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RELATION OF WEATHER CONDITIONS TO THE SPREAD OF WHITE PINE BLISTER RUST IN THE PACIFIC NORTHWEST[1]

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INTRODUCTION

Weather conditions to a large extent determine the spread and severity of fungous diseases of plants. White pine blister rust is no exception to the rule. The direction and rapidity of spore distribution over long distances depend upon winds. Favorable moisture and temperature conditions are necessary for germination of the spores and consequent infection of the host plants.

Moisture conditions are more variable than temperature and seem to determine the amount of infection which may occur. If moisture conditions are favorable, temperature conditions also are practically certain to be favorable. Particular attention has, therefore, been given to the correlation between the spread of the rust and the winds and moisture conditions.

The western white pine, *Pinus monticola* Dougl., is practically the only pine to be taken into consideration. There are several species of Ribes in the region under discussion. (See fig. 1.) Some qualifications will be necessary because of differences in both abundance and susceptibility to infection of Ribes in different localities.

It has not been possible to follow the course of the disease from year to year in the Northwest. It has, therefore, been necessary to determine, as nearly as possible, by field studies during the seasons of 1922 and 1923 the year of infection as well as the amount and direction of spread of the rust. This has been done, and it is now possible to determine in a general way how often heavy infections may be expected to occur in places containing both pines and Ribes. It is possible also to make some estimate of the length of time which will be required for the disease to spread by natural means into regions now free from it.

DETERMINATION OF SEASON OF INFECTION

Special efforts have been made to determine the year of infection in all places in which the rust has been studied. In young and vigorous trees it is practically always possible to determine the internode in which infection began. Until recently infections were classified according to the year's internode in which they first appeared. This method was found to be inaccurate. Earlier tabulations in which no reference to the age of the canker was given are not good indicators as the to year of infection.

During the season of 1922 a large number of incipient infections were found in the internodes of 1917, 1918, 1919, and 1920. Table I shows the distribution of 176 of these infections upon a few pines near Bold Point, British Columbia. (For location of infection centers see fig. 2.) There were many Ribes near these pines.

[1] Received for publication June 11, 1924; issued June, 1925.

[2] The writer wishes to express his gratitude to J. S. Boyce, forest pathologist for Washington and Oregon, and to G. B. Posey and S. N. Wyckoff, pathologists in charge of blister-rust control in 1922 and 1923, respectively, for the Western States. Each has been most cordial in his cooperation and has aided in the collection of data in every possible way. Particular credit is due to Harry G. Lachmund, junior pathologist, who most ably and faithfully assisted during the summers of 1922 and 1923 in the collection and preparation of field data. The writer acknowledges the cordial cooperation of the meteorologists and other Government and State officials in the Western States and British Columbia. He is especially indebted to the following: A. T. Davidson, in charge of blister-rust scouting for the Dominion Government, who has furnished valuable data secured by himself and his scouts and who has aided materially in other ways; and F. Napier Denison, superintendent, Gonzalès Heights Observatory, Victoria, British Columbia, who furnished all the available meterorological data for British Columbia.

The large majority of the infected internodes produced aecia in 1923 for the first time. As nearly as could be determined, not over 10 or 12 of them failed to produce aecia in April or May, 1923. Upon some of the branches there were so many infections that they coalesced before aecia were produced. On the other hand, some of the 10 or 12 which did not produce aecia may

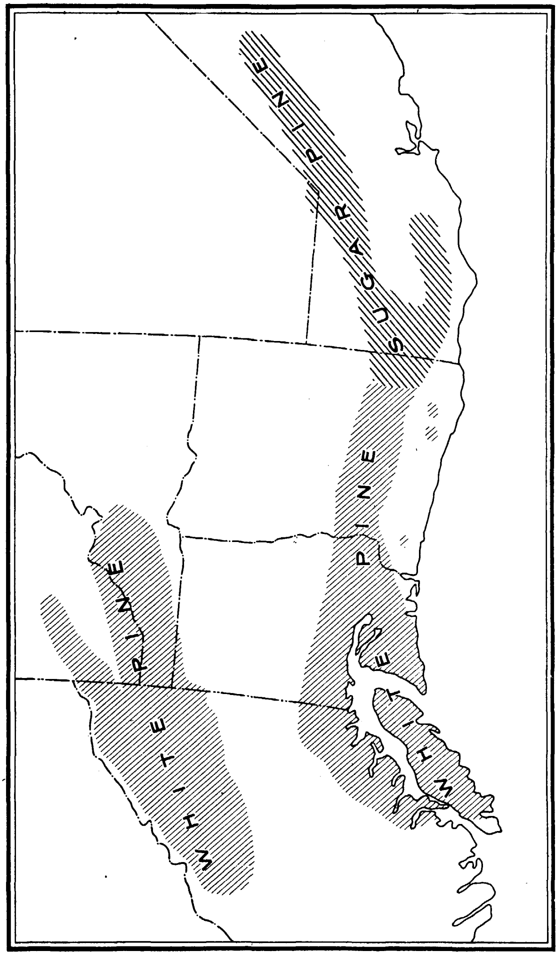

FIG. 1.—Map showing distribution of western white pine (*Pinus monticola*) and sugar pine (*P. lambertiana*) in the western United States and Canada

TABLE I.—*Distribution of 176 infections found in 1922 on pines near Bold Point, B. C.*

Internode of [a]—	Number of infections
1917	5
1918	36
1919	113
1920	22

[a] By "internode of 1917" is meant that part of a stem or branch which began its growth in the growing season of 1917.

have been 1921 infections, which were beginning to appear in 1923.

