

Eight study areas occurring in widely separated locations across Wisconsin were used in this study (Appendix I). They are located in each of the 4 climatic hazard zones within the state described and delineated by Van Arsdel (1964). One area is located in Zone 1, the lowest hazard area, 2 each in zones 2 and 3, and 3 areas are in zone 4 which has the highest climatic hazard. A total of 742 paired tree plots were established and treated. All were re-examined one or more times between 1970 and 1975 when the latest data were collected (Appendix Ia).

The large number of replications was used to assure that the results would be statistically reliable. The large sample was necessary because there were no previous experiments of this type from which the within group variance could be estimated. A small scale study to permit an estimate of variance was not performed because needed results would be available only after a delay of 4-5 years.

The pruned trees averaged 10.7 feet high with a mean pruned height of 5.3 feet when treated. Controls averaged 10.6 feet with an average prunable height of 5.2 feet. Analysis of these data using the *t* test showed that there was no significant difference in tree height or prunable height.

In the 10 years preceding this study, mean annual incidence of lethal infections was 3.2% on the selected trees. Blister rust has killed very few of the study trees so far, because of the requirement that none of the trees have a canker already in the bole when the study was initiated. Seventy-one of the 742 controls had visible lethal infections and an additional 77 had non-symptomatic lethal infections, making a total of 148, or 20% lethally infected trees at the time of pruning. An additional 37 trees became lethally infected in the 3-5 years after pruning, leaving 75% of the controls unaffected by blister rust (Fig. 6).

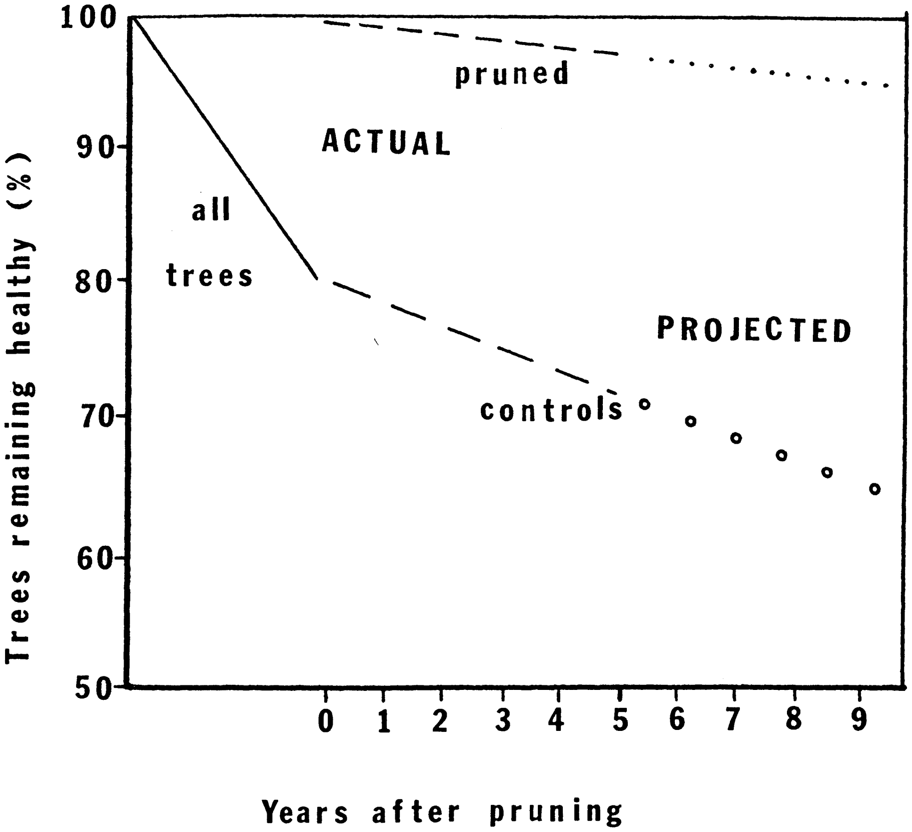


Figure 6. Actual and projected survival of pruned and control <u>Pinus strobus</u> in a paired tree pathological pruning study.

The treatment removed visible lethal cankers from 79 trees, leaving the pruned trees all apparently healthy when the treatment was completed. Later examination showed that 10 trees were infected with previously non-symptomatic trunk cankers, and 12 with non-symptomatic lethal branch cankers which were not removed by the treatment. Fifteen lethal cankers have occurred since the treatment and above the pruned height (Table 1). Only 37 of the pruned trees are now lethally infected or dead, leaving 95% unaffected by blister rust. Twenty of these could have been saved by pruning higher originally, or repruning at the time of re-examination. Average annual incidence of lethal new rust since pruning has been 1.76% and 0.58% for the control and pruned trees respectively (Fig. 6).

