United States
Department of
Agriculture

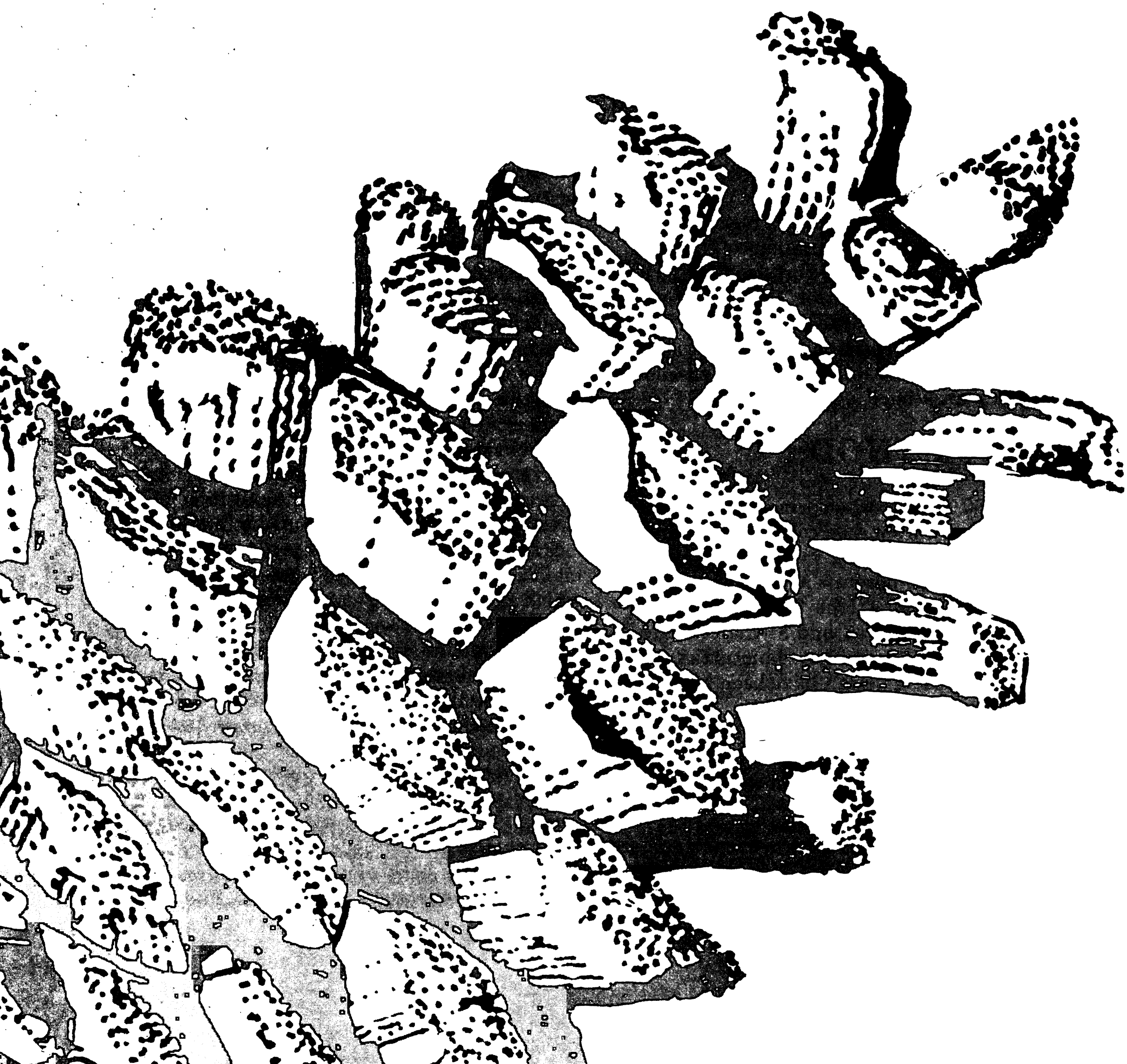
Forest
Service

North Central
Forest Experiment
Station

Research
Paper NC-225

The Susceptibility of Jack Pine from Lake States Seed Sources to Insects and Diseases