It would appear that all or nearly all of these infections occurred in the same year, since they developed practically simultaneously and produced aecia first in 1923. It is very evident that no infections which began in the 1920 internodes could have resulted from exposure earlier than 1920. If those in the internodes of 1917, 1918, or 1919 had occurred earlier than those in the 1920 internodes, they would have been older than the infections in the 1920 internodes and the greater part of them would have produced

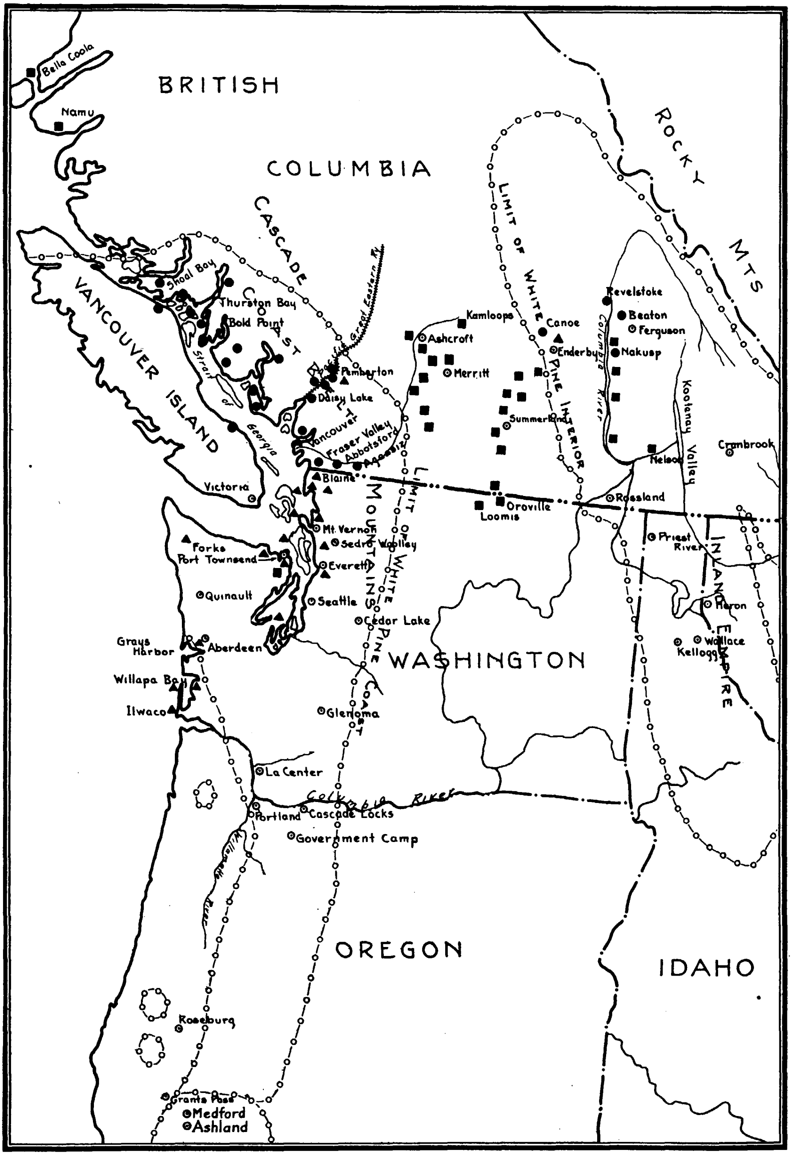

FIG. 2.—Location of infection centers: ☾, Pine infection; ▲, 1922 Ribes infection; ■, 1923 Ribes infection

aecia in 1920, 1921, or 1922. On the other hand, if the infections had occurred in 1921, there should have been some fruiting cankers in the 1921 internodes. Several thousand infected branches and stems were examined in 1923. In only one instance was a fruiting canker found in a 1921 internode. It is believed that aecia are usually produced in the third year after infection occurs (*8, p. 25–26*).[3] This is borne out by the writer's field studies both in New York and in the Northwest.

From Table I it is evident that considerable infection occurred in 1920 near Bold Point, British Columbia. Similar observations were made in other localities in the immediate vicinity of older pine infections and Ribes. As field observations were continued through the summer of 1923, it became increasingly apparent that there had been a great deal more infection in 1921 than in 1920. The data given in Table II are typical for conditions found early in July with respect to incipient infections and those which produced aecia in 1923 for the first time.

TABLE II.—*Distribution of 141 infections found early in July, 1923*

Internode of—	Number of infections
1918	13
1919	45
1920	72
1921	11

Nineteen of these produced aecia in 1923 and were probably all infections of 1920. They were distributed as shown in Table III.

TABLE III.—*Distribution of 19 infections, probably of 1920, producing aecia for the first time in 1923*

Internode of—	Number of infections
1918	6
1919	11
1920	2

The 19 infections shown in Table III subtracted from the 141 in Table II leave 122, distributed as shown in Table IV. These are all, or nearly all, infections of 1921.

TABLE IV.—*Distribution of 122 infections found in July, 1923, all, or nearly all, of which are infections of 1921*

Internode of—	Number of infections
1918	7
1919	34
1920	70
1921	11

The totals 19 and 122 (Tables III and IV) show fairly well the relative number of 1920 and 1921 infections apparent by the first week in July. As the season advanced both the actual and the relative number of incipient (1921) infections increased. Table V shows the distribution of 162 incipient infections counted the second week in August.

TABLE V.—*Distribution of 162 incipient infections found during second week of August, 1923*

Internode of—	Number of infections
1918	2
1919	32
1920	97
1921	31

These tables indicate that in any one year infection may occur in the internodes of four successive years.

The western white pine commonly retains its needles four years; that is, during the summer of a given year, as 1921, there will be needles upon the internodes of 1918, 1919, 1920, and 1921. In a favorable season it is probable that infection may occur in any of these needles. Practically all the rust mycelium, however, which might develop in the oldest needles would fail to reach the bark, since those needles would die and fall by the end of that season.

Since in any one year infection may occur in the internodes of three and occasionally four years, it is obviously impossible to determine by the position of a single canker the exact year in which infection occurred. When, however, a large number of cankers of approximately the same stages of development are found distributed through the internodes of three or four succes-

[3] Reference is made by number (italic) to "Literature cited," p. 608.

sive years, it is practically certain that infection resulted from exposure to sporidia in the last of these years.

A great many of the cankers found in 1922 had evidently produced aecia for three years, apparently beginning in 1920. This would indicate infection in 1917. Tabulations made in 1922 included all the infections found in any one place regardless of their stage of development. Table VI shows the distribution of 110 cankers found July 18, 1922, in one limited area near Mile 72, Pacific Great Eastern Railway, British Columbia.