A total of 535 blister rust cankers were recorded. Four hundred (75%) were within 18 inches of the bole and thereby considered lethal. These 400 lethal cankers were found on 302 trees, for an average of 1.32 lethal infections per infected tree.

All the cankers which were within two inches of the bole were successfully removed.

Very few adventitious branches have appeared on the pruned trees, and none are visibly infected to date.

Mortality and serious damage from other causes have eliminated only 13 (0.87%) of the 1,484 trees in the study. Competition or suppression killed four trees, including three pruned too severely to overcome heavy herbaceous competition. Allegheny mound ants (_Formica_ _exsectoides_ Forel) killed two, and three were lost to unknown causes. Single trees were; eliminated

Table 1. Field data collected in a pathological pruning study for control of *Cronartium ribicola* using paired *Pinus strobus*.

	Boudry	Spider Creek	Forest Inn	Gun Shop	Birch Hill	Jackson Co. For.	Hibma	Boys School	Total	
Trees lethally infected at pruning.	28	5	4	6	0	12	16	0	71	Control trees
Trees w/lethal non-symtomatics at pruning	28	6	3	1	3	4	11	21	77	
Trees infected after and below pruning	4	0	0	7	0	1	25	0	37	
Trees lost, total lines 1, 2 & 3	60	11	7	14	3	17	52	21	185	
Trees remaining healthy	105	42	27	41	47	73	93	129	557	
Number of pairs	165	53	34	55	50	90	145	150	742	All trees
Number of years of data	5	4	4	3	3	3	3	3		
Trees remaining healthy	158	51	30	51	45	88	133	149	705	Pruned trees
Trees saved by removing visible lethals	28	7	9	3	5	13	11	3	79	
Non-symptomatic lethals above pruning	0	2	1	0	2	1	4	0	10	
Non-symptomatic lethals in bole	5	0	3	0	3	0	0	1	12	
Lethals occurring after pruning	2	0	0	4	0	1	8	0	15	
Trees lost, total above 3 lines	7	2	4	4	5	2	12	1	37	

by shoestring root rot (*Armillaria mellea*), broken off by a windthrown tree, uprooted by a vehicle, and damaged by bear. None of these trees were infected by blister rust.

Numerous pruned trees on two study areas have suffered damage from male white-tailed deer (*Odocoileus virginiana*) rubbings. Damage varies from negligible to serious, but there has been no mortality to date.

Data of infection incidence have been subjected to the *chi-square* test and differences are significant at the .005 level. Infection percentages were compared for before treatment (Table 2), immediately after treatment (Table 3), and 3-5 years after treatment (Table 4). The proceedure described by Freese (1967) was used.

Table 2. Before treatment

	Controls	Treated	Subtotals
Visibly infected	71 (a_1)	79 (a_2)	150 (A)
Not visibly infected	671 (b_1)	663 (b_2)	1,334 (B)
Subtotals	742 (T_1)	742 (T_2)	1,484 (G)

Using the formula $X^2 = \frac{1}{(A)\,(B)} \sum_{i=1}^{2} \left(\frac{(a_1B - b_1A)^2}{T_1} \right)$

$$= \frac{1}{150 \times 1{,}334} \left(\frac{\left[(71)(1{,}334)-(671)(150)\right]^2}{742} + \frac{\left[(79)(1{,}334)-(663)(150)\right]^2}{742} \right)$$

$$= \frac{1}{200{,}100}\left(\frac{5{,}936^2}{742}+\frac{5{,}936^2}{742}\right)=0.0000049 \times 94{,}976 = 0.46$$

This value is less than the tabular *chi-square* value in the .005 column with 1 degree of freedom, so there was no significant difference in infection of control versus treated trees before the treatment.

Table 3. Immediately after pruning

	Controls	Treated	Subtotals
Infected	148	22	170
Not infected	594	720	1,314
Subtotals	742	742	1,484

Using the same formula and procedure as before:

$$X^2 = \frac{1}{(170)\ (1{,}314)}\left(\frac{\left|(148)(1{,}314)-(594)(170)\right|^2}{742}+\frac{\left|(22)(1{,}314)-(720)(170)\right|^2}{742}\right)$$

$$= \frac{1}{223{,}388}\left(\frac{93{,}492^2}{742}+\frac{93{,}492^2}{742}\right) = .0000044 \times 23{,}559{,}984 = 103.66,$$

which is greater than the tabular value in the .005 column, so there is a significant difference in the infection rate between treated and control trees immediately after pruning.

Table 4. Trees becoming infected after treatment.