A.C. Hodson, D.W. French, R.A. Jensen, and R.J. Bartelt



THE SUSCEPTIBILITY OF JACK PINE FROM LAKE STATES SEED SOURCES TO INSECT AND DISEASE PESTS[1]

A. C. Hodson, *Professor Emeritus, Entomology, Fisheries and Wildlife,*
D. W. French, *Department Head and Professor, Plant Pathology,*
R. A. Jensen, *Associate Scientist, Cloquet Forestry Center,*
and **R. J. Bartelt,** *Research Associate, Entomology, Fisheries and Wildlife,*
University of Minnesota, St. Paul, Minnesota

Jack pine (*Pinus banksiana* Lamb.) grown from seed collected from different locations varies in its susceptibility to attack by certain insects and diseases. The North Central Forest Experiment Station and the University of Minnesota worked together to determine the range in variability of jack pine susceptibility in the Lake States Region. Seed was collected from locations throughout Michigan, Wisconsin, and Minnesota and planted in several plantations within each State. Insect and disease incidence has been previously reported for plantations of the same seed sources located in National Forests of the three States (Arend *et al.* 1961, Batzer 1961, King and Nienstaedt 1965, King 1971, Jeffers and Jensen 1980). In this publication we report on the results of the disease and insect susceptibility found in three of the Minnesota plantations.

METHODS

In the fall of 1953 and the spring of 1954, jack pine seedlings grown from seed collected in Minnesota, Wisconsin, and Michigan were established in three plantations in Minnesota—at the Cloquet Forestry Center at Cloquet, at the General Andrews State Forest at Willow River, and at the Pillsbury State Forest north of Pillager. The origins of the seed sources and the planting design have been reported elsewhere (Jensen *et al.* 1960, King 1971). Four replicates of each of 29 sources plus jack pine grown from seed collected from one local source were planted in 4 randomized blocks of 30 sources at each location.

[1]*Paper Number 11,628 Science Journal Series, Minnesota Agricultural Experiment Station, St. Paul, Minnesota.*

The 16 center trees in each of the four, 64-tree replicates for each seed source were identified by source number and examined in the early fall each year from 1955 through 1961. Type and height above ground of injury by insects or fungi were recorded for each tree. For pine-oak rust (*Cronartium quercuum* (Berk.) Miyabe) percentage of the main stem encompassed by galls was also recorded. For both the eastern pineshoot borer (*Eucosoma gloriola* Hein.) and the northern pitch twig moth (*Petrova albicapitana* (Busck.)) only leader damage was reported. For the redheaded pine sawfly (*Neodiprion lecontei* (Fitch)) and the white pine weevil (*Pissodes strobi* (Peck)), tree height and the height of the living portion were also measured.

In the early fall of 1978 all the injured trees could be identified as to cause of injury were re-examined. At this time occurrence of pests, probable cause of death, tree form, and diameter were recorded. Each tree was examined for straightness of the first 9 feet of the stem and classified into one of the following four categories: Class 1—trees with relatively straight main stems; Class 2—trees with stem deviations in which any point along a straight line connecting the center of the stem would not fall outside the body of the stem on either side of a crook; Class 3—trees for which points along such a straight line would fall outside the body of the stem; and Class 4—forked or stag-headed trees (Alm and Jensen 1969).

Two factors that could reasonably affect the degree of pest attack were the seed source and the planting site. To sort this out, our analysis was done using categorical methods (Fienberg 1977). For each seed source in each plantation, the number of attacked and nonattacked trees were tabulated. For the pine-oak rust, the 1978 data were included in the analysis. The data were thus in the form of a three-dimensional contingency table, with the factors being: whether or not attacked (2 levels), seed source (30 levels), and block (12 levels). The analysis was based on the model of "no second-order interaction" (Fienberg 1977), which carries the interpretation: "In a group of trees, the ratio of those attacked to those not attacked depends on the seed source of the group and on the site of the group, but the effect of seed source on this ratio is constant from site to site." The explicit form of the model underlying this contingency table analysis can be written:

$$\log\left(\frac{A_{ij}}{N_{ij}}\right) = K + S_i + B_j,$$

where A_{ij} is the number of trees in group (ij) attacked and N_{ij} is the number not attacked. K is a constant depending on the overall rate of attack, Si_i is the effect due to seed source (i), and B_j is the effect due to block (j). The right-hand side looks exactly like an analysis of variance model, and the usual ANOVA constraints apply:

$$\Sigma S_i = 0, \Sigma B_j = 0.$$

Calculations were done using an iterative proportional fitting program (Fienberg 1977).