TABLE VI.—*Distribution of 110 cankers found July 18, 1922, near Mile 72, Pacific Great Eastern Railway, British Columbia*

Internode of—	Number of infections
1914	1
1915	8
1916	59
1917	42

The data in this table are fairly typical for the distribution of the older cankers which were found in many places. Infection in 1917 is indicated.

Table VII shows the distribution of 54 cankers as found by A. T. Davidson (*1*) May, 1922, in a swamp at North Vancouver, British Columbia.

TABLE VII.—*Distribution of 54 cankers found May, 1922, in a swamp at North Vancouver, B. C.*

Internode of—	Number of infections
1912 or 1913	5
1915	8
1916	29
1917	12

With the exception of the five in the internodes of 1912 or 1913, these cankers were apparently of the same stage of development. They were probably the result of infection in 1917. The five in the internodes of 1912 or 1913 were several years older than the others. Some of them had started in branches which were dead when found in 1922. It was impossible to determine within two or three years the internode in which infection first occurred. A reexamination of one of the old cankers showed that it might have had its origin in the internode of either 1910 or 1911.

A few of the oldest cankers were found in other places. Two at Daisy Lake and one at Mile 28, Pacific Great Eastern Railway, evidently started in the internodes of 1912 or 1913. One at Thurston Bay, British Columbia, appeared to have started in the 1912 internode; one on Green Mountain, a mile from Bold Point, might have started in either the 1910 or the 1911 internode.

These oldest cankers were not less than 3 nor more than 5 years older than the cankers which seemed to have resulted from infection in 1917. All of them had their origin in the internodes of the years 1910 to 1913, inclusive. Although it is not certain that all began in 1913, any or all of them, from their apparent stage of development and position, might have resulted from infection in 1913. Tabulations of cankers in the immediate vicinity of these oldest cankers do not indicate infection in 1914 or 1915. They do indicate, however, that there was a little infection in 1916, much in 1917, a little in 1918 and 1919, much in 1920, and a great deal in 1921. If the oldest cankers had resulted from infection before 1913, there should have been enough aeciospore production to have caused at least a little infection of Ribes and pine in the immediate vicinity earlier than 1916.

The data presented might seem to indicate that pine infection in any given locality has been largely proportional to the number of aeciospores produced in that locality. This is undoubtedly true in limited areas where an abundance of Ribes is present. It is also true that the greater the amount of aeciospore production the greater the chances for their wide distribution and infection of Ribes. The more important fact, however, is that initial infection of pine in localities where the disease has not previously occurred, and heavy infection near Ribes as well as at some distance from them, have not been proportional to aeciospore production. From the data obtained it is evident that the rust became established in several localities, probably in 1913. No evidence was found to indicate that it was established in any other locality before 1917. There is no reason to believe that there were less aeciospores in 1914, 1915, or 1916 than there were before 1914. As a matter of fact, there were probably many more in 1916 than in any previous year.

In 1917 very heavy infection occurred, not only near the older infections, but at considerable distances from Ribes. At the same time the rust became established in many localities where it had not been present previously.[4] In 1918 and 1919 aeciospore production was probably greater than in any previous year, yet infection was apparently less than in 1917, and the rust became established in few if any places where it was not already present. In 1920 the production of aeciospores was enormously increased, for the infections of 1917 resulted in aecia in 1920. No new centers of infection seem to have been established and heavy infection was confined to the immediate vicinity of fruiting cankers near Ribes.

The field studies of 1923 showed the relatively greater amount of infection in 1921 than in 1920. (See Tables II, IV, and V.) Incipient, or 1921, infections were found in the Fraser Valley near Abbotsford, B. C., and in various places along the Pacific Great Eastern Railway, not only in localities in which no 1920 infections were found, but at much greater distances from the infecting Ribes than any of the 1920 infections. They were found frequently as much as a mile from the infecting Ribes. The 1920 infections, on the other hand, were seldom over 100 yards from the infecting Ribes. The infection of pine in the North Vancouver swamp illustrates very well the frequency of general or widespread infection. In Table VII it is shown that in the North Vancouver swamp there was infection probably in 1913 and again in 1917. Further studies made in August 1923 by H. G. Lachmund [5] showed incipient infections such as those noted in Table V. These indicate a third period of infection in 1921.

From the tabulation given and from numerous field observations, the years of heaviest and most widespread infection appear to have been 1913, 1917, and 1921. As these waves or periods of infection can not be explained on the basis of abundance of aeciospore production, the attempt was made to correlate them with weather conditions.

HISTORY AND DISTRIBUTION OF THE RUST

It has already been shown that considerable infection of pine had occurred in British Columbia not later than 1913. Infection occurred at North Vancouver, at various places along the route of the Pacific Great Eastern Railway, at least 60 miles north of Vancouver, and at Bold Point, Thurston Bay, and Shoal Bay, a distance of 125 miles northwest of Vancouver.[6] There must have been considerable aeciospore production to have caused infection in so many widely separated places.

The only place in which the rust is known to have been present in the Province at that time is Point Grey, near Vancouver. In May, 1922, Davidson (*1*) found on Point Grey, near Vancouver, 180 eastern white pines (*Pinus strobus*), of which 68 were infected with the rust. Some of these had cankers in the growth of 1910. The 180 trees were all that remained of 1,000 which had been imported in 1910 from Ussy, France. Since infected white pines are known to have been shipped from Ussy in 1910 (*7, p. 36*), it is altogether probable that some of the trees imported into Vancouver were already infected. If so, aeciospores should have been produced by 1913, and it is of course entirely possible that they were produced in 1910, 1911, and 1912 also. The plantation on which the infected trees were growing was in an exposed situation upon one of the highest points of Point Grey, where the escaping aeciospores could have been caught easily by the winds and carried in every direction.

It is known that some five-needle pines were imported into Victoria from Europe earlier than 1910. There is no evidence, however, to show that any of them were diseased, nor is there any reason to believe that any pines have been carried into or transplanted in the other places in British Columbia where early infection occurred. Nor is it likely that the rust was carried into the places outside of Vancouver on cultivated black currants, for although these plants are found fre-

[4] LACHMUND, H. G. STUDIES ON WHITE PINE BLISTER RUST IN THE PACIFIC NORTHWEST. Report for 1923. [Unpublished. Typewritten copy in Office of Blister Rust Control, Bureau Plant Industry, U. S. Dept. Agriculture.]
PENNINGTON, L. H. FIELD INVESTIGATIONS OF THE WHITE-PINE BLISTER RUST IN WASHINGTON AND BRITISH COLUMBIA. Report for 1922. [Unpublished. Typewritten copy in Office of Blister Rust Control, Bureau of Plant Industry, U. S. Dept. Agr.]