	Controls	Treated	Subtotals
Infected	38	15	53
Not infected	557	705	1,262
Subtotals	594	720	1,314

Using the same formula and procedure:

$$\underline{X}^2 = \frac{1}{(53)\ (1,262)} \left(\frac{|(38)(1,262)-(557)(53)|^2}{594} + \frac{|(705)(53)-(15)(1,262)|^2}{720} \right)$$

$$= \frac{1}{66,886} \left(\frac{18,435^2}{594} + \frac{18,435^2}{720} \right) = .0000149 \times 1,044,148 = 15.55,$$

which is greater than the tabular value in the .005 column, so there is a significant difference in the infection rate between treated and control trees in the post-treatment period sampled in this study.

Discussion

This study has shown that the blister rust control value of pathological pruning as now practiced is greater than anticipated by disease incidence surveys which consider only those infections which are visible at the time of the survey. The elimination of visible cankers is an obvious and well-known benefit.

An additional benefit quantitatively demonstrated here has been the removal of numerous non-symptomatic infections by pruning all lower branches. Slightly more than half of the trees lethally infected at the time of pruning were not visibly affected by blister rust. Fifty-two percent of these infected trees (10.37% of all controls) had blister rust infections which were not observed. Some of the cankers not seen initially were possibly in an incipient stage or so atypical as to not be recognized, or were simply missed. However, the probability of this happening in so many instances is slight because all trees were examined by two or more persons experienced in blister rust surveys. Some of these infections were as much as 5-7 years old, and a few were not found until the second re-examination. Individual blister rust cankers were proven to vary in development rate in other studies (Hirt 1939, Phelps and Weber 1969a) but the magnitude found in this study was greater than anticipated. Martin and Gravatt (1942) recommended subsequent canker pruning operations at 3-5 year intervals to remove these non-symptomatic infections. The present pathological pruning practice eliminates the need for reinspections and removes many infections which could grow into the bole in the interim. Efficiency checks performed by this writer, of canker pruning operations in Wisconsin showed that average field laborers were expending fully as much time searching for cankers as would be used pruning all lower branches, and still numerous infections were missed. Thus the currently used pruning practice is much more effective, and little more expensive than canker pruning.

The anticipated, but heretofore unproven, preventative effect has been demonstrated despite a comparatively short post treatment period during which infections could occur and develop. Since only 2 or 3 growing seasons have elapsed between 1972, when infection conditions were especially favorable, and the latest collection of data in 1974 and 1975, it is believed that considerable numbers of infections are present on lower branches of the controls, but still remain undeveloped. This is because of the five or more year period needed for complete canker development as shown by this study and by earlier observations. Thus the actual preventative benefit effect will probably be much greater than the 1:3.03 pruned to controls infection ratio which has been shown to date.

This study indicates that pruning to 6 feet above ground may give adequate protection because 93% of all cankers (Fig. 7) and 92% of the lethal ones occured below that height. These figures should be interpreted with caution because four of the eight study areas, involving 550 plots, are located in a climatic hazard zone considered moderate by Van Arsdel (1964). In this zone, infections are seldom found in the upper crown, compared to a greater frequency of occurrence in the higher hazard areas. The length of time the pine needles above 6 feet have been exposed to inoculum in this study has been