Spatial patterns of infestation became evident when the residuals of this initial analysis were plotted on the plantation maps. The blocks were so large that infestation was not uniform, even after allowing for differences due to seed sources. There were "hot spots" of heavy infestation and other areas nearly devoid of infestation in many of the blocks. Therefore, the blocks were redefined as smaller square areas, each containing 4 seed sources (instead of the original 30). Each of these smaller blocks was more realistically described by a single B_j characteristic. Using these 90 blocks instead of the 12 large ones changed the form of the contingency table from "complete" to "incomplete," but the form of the model and the calculation procedure remained as above.

The summary statistics of the model for three pests show the Pearson's statistic is significant for all, indicating that larger than expected residual variability remained (table 1). It would have been surprising if so simple a probability model had fitted such a large data set very well. However, the lack of fit was minor compared with the variability "explained" by the model, and subsequent statistical tests are believed to be reasonable. The lack of fit was spread evenly over data; no residuals were very large, and no spatial or varietal patterns were obvious.

Of greatest importance is the test of whether "real" differences in susceptibility existed in the seed sources (whether one or more of the S_1 are not equal to 0). In all cases, the conditional likelihood ratio statistic, G^2, was highly significant, $p < 0.005$, indicating that the seed sources are **not** all the same in susceptibility. (G^2 is exactly parallel to the F test for treatments in an analysis of variance, except that G^2 is compared to the chi-square distribution rather than the F distribution.)

Similarly, the conditional G^2 for blocks was also highly significant. If the block effect had not been included in the analysis, the categorial analysis would have failed badly. Degree of attack differed considerably from area-to-area, probably due to variation in population density.

An important question is whether the differences among seed sources are consistent from plantation to plantation. A model including the seed source by

Table 1.—*Results of statistical tests for susceptibility to insect and disease pests of jack pine from 30 seed sources from the Lake States*

Test	Type of injury: Eastern pine shoot borer	Pine-oak rust	Northern pitch twig moth[1]
Overall fit of model:			
Pearson's statistic	[3]300.1	[3]302.9	[3]226.3
df	241	[2]239	151
Chi-square (0.05)	276.9	274.5	179.6
Test for differences among seed sources (allowing for differences among plots)			
Conditional G^2	77.3	459.8	54.9
df	29	29	29
p level	<<0.005	<<0.005	≈0.005
Test for differences among plots (allowing for differences among seed sources			
Conditional G^2	401.2	769.2	189.2
df	89	89	59
p level	<<0.005	<<0.005	<<0.005
Test for consistency of seed source differences from plantation to plantation			
Conditional G^2	74.1	77.0[3]	49.3
df	60	60	30
p level	>0.05	>0.05	≈0.01

[1]The Pillsbury plantation was omitted from the analysis for the pitch twig moth because this pest was almost absent in this plantation.
[2]Two groups of 16 trees were missing in the Pillsbury plantation in 1978 so the error degrees of freedom were reduced by 2.
[3]Significant at 0.05 level.

plantation interaction was fitted for each pest. This interaction was not significant ($p > 0.05$) for the eastern pineshoot borer or pine-oak rust, but it was for the northern pitch twig moth ($p \approx 0.01$). The consistency of the shoot borer and rust results suggest good predictive value, but the pitch twig moth results are suspect: if they are not consistent between the plantations, we do not know what to expect in future plantings.