[5] LACHMUND, H. G. Op. cit.

[6] See map (fig. 2) for localities mentioned.

quently in British Columbia, most of the oldest infections noted above were in places where they were absent. None were found at Thurston Bay and there was no evidence that any had ever been planted in that locality. The oldest infections at Bold Point were in a mountain ravine fully a mile from any black currants. This does not mean that the black currants were not susceptible to the rust, but rather that there was an abundance of susceptible wild Ribes near the infected pines. As a matter of fact, these cultivated black currants apparently caused infection in pines near them in 1917 and again in 1920 and 1921. At Shoal Bay the single old infection and two of more recent date evidently came from old cultivated black currants.

It has been pointed out that there was little or no infection in British Columbia in 1914 or 1915 and very little in 1916. In 1917, however, there seems to have been a great deal and a much wider spread of the rust than in any previous year. It advanced to the east 60 miles as far as Agassiz, 40 miles southeast to Blaine, Wash., north and west 150 miles practically to the limits of the white pine in the coast belt, and apparently eastward for at least 150 miles across the dry belt to Canoe, Revelstoke, and Beaton.

The infections at Agassiz were upon the outer branches of 30-year-old *Pinus strobus* [7] near cultivated black currants. The infected pine near Blaine and in nearly all the other places in the Fraser Valley were found in the vicinity of cultivated black currants.

Fourteen infections were found in 1922 east of the dry belt, 7 at Canoe, 1 at Revelstoke, and 6 at Beaton. They were apparently of the same age and were in the 1916 and 1917 internodes (*1*). Of seven cankers examined by the writer, five were in the 1916 internode and two in 1917 internodes. They were apparently of the same age as those found in the 1915, 1916, and 1917 internodes in the coast region.

No infection was found south of Blaine, although much more intensive scouting was carried on in Washington than in British Columbia. A great deal of the scouting was done by men who worked both in Washington and in British Columbia.

In 1918 and 1919 there was a little infection in the vicinity of the oldest cankers in the coast region.[8] In 1920 there was considerable infection in the immediate vicinity of Ribes near 1917 infections (see Table I). In 1921 there was a much heavier infection than in 1920 (see Tables II, IV, and V).

Very careful search was made during the summer of 1923 in the interior of British Columbia, particularly at Canoe, Revelstoke, and Beaton, to find and destroy all pine infections. Of these 88 are shown in Table VIII.

TABLE VIII.—*Distribution of 88 pine infections found at Canoe, Revelstoke, and Beaton, B. C., during the summer of 1923*

Internode of—	Number of infections at—		
	Canoe	Revel-stoke	Beaton
1917	4	5	1
1918	3	11	1
1919	1	9	9
1920	6	14	10
1921	6	8	----------

In addition to the 88 infections mentioned in Table VIII, 10 were later reported by Davidson (*2*). These with the 14 found in 1922 and the 1 at Nakusp make a total of 113 for the four centers east of the dry belt. These apparently represented three stages in the development of the disease, incipient infections, cankers of one year, and those which had produced aecia for three or four years. This is a very small number upon which to determine the exact years of infection. It has been suggested that the original infection occurred in 1918. From the age of the cankers, however, and their distribution in the branches and stems it seems more probable that infection first occurred in three of the localities in 1917, and that later infection occurred in 1920 and 1921. The single infection found at Nakusp was in the internode of 1919 or 1920. This could not have occurred earlier than 1919, and since it produced aecia in 1923, it probably did not occur later than 1920.

[7] These trees were brought from Ontario in about 1894 or 1895. No evidence was found to indicate that any of them were infected before 1917.

[8] One infection at least occurred in either 1919 or1920 at Nakusp, in the Columbia Valley.

There is no evidence that infection in these widely scattered centers was caused by the introduction of diseased pines or Ribes. No five-needled pines were found, except native *Pinus monticola.*

Since 1912, and particularly during the period of the war, there seems to have been very little transporting or planting of ornamental stock in British Columbia. The infections in pine were found in native trees in the immediate vicinity of old black currant bushes. The bushes at Revelstoke were said to have been brought from eastern Canada in 1898. It would have been a very unusual thing if the rust had been introduced into any one of these places upon pines or Ribes. That it should have been introduced into three or four widely separated places is practically outside the range of possibility. The Canadian scouts were unable to find any evidence that the rust had been introduced upon either pines or Ribes.

Little is known of the distribution of infection upon Ribes previous to 1922, except as it is indicated by the infection of pines. A little scouting was done late in the season of 1921 and some infection found upon cultivated black currants in the Puget Sound region near Port Townsend, Everett, and Mount Vernon, Wash. A great deal of scouting for the rust was done in 1922. Infection was found upon black currants in the Pemberton Meadows and near Mable Lake, B. C., and occasionally upon wild Ribes in many places in the Puget Sound region, near Forks, Grays Harbor, and in the vicinity of Willapa Bay, Wash. The black currant infections in the Willapa Bay region in the extreme southwestern part of Washington were fully 200 miles from the nearest known infection upon white pine and many miles from any 5-needled pines.

In 1923, infection was found upon susceptible wild Ribes in the Puget Sound region as far south as Chimacum, near Port Townsend. The cultivated black currants in this part of the State had been removed in 1922. No infection was discovered upon either the cultivated black currants or the wild Ribes in the Willapa Bay region. On the other hand, cultivated black currants were found infected at 26 places in the dry belt and the Columbia and Kootenay River Valleys in British Columbia.[9] On the coast infection was found at Namu and Bella Coola, 80 and 110 miles, respectively, north of the northern limit of white pine (*1*, *2*).[10]

WINDS IN THE NORTHWEST

The period of aeciospore production was found to be long and to vary considerably in different years. In 1922 aecia began to break open by the first week in May. The heaviest spore dispersal was between about May 15 and June 15. Considerable quantities of fresh aeciospores were found at Vancouver as late as July 5 and some were found in the mountains as late as July 18. In 1923, aecia began to break open the first week in April. The heaviest spore dispersal was between April 15 and May 15. Very few aeciospores were seen as late as June 29.