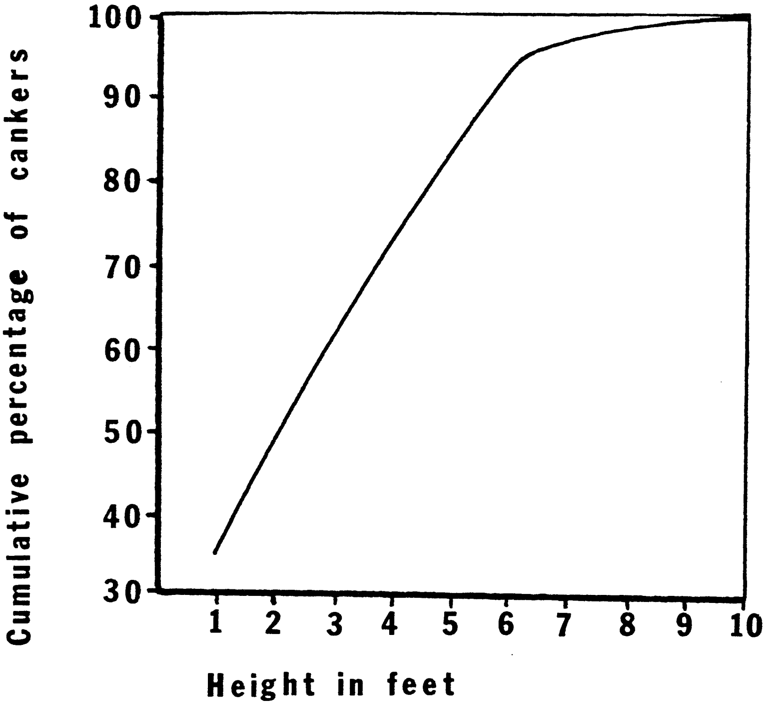


Figure 7. Cumulative height of occurrence of <u>Cronartium ribicola</u> cankers in a pathological pruning study with paired <u>Pinus strobus</u>. This includes only those which were not fatal cankers when the study was begun and those occurring on the study trees after that time. Many other cankers occurred on non-study trees on the study areas.

limited, thus affecting the amount of rust possible. There is also a much smaller amount of susceptible pine host material at increasing heights, because of the approximately conical shape of young pine crowns. Thus the proportion of infections occurring at the respective heights would favor the lower occurrence until more foliage is present at the greater heights. It appears that a pruned height of six feet will provide adequate protection in the lower hazard areas. Higher pruning, in two steps, beginning when trees can be pruned to 3 or 4 feet, and again when they can be pruned to 9 feet should give adequate protection in most higher hazard areas (Lehrer 1971, 1975), however, more time is needed to fully test this hypothesis.

This study also strongly indicates that the pathological effects of pruning are not temporary. If, as early data indicate, it can be shown that few lethal infections occur above a certain height, then most trees pruned to that height can be brought to maturity in normal forestry rotations without further blister rust control measures. Additional time is needed to prove this contention also.

This study was designed to show results of a single pathological pruning operation, rather than the several repetitions as performed by Weber (1964a). The main objectives will be reached when lower branches on the controls have all been shaded out to the height prunable when the plots were installed. After that there will be no difference in blister rust incidence or mortality which is attributable only to the treatment on these plots. This is because the infections must initiate on live green needles. This will occur within a few years on the areas with older trees, and those well stocked enough that lower branches are shaded by neighboring trees. All areas should reach this stage in 15 years or less. At that time consideration can be given to pruning to greater heights on some of the areas to determine the value of pruning higher than has been done so far.

Additional data concerning fate and approximate growth rate of individual cankers are being gathered, and can be analyzed after the main objectives of the study are met.

Valuable information concerning other causes of mortality and damage to young white pine was also accumulated in this study. Blister rust mortality exceeds that from all other causes by a ratio of over 16 to 1.

Recommendations

The planting and management of white pine, one of the most desirable timber species in Northeastern North America has been greatly reduced because of the fear of blister rust and costs of its control. Outlined below are recommendations for growing white pine with minimal losses to rust at the lowest possible protection costs. Some of these recommendations are cultural, and thus no direct cost of control is incurred. Another method, pruning, requires expenditure of control funds, but has the additional result of greatly increased production of more valuable clear lumber so the cost should not all be assigned to disease control. Ribes eradication requires expenditures which must be charged to disease control alone.

1. Grow white pine under a high, light crowned overstory. This could be aspen, thinned white birch, oak on sand, jack, red or white pine. The overstory reduces or prevents occurrence of the cool damp environmental conditions required for production, dissemination and germination of sporidia. It also reduces the amount of white pine foliage available for inoculation and reduces the amount of Ribes foliage on which sporidia can be produced. When Ribes populations under an overstory are eradicated recovery of these populations is much less likely. Spore movement under an overstory is also greatly reduced. Maintaining a canopy of vegetation has the added benefit of preventing white pine weevil damage.

The overstory should be maintained until the trees are 18-20 feet high, however, if growth of the white pine is not reduced, and if mechanical damage to the leaders is not occurring, release can wait until trees reach 35 feet in height.

2. Promote and maintain uniform stocking as high as possible while maintaining good growth. This keeps the air dry below the canopy, shades out *Ribes* and shades out the lower pine limbs to kill or prevent some blister rust infections. White pine will maintain good growth at high stocking levels, so, intermediate cuts should be performed when stocking reaches 180 - 200 square feet of basal area per acre, and should reduce stocking to about 100 - 120 square feet of basal area per acre.

Lumber quality in the better stocked stands should also be better because of smaller branch size, less weevil damage and earlier recovery from this damage.

3. Prune early, prune often and prune high. All white pine stands in which timber production is the main purpose should have up to 250 eventual crop trees pruned per acre. Pruning when trees are young has significant rust control benefit as shown by this study. Pruning also maximizes the production of more valuable clear lumber in short rotations. Pruning for blister rust control helps to maintain the uniform high stocking advocated in the previous section with the same beneficial results.