To determine the susceptibility of the various sources to attack by the shoot borer, pine-oak rust, and twig moth, the estimates of the S_i parameters of the model were calculated from the fitted values of the contingency table. Rather than listing the S_i, however, we listed $\exp(S_i)$ because the latter have the following intuitive meaning: "If the overall attack rate in the experiment had been 50 percent and if block effects were negligible, the ratio of attacked to nonattacked trees in seed source (i) is estimated by $\exp(S_i)$," referred to below as "susceptibility." One is "average," and the higher it is, the more susceptible the seed source.

Two seed sources are compared by taking the ratio of their susceptibilities. This ratio has the following meaning: "If seed from two sources is planted in a small, uniform area, and if the seed source in the denominator of the ratio is 50 percent infested, the ratio represents the predicted ratio of attacked to nonattacked trees for the other source." This ratio of susceptibilities is also the estimate of the cross product ratio discussed in Fienberg (1977), which is a commonly used measure of association.

How large must this ratio of susceptibilities be to be "significant," that is, for the two seed sources to be considered genuinely "different"? A number of contrasts were computed, testing if seed sources, taken two at a time, were different from each other. The conditional G^2 statistics were plotted against the ratios of susceptibilities (larger over smaller). These points formed a "tight" curve, from which the ratios corresponding to 0.05 and 0.01 levels of the chi-square distribution could be read. These smallest significant ratios are parallel to the least significant differences in an analysis of variance.

RESULTS

Eastern Pineshoot Borer, *Eucosoma gloriola* Hein.

The injury caused by the eastern pineshoot borer is easily identifiable. Infested leaders break off from 2 to 8 mm above the base leaving a flat-topped stub. This injury can cause various degrees of stem crookedness or more rarely forked trees, and often results in trees becoming suppressed.

The infestation rate in the three plantations ranged from 41 to 15 percent (table 2). The average rates of infestation for the individual plantations were 18, 37, and 30 for Cloquet, General Andrews, and Pillsbury, respectively. The percentages of infestation for trees grown from seed collected from each of the three States were 28 for Minnesota, 26 for Wisconsin, and 27 for Michigan.

Trees from the more northerly sources were most susceptible to shoot borer infestation (table 2). To investigate this geographical relation, the logarithms of the susceptibilities were regressed on latitude and longitude of the seed source origins. Only latitude was a significant predictor ($t = 3.197$, $p < 0.005$), the correlation coefficient being 0.53. Susceptibility increased on the average by a factor of

Table 2.—*Susceptibility and infestation rate of jack pine from 30 seed sources to the eastern pineshoot borer*

Seed source (number)	Latitude	Susceptibility[1]	Infestation
	Degrees		*Percent*
1592	47.75	1.81	40
1594	48.03	1.74	38
1621	46.60	1.56	41
1615	46.26	1.52	36
1601	47.48	1.45	34
1593	48.00	1.38	36
1607	45.86	1.34	29
1618	45.00	1.27	29
1613	46.56	1.27	32
1608	45.89	1.25	29
1605	46.75	1.20	31
1604	46.36	1.14	28
1597	47.08	1.11	31
1589	47.00	1.07	30
Local	—	1.05	27
1600	46.75	1.05	30
1595	45.95	1.05	25
1602	47.74	1.03	34
1609	45.28	.94	28
1610	45.75	.93	24
1614	46.20	.91	25
1591	47.55	.80	28
1596	46.30	.76	25
1611	44.45	.76	22
1616	44.26	.64	19
1620	44.52	.60	23
1612	46.22	.58	22
1606	46.02	.56	19
1590	47.34	.56	17
1617	44.34	.47	15

[1]Any two susceptibilities with a ratio (larger over smaller) of less than 1.9 are not significantly different at the 0.05 level.

1.19 for each degree increase in latitude. King (1971) also found a positive correlation between the incidence of attack by the eastern pineshoot borer and latitude in the National Forest plantations he studied. His data show sources 1592 and 1593 from Minnesota and 1615 and 1621 from Michigan to be the most susceptible. These sources along with Minnesota sources 1601 and 1594 were the most most heavily infested in the three Minnesota plantations we investigated. The sources showing the lowest infestation rates were Minnesota sources 1595 and 1590, Wisconsin sources 1609 and 1611, and Michigan sources 1616 and 1617. King's data also show these same sources with low percentages of dead leaders, except source 1611 which had a high percentage of dead leaders in their plantations. In a 20-year study of tree response, Jeffers *et al.* (1980) recorded heights, diameters, and volumes for the various seed sources and found that the sources with the poorest height and diameter growth were the same as those that we found most susceptible to shoot borer injury.