Possible agents for aeciospore distribution are winds, birds, animals, and man. It is scarcely conceivable that any considerable number of the Ribes infections in Washington or in British Columbia in either 1922 or 1923 could have been caused by spores carried by man. The large majority of the bushes had not been seen by any person who had been in the vicinity of infected pines before those bushes were discovered with infection. There are no other migrating animals which could have carried spores over the wide area in which infected Ribes were found.

Migratory birds move along the coast or north or south in the interior. They do not migrate east and west across the mountains. The species and subspecies of birds east of the Cascade Divide are largely different from those along the coast. It is very unusual to find a bird from the interior west of the Cascade Divide. Ribes infection in Washington was found before the migrating birds had returned from the north. The infections at Namu and Bella Coola are the only ones which by any stretch of the imagination could have been effected by birds. On the other hand, spores carried by winds may account for the infection wherever it has been found upon Ribes.

It is a well-known fact that the prevailing winds of the temperate regions of the earth's surface are from the west or southwest. Cyclones and anticyclones about centers of low or high barometric pressure cause temporary but more or less periodic variation in the direction and velocity of winds. The topography of the earth's surface

[9] See map for localities.

[10] LACHMUND, H. G. STUDIES ON WHITE PINE BLISTER RUST IN THE PACIFIC NORTHWEST. Report for 1923. [Unpublished. Typewritten copy in Office of Blister Rust Control, Bureau of Plant Industry, U. S. Dept. of Agriculture.]

causes local variation in the direction of surface winds. This is particularly marked in a broken country such as British Columbia and the Western States.

There is also considerable variation in the direction of wind in a given season in different years. For example, meteorological records for the northwest coast bear out the statements of close observers that a late spring and a dry summer are accompanied by an unusual aggregate of northerly winds. Tables IX and X show that in May and June the number of northerly winds, that is, those from the northeast, north, or northwest, at Seattle and Vancouver, is very considerable.

TABLE IX.—*Percentage of northerly winds at Seattle, Wash.*

Year	1917	1918	1919	1920	1921	1922	1923
May	28. 8	23	30	27	43	27	26
June	36	49	42	34	27	44	41

TABLE X.—*Percentage of northerly winds at Vancouver, B. C.*

Year	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923
May	12	18. 2	13. 1	19. 5	11. 5	13	15. 1	14. 3	20. 7	24. 8	16. 1
June	23	25. 1	13. 2	17	23. 1	27. 6	23	33. 3	24. 5	38. 4	24

When taken in connection with Tables IX and X given above, the anemometer records for 1922 show fairly well the amount of wind movement from the different directions at representative stations in the region under consideration. Table XI shows the total number of miles which the wind traveled from each of the eight points during May and June of 1922:

TABLE XI.—*Anemometer records showing the number of miles which the wind traveled from each of eight points during May and June, 1922*

Station	Direction								
	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Total
	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
Vancouver, B. C.:									
May	41	211	749	769	312	398	270	706	3, 456
June	72	105	443	445	154	310	348	885	2, 762
Steveston, B. C.:									
May	70	189	739	1, 450	1, 172	973	619	1, 078	6, 290
June	204	22	846	1, 235	999	364	582	1, 262	5, 514
Victoria, B. C.:									
May	724	633	212	387	1, 304	4, 739	814	27	8, 840
June	247	234	61	63	1, 966	6, 191	241	31	9, 034
Summerland, B. C.:									
May	904	303	510	1, 168	430	865	716	1, 164	6, 060
June	1, 350	99	83	571	83	1, 273	720	2, 497	6, 676
Seattle, Wash.:									
May	1, 103	626	383	825	2, 246	1, 468	531	307	7, 489
June	1, 119	523	14	375	1, 253	717	661	730	5, 392
Portland, Oreg.:									
May	702	199	832	197	561	827	685	2, 094	6, 097
June	1, 082	76	29	127	184	177	185	2, 144	4, 004
Roseburg, Oreg.:									
May	811	139	28	34	167	346	271	694	2, 490
June	1, 381	89	31	6	22	60	130	636	2, 355
Red Bluff, Calif.:									
May	1, 060	36	19	1, 045	246	38	291	2, 213	4, 948
June	323	40	112	1, 665	866	50	34	529	3, 619
San Francisco, Calif.:									
May	207	81	28	105	77	1, 615	4, 788	776	7, 677
June	--------	32	20	36	23	1, 581	5, 420	88	7, 200

19977—25†——2

The Victoria and San Francisco stations are in exposed situations and record more of the prevailing winds of the coast. The Vancouver and Roseburg Stations are in more sheltered situations and, consequently, record less of the prevailing winds. The latter do, however, give a good record of local and surface winds.

Anemometer records, as well as the recorded observations of many weather bureau observers, show that the Strait of Georgia, Washington Sound, and Puget Sound form a very favorable channel for the movement of a wide current of air from the northwest down into the interior and southwestern part of Washington. There are periods of one to several days with continuous northerly winds. Between May 26 and June 26, 1922, the Seattle records show that there were three such periods with winds, as follows:

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
May 26–31	502	207	186					60
June 15–18	227	298	3			6	89	143
June 23–26	321	82				3	70	200

The continuity of the surface winds is interrupted by cross currents caused by mountains and valleys below, and by countercurrents in the upper atmosphere. The valley of the Columbia River causes particularly strong currents to the east or west. Pilot balloon records at Camp Lewis, Wash., show that for June, 1922, the direction of the prevailing winds at the surface was northwest and that above 1,500 feet elevation the prevailing direction was southwest. Rarely would it be possible for the same body of air to move from the Strait of Georgia across Washington into Oregon. There was, however, one brief period, June 16 and 17, 1922, when this might have occurred. During these two days there were 502 miles of northerly wind at Seattle, Wash., and 453 miles at Portland, Oreg. The pilot balloon at Camp Lewis showed for June 17 a continuous north wind up to an elevation of 5,000 feet.