Pathological pruning should be performed in the low hazard areas first when trees reach 12 - 14 feet in height and can be pruned to about 6 feet. Subsequent pruning would have more silvicultural than pathological value and should be scheduled to produce a clear bole 17 feet long.

In the higher hazard areas the first pruning should be performed when a clear bole of 3 - 4 feet can be pruned on trees of 6 - 8 feet. Subsequent pathological prunings should be performed to produce a clear bole of 9 - 12 feet, after which the benefits of pruning to 17 feet are mostly silvicultural.

All young white pines of crop tree potential, no matter how few, which are found in red pine stands should be pruned if the red pine is to be managed for sawlogs, or if eventual conversion to white pine is desired.

When 50 - 250 young white pines of crop tree potential are present per acre, pathological pruning should be performed when rust incidence averages 0.5% per year. Rust incidence should be determined by tabulating the percentage of trees first lethally infected during the fourth through the tenth years previous to the survey. This figure is divided by 7 to give the average annual rate of new rust incidence. When stocking is 250 to 500 crop trees per acre, 1% new rust would warrant pathological pruning. Stands with 500 to 750 trees per acre should be protected when infection is 2% per year or greater. When lethal rust infects 3% or more trees annually controls are warranted at any stocking level.

The lowest 1 foot of bole of all white pines grown for Christmas trees should be pruned as soon as possible, for control of blister rust, and to satisfy USDA grading requirements for a handle.

Branches on the lowest 1 or 2 feet of ornamental pines can be pruned even when dense foliage at ground level is desired for the screening effect. As the next higher branches lengthen, they will droop so the ends nearly touch the ground and provide the desired screening. Cankered branches occurring later can then be individually removed as they become evident.

4. Eradicate Ribes within and for varying distances beyond the borders of the pine stand.

In the low hazard areas Ribes generally need not be controlled except in some very localized areas if pruning is not performed. Visual evidence of rust incidence, or site analysis by a blister rust specialist according to Van Arsdel's (1964, 1965) recommendations can provide a fairly reliable assessment of probable rust impact.

In the medium hazard areas Ribes should be eradicated within and 70 feet beyond the edge of the pine stand.

In the high hazard areas Ribes should be eradicated 100 feet into adjoining wooded areas despite the intervening distance.

Proper use of registered herbicides can greatly increase the speed and effectiveness of Ribes eradication projects.

Ribes eradication is most effective and economical where performed to protect large blocks of white pine. It is not recommended in areas of less than 10 acres in the high hazard zone.

There are some sites where land managers should not attempt to grow white pine before genetically rust resistant stock is available. These sites are mostly in the northern or higher altitude parts of the range of white pine. When white pine is present on these sites as a remnant of populations present before the rust was introduced, it will be heavily infected at all heights and restocking size classes will be almost entirely absent. These sites should be avoided because cultural and pruning practices will not provide enough control and the expense of needed Ribes eradication would prohibit the economical growing of white pine.

Where white pine is not present rust impact can be predicted with fair reliability so land managers should consult a blister rust control specialist or a pathologist experienced in blister rust, for help in appraising suitability of sites.

Appendix

Ia. Description of study areas.

1. Boudry Area. Portage County, T22N, R10E, S15. This is a privately owned plantation established about 1960 under a fairly uniform, medium overstory of mixed poor quality oak. The area was crop tree pruned by the landowner in the winter of 1969 - 1970 and the 165 paired tree plots were selected and data recorded in October, 1970. Antecedent rust rate in the plantation was 5% per year. Because the trees selected as the treated part of this test were previously pruned, equal infection rates were assumed for treated and control trees in computation of data for this area. This plot was reinspected in 1973 and 1975 so 5 years of data are available.

2. Spider Creek Area. Langlade County, T34N, R12E, S19. This is a small area on the Langlade County Forest planted about 1942, averaging about 20' total height. It was suppressed for some time but is now recovering and making good growth after an aerial release from overtopping aspen in 1959. Antecedent rust rate was 2% annually in the 1958 - 1968 period. Fifty-three plots were established in February 1972 and re-examined in 1974 and 1975 so 4 years of data are available.

3. Forest Inn Area. Langlade County, T34N, R12E, S4. This is a small privately owned area with white pine naturally seeding into an old field, with antecedent infection rate of 3.1% annually. Thirty-four pairs were established in December, 1971 and re-examined in 1974 and in 1975 so 4 years of data are available.

4. Gun Shop Area. Lincoln County, T32N, R7E, S33. This area of

natural reproduction in an old pasture had a 3.1% annual new rust incidence when 55 plots were established in August, 1972. The plots were re-examined in 1975, so 3 years of data are available.