Tree heights and degree of shoot borer infestation were compared for the Cloquet and General Andrews plantations (table 3). Trees between 1.52 and 2.1 meters tall sustained the greatest damage in both plantations. It was unusual to find a tree more than 3 meters tall with an injured leader and little damage occurred during the first 2 years after planting.

Pine-Oak Rust, *Cronartium quercuum* (Berk.) Miyabe

The galls formed on the main stem and branches as the result of pine-oak rust infection are easily distinguishable from other insect and disease damage by their globose form. Another rust on jack pine caused by *Endrocronaitium harknessi* (J. P. Moore) Y. Hiratsuka, which also causes globose galls, does not occur where these plantations are located. The records of infection included the number of stem galls, their height above the ground, and the extent they enveloped the circumference of the tree.

When the seed sources were ranked according to their susceptibility, the highest susceptibility was almost three times greater than the like value obtained from the shoot borer (table 4). The average percentage of trees infected in the three plantations was markedly different—36, 19, and 61, respectively, for Cloquet, General Andrews, and Pillsbury. The average percentage by State of origin was less different—37 for Minnesota, 30 for Wisconsin, and 41 for Michigan.

Table 3.—*Average number of trees infested by the eastern pineshoot borer in the Cloquet and General Andrews Plantations by height*

(In numbers)

State of seed source	Tree height (meters)				
	0.3-0.88	0.91-1.5	1.52-2.1	2.13-2.71	2.74-3.32
CLOQUET PLANTATION					
Minnesota	1.5	4.4	5.0	2.5	1.8
Wisconsin	1.0	5.5	5.0	2.0	3.0
Michigan	2.0	3.6	4.7	2.5	1.0
Average	1.5	4.4	5.0	2.5	1.8
GENERAL ANDREWS PLANTATION					
Minnesota	9.6	9.8	13.8	7.5	0
Wisconsin	5.4	9.4	8.7	0	0
Michigan	8.3	8.1	10.7	7.0	0
Average	7.8	9.1	11.1	7.8	0

Table 4.—*Susceptibility and infection rate of jack pine from 30 seed sources to pine-oak rust seed source*

Seed source (number)	Latitude	Longitude	Susceptibility[1]	Infected
	Degrees			*Percent*
1592	47.75	91.23	5.23	62
1602	47.75	93.28	4.39	60
1621	46.60	85.38	3.66	64
1612	46.22	89.20	3.35	50
1594	48.03	92.42	3.08	57
1593	48.00	90.33	2.67	59
1614	46.26	86.62	2.40	60
1615	46.26	84.84	2.09	54
1610	45.75	89.93	1.83	48
1606	46.02	88.93	1.62	42
1608	45.89	92.03	1.46	40
1613	46.56	89.02	1.36	46
1591	47.55	93.73	1.25	36
1596	46.30	92.93	1.25	38
1601	47.48	95.00	1.15	31
1618	45.00	83.54	.94	31
1617	44.34	84.12	.78	29
1597	47.08	95.47	.73	32
1590	47.34	94.52	.73	27
1607	45.86	89.17	.73	37
1589	47.00	94.00	.63	31
1616	44.26	86.26	.52	15
Local	—	—	.50	25
1605	46.75	90.95	.49	26
1604	46.36	91.73	.49	26
1600	46.75	93.97	.47	22
1620	44.52	85.37	.32	17
1609	45.28	92.55	.23	17
1611	44.45	89.72	.16	6
1595	45.95	92.55	.13	12

[1]Any two susceptibilities with a ratio (larger over smaller) of less than 2.2 are not significantly different at the 0.05 level.