In a similar manner the air moves southward over western Oregon, especially along the Willamette Valleys into southern Oregon and northern California. Although there are more intervening valleys and mountains here than in the north, their influence is offset by the relatively greater number of north winds.

Between the Cascades and the Rocky Mountains, wind movements are similar to those west of the Cascades. The anemometer records for Summerland, B. C. (Table XI) may be taken as fairly representative for the valleys which extend north and south in the interior and southeastern part of British Columbia. Observations made twice each day at Nelson, B. C., give the frequency of the winds at that station for 1922 as follows:

Direction	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	Total observations
May	1	7	4	12	1	5	8	17	7	62
June	4	2	2	6	1	2	12	16	15	60

Although there are no anemometer records for northeastern Washington and northern Idaho, the eye observations by meteorologists in that part of the country indicate considerable northerly wind in the north and south valleys. There is probably as much northerly wind at any one place in these valleys as in Puget Sound. They are, however, relatively narrow. The country is more broken, and the daily range of the temperature is greater. These factors all tend to break the continuity of air currents and make it improbable that they can flow continuously in the interior as far as they do along the Strait of Georgia and Puget Sound. It should be noted that Summerland is in the dry country between the white pine belts and that there is a greater amount of northerly wind in the dry belt than in country farther east. The continuity of northerly winds down the Arrow Lake Valley is broken by cross currents at Nelson.

PRECIPITATION IN THE NORTHWEST

Infection of Ribes and probably nearly all infection of pines is dependent upon moisture conditions during the summer months. This statement is based largely upon the writer's observations and experiments upon the rust in the Eastern States. In some localities near the coast fog may be an important factor. Precipitation records, however, have been found to indicate very well the moisture conditions in any given locality, that is, with a few exceptions, the total precipitation for a month indicates fairly well the favorableness of the weather during that month for the development of the rust.

Precipitation records (Table XII) for Vancouver are representative of the moisture conditions for practically all the coast region in which the rust has been found. They also illustrate very well the variation in amount which may be expected in different years at any place in the white pine country (Tables XIII to XVI).

TABLE XII.—*Precipitation, in inches, of rainfall for June, July, and August at Vancouver, B. C.*

Year	June	July	August	Total
1913	3.75	2.02	0.85	6.62
1914	3.58	.42	.75	4.75
1915	.91	.91	.36	2.18
1916	1.34	5.35	.58	7.27
1917	5.40	.48	.93	6.81
1918	1.00	2.20	4.50	7.70
1919	.98	.15	1.15	2.28
1920	3.08	.67	2.91	6.66
1921	3.64	.32	.84	6.80
1922	.17	.02	2.01	2.20
1923	2.08	.52		

TABLE XIII.—*Average summer precipitation, in inches, for stations at or near which infection has been found upon pines*

	June	July	August	Total or average for season
Agassiz, B. C	4.54	2.05	2.55	9.14
Blaine, Wash	2.12	.88	1.22	4.22
Enderby, B. C	2.06	1.29	1.21	4.56
Ferguson, B. C	2.64	2.01	2.06	6.71
Pemberton, B. C	1.46	.97	1.51	3.94
Revelstoke, B. C	2.69	2.49	2.49	7.67
Vancouver, B. C	2.59	1.31	1.74	5.64

TABLE XIV.—*Average summer precipitation, in inches, at stations in the inland region of white pine*

	June	July	August	Total or average for season
Cranbrook, B. C	1.62	1.51	0.93	4.06
Enderby, B. C	2.06	1.29	1.21	4.56
Ferguson, B. C	2.64	2.01	2.06	6.71
Nelson, B. C	2.44	1.70	1.51	5.65
Revelstoke, B. C	2.69	2.49	2.49	7.67
Rossland, B. C	2.33	1.38	1.23	4.94
Priest River, Idaho	1.73	1.13	1.17	4.03
Kellogg, Idaho	1.99	1.10	1.07	4.16
Wallace, Idaho	2.15	1.13	1.21	4.49
Dayson, Mont	2.35	1.25	1.22	4.82
Fortine, Mont	2.71	1.52	1.48	5.71
Heron, Mont	1.89	1.46	1.22	4.57
Polson, Mont	2.22	1.17	.93	4.32

TABLE XV.—*Average summer precipitation, in inches, at stations in Western Washington, Oregon, and Northern California*

	June	July	August	Total or average for season
Aberdeen, Wash	3.36	1.17	1.06	5.59
Cedar Lake, Wash	5.23	2.34	2.48	10.05
Glenoma, Wash	2.43	1.17	1.50	5.10
La Center, Wash	2.36	.95	1.06	4.37
Quinault, Wash	5.29	1.53	2.17	8.99
Sedro Woolley, Wash	2.68	1.46	1.70	5.84
Cascade Locks, Oreg	2.39	.80	.92	4.11
Cascadia, Oreg	3.16	1.04	1.05	5.25
Government Camp, Oreg	3.28	1.58	1.90	6.76
Prospect, Oreg	1.44	.66	.32	2.42
Grants Pass, Oreg	.85	.17	.23	1.25
Jacksonville, Oreg	.96	.33	.32	1.61
Medford, Oreg	.84	.43	.13	1.40
Montague, Calif	.75	.45	.20	1.40
Sisson, Calif	.62	.16	.30	1.08
Summit, Calif	.56	.22	.11	.89

All available data show somewhat less summer precipitation in the "Inland Empire" and in the greater part of western Washington than in the coast region of British Columbia. The amount of precipitation for the summer months diminishes southward. In southern Oregon and northern California many seasons have no precipitation during the summer season. Table XVI, precipitation for Summit, Calif., represents the conditions at nearly all places in the sugar-pine country. This shows that rarely is there a summer with precipitation equal to that of the driest of the British Columbia stations at which the rust has been found.

It is to be noted that, as a rule, the summers with the greatest amount of northerly wind have the least precipitation.