5. Birch Hill Area. Ashland County, T47N, R2W, S25. This is a poorly stocked natural stand of white pine infected at 1% annually. It is somewhat suppressed by a poor quality hardwood overstory. Fifty pairs were established in May, 1972, and re-examined in 1975 so 3 years of data are available.

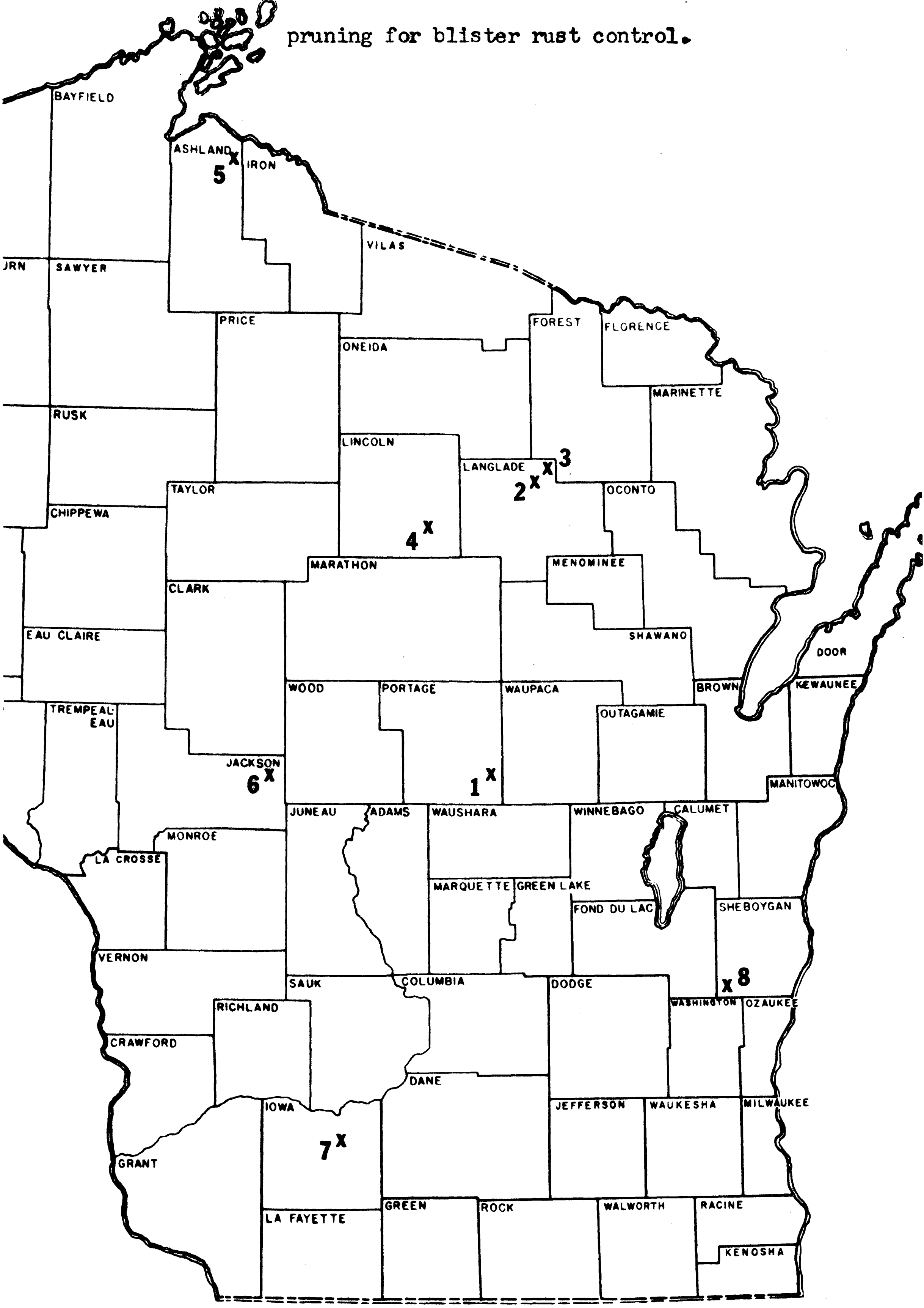
6. Jackson County Forest Area. Jackson County, T22N, R1E, S4. This a 16 year old County Forest plantation with an average annual new rust incidence of 1.23%. It has no overstory. Ninety pairs were established in June, 1971 and re-examined in 1974 so 3 years of data are available.

7. Hibma Area. Iowa County, T7N, R4E, S36. This is a privately owned eleven year old plantation with a 2.3% annual infection rate due to locally favorable micro-climate. In October, 1971, 145 pairs were established. Re-examination was completed in 1974 so 3 years of data are available.