In all three plantations, 1592, 1593, 1594, and 1602 had the highest infection rate among the Minnesota sources. Those with the highest incidence of the rust in sources from Wisconsin were 1610 and 1606, and from Michigan 1621, 1614, and 1615. For the Minnesota sources the least susceptible were 1595 and 1600 with corresponding low ranking for Wisconsin sources 1609 and 1611 and for Michigan sources 1616, 1617, and 1620. Arend *et al.* (1961) found source 1592 highly susceptible, and King (1971) also found Minnesota sources 1594, 1602, 1592, and 1593 most susceptible in that order. These same sources were the most heavily infected in our study. King also found Wisconsin sources 1606 and 1610 with a high rate of infection and 1614, 1615, and 1621 high for Michigan. His data showed that the trees least susceptible to the rust were identical with those in our plantings, 1595 and 1600 from Minnesota, 1609 and 1611 from Wisconsin, and 1610 and 1620 from Michigan. Jeffers and Jensen (1980) stated that sources with the highest rust incidence had the smallest diameters. This is inconsistent with our results because the largest diameter trees in the Pillsbury plantation had the highest infection rate.

The average percentage of pine-oak rust infection was much higher in the Pillsbury plantation than in the other two. This can be explained by the large amount of red oak surrounding the plantation and the fact that pine-oak rust is abundant in this part of Minnesota. Trees grown from seed collected at the most northern latitudes were more susceptible to pine-oak rust (table 4). The validity of this relation was tested by the method described for the eastern pineshoot borer. The overall correlation coefficient was 0.80 ($r^2 = 0.636$) and both latitude and longitude had significant coefficients ($t = 6.68$ and -4.90, respectively, $p < 0.001$). The susceptibility to attack increased with the increase of the latitude of the seed source but decreased with increasing longitude, by a factor of 2.44 for the increase of each degree north, and a factor of 1.228 for each longitude degree to the east. King (1917) also found the northern-most sources with the highest incidence of rust infection. He suggested that the southern sources may have been subjected to more severe selection for resistance, whereas the northern sources, where the alternate red oak host is not as plentiful, may not have been exposed to as much selection pressure.

Because we recorded the extent pine-oak galls encompassed the stems of infected trees, it was possible to relate gall development with the response of infected trees (table 5). Rust-infected trees were categorized by the amount of their stem that was encompassed by galls (either less than 75 percent or more than 75 percent) and by whether they were alive or dead. The numbers were tabulated separately for each seed source. These data were analyzed as a 30x4 contingency table to determine whether the disease progressed the same way in all 30 seed sources, given that all trees were infected. Pearson's statistic was highly significant ($X^2 = 133$ with 87 df, $p < 0.005$), but the lack of fit was due to the small number of observations. Sources 1604, 1617, and 1595 had fewer than average numbers of dead trees with greater than 75 percent of their stem encompassed by galls. Sources 1604 and 1595 had low infection rates. Sources 1621 and 1606 had a greater than average proportion in this class, and source 1594 had a larger than average number of trees that were alive with greater than average proportion of the stem encompassed by galls. These three sources (1621, 1606, and 1594) had been among those with the highest infection rate. Although suggestive, these differences were based on small numbers of trees. Except for these observations, there was no evidence that the 30 seed sources did not behave uniformly with respect to progression of the disease. However, as might be expected, more trees died that had more than 75 percent of the stem encircled by galls. Of the trees with more than 75 percent of the stem encompassed by galls, over-all an average of 93 percent died, while 81 percent with less of the stem encircled lived.

The analysis was repeated with the data categorized by how the gall changed from 1 year to the next: increased in size, decreased in size, remained the same, or closed (table 5). Again, Pearson's statistic was significant($X^2 = 145$ with 87 df, $p < 0.005$), but again the lack of fit was due to a small number of trees. Of greatest interest, sources 1605 and 1608 had a greater than average number of trees with galls that were closed and 1591 had a smaller than average number of trees with galls that increased in size. It should be noted that some of the trees included in these analyses may have died from causes other than rust infection. This would be more likely for the trees with less than 75 percent of the stem encircled by the gall.