TABLE XVI.—*Precipitation, in inches, during June, July, and August, 1871 to 1922, inclusive, at Summit, Calif.*

	June	July	August	Total
1871	0.89	0.00	0.00	0.89
1872	.00	.00	.00	.00
1873	.00	.03	Trace	.03
1874	Trace	.00	.00	--------
1875	2.55	Trace	.00	2.55
1876	Trace	1.21	.10	1.31
1877	.12	.00	.00	.12
1878	.00	.00	.09	.09
1879	.10	.00	.00	.10
1880	.00	.80	.00	.80
1881	.50	.00	.00	.50
1882	.00	.00	.00	00
1883	.00	.00	.00	.00
1884	4.04	.00	.00	4.04
1885	.80	.00	Trace	.80
1886	.00	.00	.00	.00
1887	1.60	.10	Trace	1.70
1888	3.72	3.51	.28	7.51
1889	.22	.00	.00	.22
1890	.00	.00	.00	.00
1891	.00	.00	.00	.00
1892	.20	.00	.00	.20
1893	.00	.00	.00	.00
1894	.00	.00	.00	.00
1895	.00	.00	.00	.00
1896	.00	.21	.02	.23
1897	0.70	0.00	0.00	0.70
1898	.90	.00	.00	.90
1899	.70	.00	1.00	1.70
1900	.50	.25	Trace	.75
1901	.00	.00	.00	.00
1902	.30	.00	1.00	1.30
1903	Trace	.00	.00	--------
1904	.05	.04	.03	.12
1905	1.40	Trace	.00	1.40
1906	2.10	Trace	1.00	3.10
1907	2.22	.12	Trace	2.34
1908	.44	.00	.76	1.20
1909	.88	.00	.00	.88
1910	.00	1.16	.00	1.16
1911	.04	.00	.00	.04
1912	.20	.30	.00	.50
1913	.05	2.45	.15	2.65
1914	1.19	.00	Trace	1.19
1915	.00	.55	Trace	.55
1916	.05	.50	Trace	.55
1917	.00	.00	.21	.21
1918	.15	.00	.16	.31
1919	.00	.00	.00	.00
1920	1.60	.00	.67	2.27
1921	.57	.00	.00	.57
1922	.78	.00	.00	.78

DISCUSSION

The prevailing winds and the distribution of precipitation through the summer months have favored the spread of the white pine blister rust in the coast region of British Columbia to the north and northwest, as well as along the valleys to the north and east through the Cascade Mountains. Although aeciospores have been produced in increasing numbers since 1913, at least, and there have been winds sufficient to carry them long distances in every direction, it is apparent that but one season in four has been favorable for any considerable spread of the rust. There was a little infection in the other years. This occurred, however, only in the immediate vicinity of Ribes growing near pines with fruiting cankers.

It is not difficult to understand why very little infection occurred in the years with light summer precipitation, as 1915, with a total of 2.18 inches and 1919 with 2.28 inches, as compared with the average of 5.64 inches, and 6.81 inches for 1917 or 6.80 inches for 1921. On the other hand, it is not easy to see why infection was not greater in other years with a fairly high summer precipitation. In this connection it is necessary to note the requirements for general or heavy infection.

Heavy precipitation in the period of aeciospore production has been observed to reduce greatly the dispersal of spores by washing them out of the aecia. In moist weather many of the aeciospores germinate within the aecia. Their germ tubes then prevent or retard the dispersal of the remaining spores.[11] After the spores are deposited upon Ribes leaves there must be a period with sufficient moisture to permit them to germinate and invade the leaf tissue. After uredospores begin to form there must be occasional moist periods to permit further infection of the leaves if there are to be any considerable number of telia produced. After telia are produced there must be a period favorable for the production of sporidia and the immediate infection of pine needles.

The production of sporidia and the infection of the pine needle seems to be a most critical point in the life history of the rust. York and Snell (*10*) found that a continuous period of 18½ hours with a practically saturated atmosphere is necessary to secure infection of the pine needle. The sporidia are delicate and short-lived. Whatever the combination of circumstances or causes may be, it seems to be a fact that little infection of pine will result in the year with a very dry summer. It is also true that heavy infection does not always occur in years with normal or more than the normal summer precipitation.

The infection in the interior of British Columbia at Canoe, Revelstoke, and Beaton can scarcely be attributed to any other source than wind-borne aeciospores from the coast. The infection at Nakusp may have resulted in the same way or by aeciospores carried down the Columbia Valley

[11] From the author's unpublished manuscript.

from Beaton or Revelstoke. These places are all in the path of the prevailing winds from the coast. There are frequently strong surface winds which blow up through the valley along the Pacific Great Eastern Railway and over the divide into the interior.

The widespread infection of black currants in 1923 at many places in the dry belt, as well as to the east of it, is further evidence of wind dissemination. A glance at the map shows that these places also are all east of the region of heavy pine infection and in line with the prevailing westerly winds from the coast.

The widely distributed infection of Ribes in western Washington in the season of 1922 must have been caused by long-distance spread of aeciospores from British Columbia. This was made possible by the enormous number of spores produced through an unusually long season, from the middle of May until the middle of July, and by the unusual amount of northerly winds at certain periods which came down the Strait of Georgia, through Puget Sound, and spread over the country to the south and west.

All the evidence seems to indicate that long-distance spread of the rust has been caused by wind-borne aeciospores. The only remaining explanation requires long-distance spread by uredospores or a gradual spread and overwintering upon Ribes. Long-distance dissemination of uredospores would be much more remarkable than long distance dissemination of aeciospores. All field studies made by the writer in the East as well as in the West fail to show any considerable spread of the rust by uredospores (*6*). Overwintering upon *Ribes nigrum* has been demonstrated twice under experimental conditions. On the other hand, many experiments have given negative results. Field observations have never shown that the rust has overwintered upon either cultivated or wild Ribes (*8, p. 68–71*). The rust did not survive the winter of 1922–23 upon *R. nigrum* in the Willapa Bay region of southwestern Washington. The bushes on four plantations, all heavily infected in 1922, failed to show any infection in 1923. These were examined in June and again the last week in August. All the other *R. nigrum* in this part of the State were eradicated in 1922. The plants in question were to be destroyed in the autumn of 1923.

It is very improbable that these spores came from local pine infections in Washington. The distribution of the infected Ribes indicated a distant source of spores. If the spores did not come a long distance there must have been many local centers of infection. Thorough scouting, however, failed to show any fruiting cankers in Washington. Many of the infected Ribes, particularly those in the Willapa Bay region, were long distances from any five-needle pines. (See figs. 1 and 2.)