8. Boys School Area. Sheboygan County, T14N, R20E, S9. This is a 12 year old state forest plantation with a 4.3% antecedent infection rate. In May, 1971, 150 pairs were established. First re-examination was in 1974, so 3 years of data are available.

The area locations are indicated on the map on the following page according to numbering in the preceding text.

Ib. Location of paired tree plots in a study of pathological pruning for blister rust control.



Appendix

II. Sample plot data sheet for paired tree pathological pruning study.

PAIRED PLOT PATHOLOGICAL PRUNING SURVEY

AREA NO. 4

Date Surveyed 8-3-72 Transect No. 1 County Lincoln Location S33, T32N R7E

Name of Area Gun Shop Area Hazard Zone HIGH Date Ribes Worked —

Planted ____ Natural X Age 10 Pine Acres 15 Crop Trees per acre 200+

Annual Infection Rate (7 Readable Years) 3.1% Damage: Weevil Moderate Deer NONE

9-10-75

Sub-Plot #	Pruned Tree Height		Infection Yrs. Later				Distance & Direction to	Unpruned Tree Height		Infection Yrs. Later				B.R. Canker Data						Remarks Ribes Etc.
														Ht.		Dist.		Yr.		
	Total	Pruned	3	6	9	12		Total	Prunable	3	6	9	12	Pr	Up	Pr	Up	Pr	Up	
1	9	4	0				7'SE	10	5	0x					1'		6"		'68	#1c inf. fatal in 1975
2	8	4	0				8' S	8	3	0										
3	11	5	0				5' S	11	5	✓					6"		2"		67	c inf. not seen in 1972
4	10	5	✓				6'SW	10	5	0				5'		2.5"		72		
5	15	8	0				5'SW	15	7	0										
6	11	5	0				12'SW	11	5	0										
7	8	4	0				9'SW	7	3	✓					8"		6"		'72	
8	6	3	0				16'SW	6	3	✓					1'		7"		'72	
9	8	3	0				6' S	8	3	0										

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(1/28/60)

BRC SURVEY MAP

Area No. NE 2

Path. Pruning Plot Location Map

State Wisconsin

T. 34N R. 12E Sec. 4

County Langlade

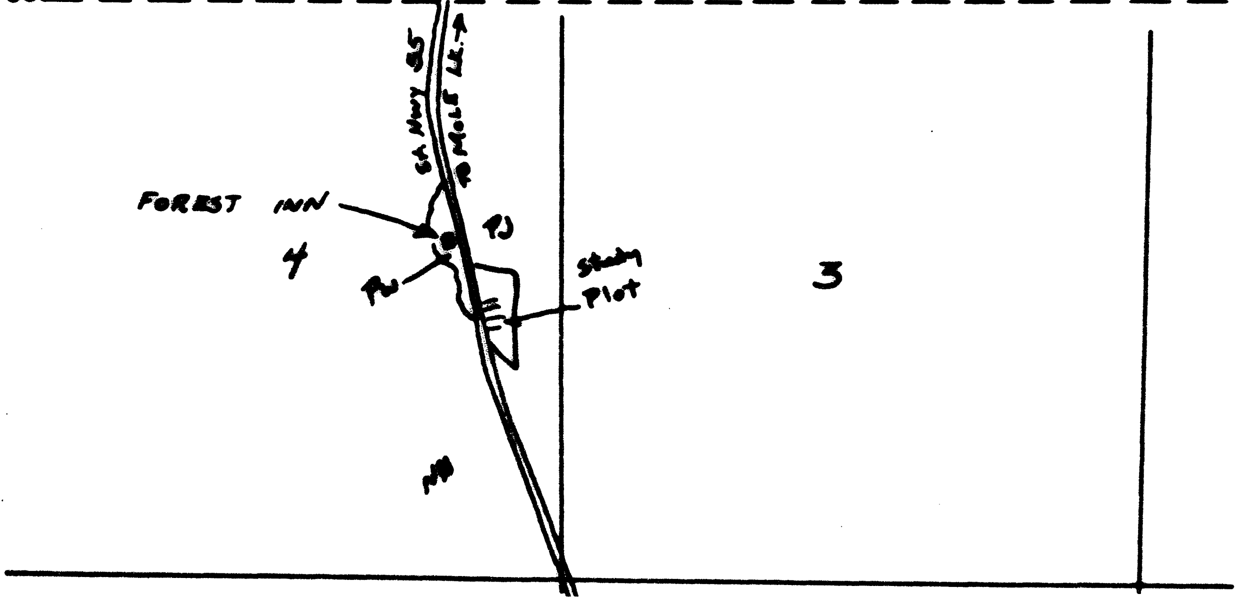
Month and Year 12-'71

Data By G.F. Lehrer

Forest or Unit Forest Inn Plot

Scale 1:20,000

Notes



IIIa. Example of plot location map.