The greatest number of pine-oak rust galls for both the General Andrews and the Pillsbury plantations occurred while the trees were less than 1.5 m tall (table 6). The greatest number at the Cloquet plantation occurred when the trees were from 2.25 to 4.57 m tall. The only other notable differences between plantations were the somewhat greater number of taller trees, those ranging from 4.9 to 6.1 meters, infected in the Pillsbury plantation.

Table 5.—*Trees infected with pine-oak rust by size of gall, and change in gall development from year to year (Pillsbury Plantation)*

(In percent)

State of seed source	Amount of stem encompassed by a gall: Less than 75 percent, Alive	Less than 75 percent, Dead	More than 75 percent, Alive	More than 75 percent, Dead	Annual change in gall encompassed of stem: Increased	Decreased	None	Closed
Minnesota	63	14	2	21	59	15	12	13
Wisconsin	67	13	1	19	59	10	5	17
Michigan	57	20	2	21	63	6	10	11

The Northern Pitch Twig Moth, *Petrova albicapitana* (Busck.)

The northern pitch twig moth forms conspicuous thin-walled pitchy blisters at the base of terminal shoots or at twig crotches under which the larvae feed. This insect has a 2-year life cycle with the most obvious blisters being formed the second year. In all three of our plantations there was only a single brood because second year blisters were found every other year: 1955, 1957, 1959, and 1961. The damage caused by larval feeding may kill terminal twigs including the leader. However, we saw few dead leaders (table 7). In a few cases, the leader was broken over and when the bent leader continued to grow it formed a goose-necked crook.

Table 6.—*Trees infected by pine-oak rust by tree height*

(In numbers)

State of seed source	Tree height (meters): 0-1.5	1.82-3.04	3.35-4.57	4.88-6.09	6.4+	Total
CLOQUET PLANTATION						
Minnesota	2.8	4.0	19.9	1.2	0	27.8
Wisconsin	2.0	6.0	17.3	0.9	0	26.1
Michigan	2.6	4.3	23.0	1.3	0	31.2
Average	2.5	4.8	20.1	1.1	0.0	28.4
GENERAL ANDREWS PLANTATION						
Minnesota	10.9	2.2	0.5	0.1	0.1	14.1
Wisconsin	5.5	2.1	0.6	0	0	8.5
Michigan	11.7	2.6	1.2	0.4	0	14.4
Average	9.4	2.1	0.8	0.2	0.03	12.3
PILLSBURY PLANTATION						
Minnesota	37.2	4.2	5.5	1.6	0	46.9
Wisconsin	22.2	2.3	4.5	0.5	0	29.7
Michigan	34.8	4.3	9.2	2.6	0	50.8
Average	31.4	3.6	6.4	1.6	0.0	42.5

The analyses to determine the significance of differences in source susceptibility and the relation of latitude to seed source damage were as described for

Table 7.—*Susceptibility and infestation rate of jack pine from 30 seed sources to nothern pitch twig moth (based on only the trees with twig moth blisters on the leaders) at the Cloquet and General Andrews Plantations*

Seed source (number)	Latitude	Susceptibility[1]	Infested
	Degrees		*Percent*
1596	46.30	2.00	66
1600	46.75	1.60	62
1620	44.52	1.56	62
1593	48.00	1.42	58
1607	45.86	1.40	59
1616	44.26	1.28	60
1601	47.48	1.26	53
1618	45.00	1.22	53
1610	45.75	1.20	52
1591	47.55	1.18	55
1613	46.56	1.18	50
1608	45.89	1.10	54
1612	6.22	1.06	55
1597	47.08	1.04	52
1614	46.24	1.02	46
1621	46.60	1.02	43
1605	46.75	1.00	50
1615	46.26	.98	48
1595	45.95	.92	50
1589	47.00	.88	45
1590	47.34	.84	45
1617	44.34	.82	41
1606	46.02	.80	44
1594	48.03	.74	42
1592	47.75	.74	47
1604	46.36	.72	47
1611	44.45	.70	44
1602	47.75	.64	45
1609	45.28	.62	44
Local	—	.50	38

[1]Any two susceptibilities with a ratio (larger over smaller) of less than 1.9 are not significantly different at the 0.05 level.

the other two pests. There were significant differences among seed sources ($p \approx 0.005$), but they were not consistent from plantation to plantation ($p \approx 0.01$) as they were for the eastern pineshoot borer and the pine-oak rust (table 1).