Aeciospores are well adapted for dissemination by air currents. They are dry and powdery and retain their vitality for many days or weeks under adverse conditions. Smut spores are known to be carried long distances by wind (*4*.) Spores of wheat rust have been found over 10,000 feet above the surface of the earth (*9*).[12]

All the species of Ribes found in British Columbia were in a dormant condition and without leaves by the middle of December, 1922, and they so remained until April, 1923. In February, 1923, many plantations of *Ribes nigrum* were examined in Washington and in Oregon as far south as Ashland. All were found to be perfectly dormant, without leaves and with no buds opening. Below Roseburg, Oreg., some wild Ribes were found with a few green leaves of 1922, and buds beginning to open. All the Ribes seen in Washington were in a dormant condition at that time. It has been reported, however, that *R. sanguinium* as far north as Seattle holds a few of its old leaves until the next season's buds open. It appears that the chances for overwintering were very slight even if there had been uredospores upon the old leaves. Many infected *R. nigrum* leaves collected late in October and in November, 1922, were examined. No uredospores, however, could be found upon them.

In the vicinity of Port Townsend, infection was found again in 1923 upon Ribes in the same locality in which it appeared in 1922. In one instance the same plants of *R. bracteosum* and *R. divaricatum* were found with infection in 1922 and in 1923. These were some 9 or 10 miles from the *R. nigrum* which were found infected in 1921. This place is near Puget Sound, less than 80 miles from infected pine in British Columbia. It is altogether probable that these plants as well as many others in favorable situations upon Puget Sound may become infected each year by aeciospores from

[12] Since this paper was submitted for publication, J. A. Larsen (*5*) has called attention to wind dissemination of dust from Oregon and Washington to northern Idaho and Montana.

British Columbia. The probability of overwintering of *Cronartium ribicola* does not seem to be greater in the Northwest than in the Northeastern States.

It is not easy to predict accurately how rapidly the rust will move southward either west of the Cascades or in the "Inland Empire." Its history indicates that its spread upon pine to the south is relatively slow, not over 40 miles since it was introduced into Vancouver in 1910. The fact that north winds accompany dry seasons seems to be an important factor favoring a slower spread of the rust toward the south. On the other hand, *Ribes nigrum,* and to some extent other species of Ribes, may become infected in dry seasons like 1922, and a little pine infection may occur. The volume of aeciospore production is increasing each year in British Columbia. Infection has appeared in the Puget Sound region for at least three years in succession. It is practically certain, therefore, that the rust will become established in western Washington within a few years. When it is once established there, and aeciospores are produced in considerable quantities, it will tend to spread into and through the Cascades to the north and east. Aeciospores may then be carried southward into Oregon and when it becomes established there north winds may carry aeciospores into southern Oregon and northern California.

Although it is scarcely possible that much, if any, infection may occur in the sugar pine region (fig. 1) during the usual dry season, it is very probable that abundant infection may occur in the occasional wet summers such as those of 1888, 1906, and 1913. This possibility is emphasized by the presence of a similar rust, *Cronartium pyriforme,* upon the yellow pine in northern California.

The white pine in the "Inland Empre" is in line with the prevailing winds from the coast. It is also in line with local currents which move southward along the Columbia and Kootenay Valleys. The spread of infection in 1923 to *Ribes nigrum* in the interior of British Columbia and northeastern Washington shows that spores of the rust are practically certain to be carried into the white pine regions of Idaho and Montana. When this happens, infection of pine will depend upon moisture conditions and the presence of susceptible Ribes.

Comparison of the summer precipitation at various stations (Tables XII, XIII, and XIV) in the white pine districts shows less summer rainfall in the interior of British Columbia than upon the coast. It also shows less for Idaho and Montana than for places farther north in British Columbia. The average summer precipitation for these three districts is as follows.[13]

	Inches
Coast region of British Columbia	6.58
Interior of British Columbia	5.93
Idaho and Montana	4.68

These figures indicate, other conditions being equal, that infection of pine should be less severe in the interior than upon the coast of British Columbia. The relatively small amount of infection thus far discovered in eastern British Columbia seems to substantiate this claim (see Table VIII). For the same reason infection should become established more slowly and be less severe in Idaho and Montana than in eastern British Columbia.

The destruction of all infected pine material which has been found in eastern British Columbia should tend to retard the spread of the rust.

It is a significant fact that all the pine infection in eastern British Columbia can be attributed to *Ribes nigrum* and that practically all the infected Ribes found in the dry belt or east of it were this species.

Climatic factors can not be changed materially by man, but the elimination of *Ribes nigrum* from the pine districts of Idaho and Montana should lengthen greatly the time before the rust becomes established in these States.

SUMMARY

The white-pine blister rust has been in British Columbia at least since 1910.

It became widespread by 1913.

It has spread upon the white pine practically to the north and east limits of the coast belt of white pine.

It has spread a relatively short distance to the south.

It has become established at four places in the eastern belt of white pine in British Columbia.

An average of one season in every four years has been favorable for general spread of the disease along the coast of British Columbia.

In the summer of 1922 there was infection of Ribes by aeciospores as far south as Ilwaco, Wash. In 1923 infection was not found south of the vicinity of Port Townsend, Wash.

[13] These figures were obtained by taking an average for the six stations in each district with the greatest summer precipitation. The data for British Columbia is from "Climate of British Columbia," by F. Napier Denison (*3*).

In 1923 infection was found on Ribes at Namu and Bella Coola, 80 and 110 miles, respectively, north of the limit of white pine upon the coast.

Prevailing westerly winds favor aeciospore dispersal from the coast toward the east.

Northerly winds, which favor aeciospore dispersal to the south, are most common in dry seasons, which are unfavorable for pine infection.

West of the Cascades, northerly winds in the period of aeciospore production increase to the southward as far as northern California.

The amount of summer precipitation diminishes southward.

The rust is practically certain to spread southward at a much slower rate than to the north and east.

The spread of the rust to the "Inland Empire" may be greatly retarded by the elimination of *Ribes nigrum* from that region.

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