R9-5270-6
(1/28/60)

BRC SURVEY MAP

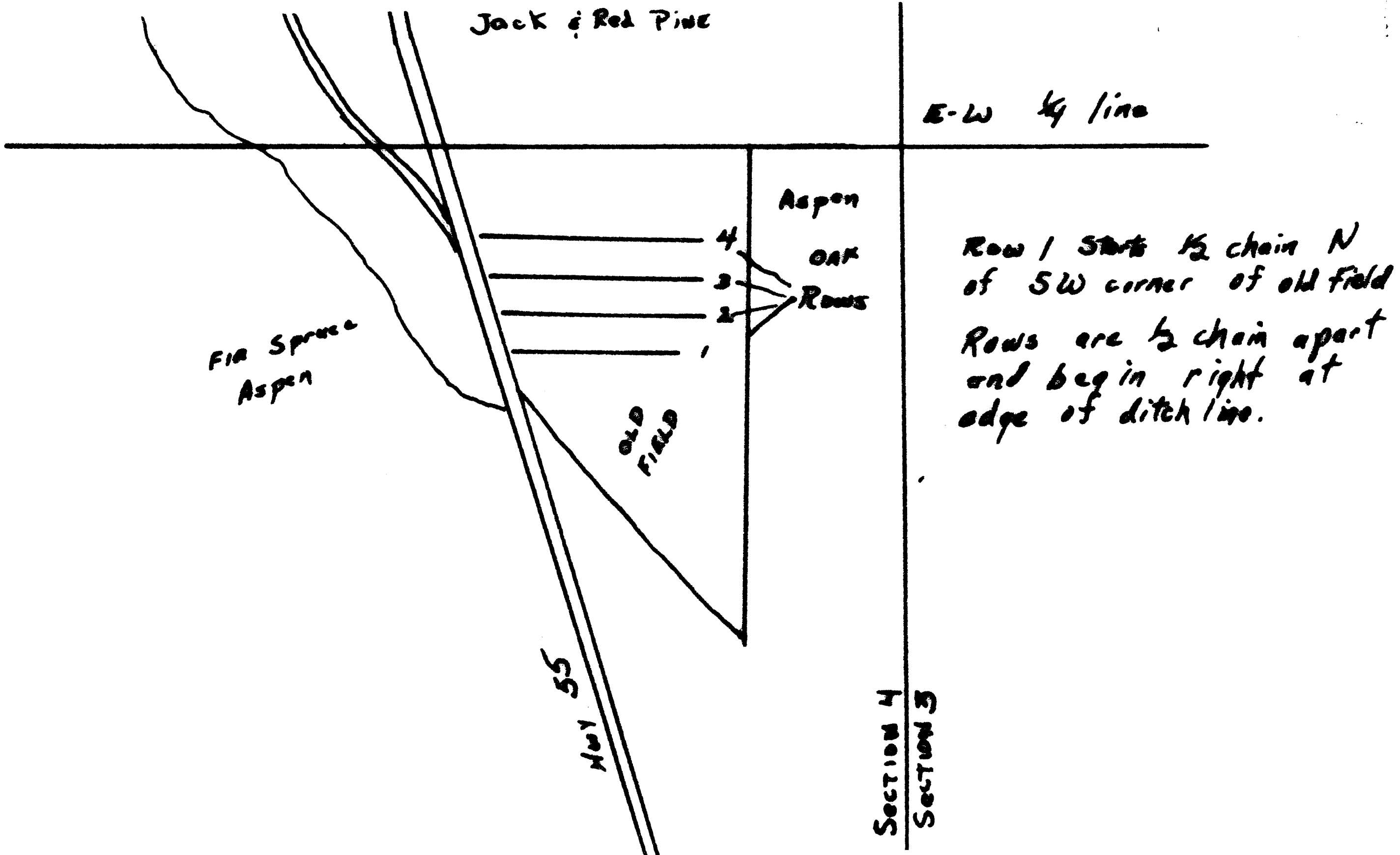
Area No. NE 2

State WISCONSIN PATH. PRUNING PLOT DETAIL Map T. 34N R. 12E Sec. 4

County LANGLADE Month and Year 5-'72 Data By G.F. LEHRER

Forest or Unit

Scale 1:5000



Row 1 Starts ½ chain N of SW corner of old field.

Rows are ½ chain apart and begin right at edge of ditch line.

IIIa. Example of pruning plot detail map.

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