The average percentage of leaders attacked for the sources from each of the three States were almost identical—51, 49, and 51 for Minnesota, Wisconsin, and Michigan, respectively. The sources showing the least susceptibility to twig moth infestation were local (Minnesota), 1609 and 1611 (Wisconsin), and 1617 (Michigan). These same sources also had the lowest percentage of attack by the eastern pineshoot borer and the pine-oak rust, except for the local Minnesota sources. Source susceptibility was not related to latitude or longitude of the source origins for the northern pitch twig moth. King (1971) reported that he found no significant differences among seed sources for this insect in the National Forest plantation he investigated.

Additional Insects

Because of the small number of trees infested by the following insects, we were not able to detect significant results by statistical analysis. Therefore, we will discuss the sources showing only the highest and lowest infestation rates.

The White Pine Weevil, Pissodes strobi *(Peck)*

The greatest number of trees damaged by the white pine weevil were from sources 1595 and 1600 (Minnesota), 1609 and 1611 (Wisconsin), and 1618 and 1620 (Michigan). These sources were among the lowest to be infested by the pine shoot moth and the pine-oak rust. King (1971) also found 1609 and 1611 with a high rate of weeviling and that the five sources with low infestation rates were shorter than average while the four most heavily weeviled sources were taller than average, although the differences are not significant. Batzer (1961) also found sources 1595, 1609, and 1611 to have a high rate of weevil attack. Arend *et al.* (1961) agreed that Wisconsin sources 1609 and 1611 were susceptible to weevil damage. Our data and those of King (1971) show Minnesota 1593, Wisconsin 1606, and Michigan 1621 to be remarkably free of weevil attack.

The Redheaded Pine Sawfly, Neodiprion lecontei *(Fitch)*

The General Andrews Nursery plantation was the only one with many trees that were defoliated by the redheaded pine sawfly. Consequently, our remarks will be based on the infestation in that planting. The sources with by far the highest rate of attack were the local source and Wisconsin source 1606. Arend *et al.* (1961) also found source 1606 to have the highest rate of infestations for trees planted in Michigan's Lower Peninsula. The other sources that were defoliated were 1595 and 1594 from Minnesota, 1604 and 1608 from Wisconsin, and 1612 and 1614 from Michigan. Those showing the least susceptibility to attack were 1589 and 1593, 1611 and 1605, and 1613 and 1621 for Minnesota, Wisconsin, and Michigan, respectively. The heaviest defoliation occurred in 1958 during the fifth summer the trees were in the planting. By the time the canopies had begun to close in 1961, no trees were defoliated by this sawfly.

The Pine Tortoise Scale, Toumyella parvicornis *(Cockerell)*

The General Andrews plantation was the only one significantly damaged by the pine tortoise scale. Of all the seed sources Minnesota source 1595 had the most severe infestation. Others with less injury but with substantial infestation were 1592, 1594, and 1591 (Minnesota), 1606 and 1608 (Wisconsin), and 1613 and 1614 (Michigan). The least infested trees were found in the Minnesota local source, Wisconsin sources 1607 and 1609, and Michigan sources 1615 and 1618.

A Bud Moth, Petrova pallipennis *Mcd.*

The bud moth was not economically important in any of the plantations but did destroy the terminal buds of some trees. The sources with the heaviest infestation were 1592 and 1593 from Minnesota, 1609 from Wisconsin, and 1612 from Michigan.

The Causes of Death

In the fall of 1978 the various causes of individual tree mortality were recorded on the basis of current and past history of damage caused by certain insects, the pine-oak rust fungus, and miscellaneous causes such as porcupine feeding, snow breakage, and windthrow. In only the Pillsbury plantation pocket gophers caused severe losses of 30, 31, and 23 percent for Minnesota, Wisconsin, and Michigan, in that order. Suppression and pine-oak gall infections were the most common causes of death (table 8). For the Minnesota and Michigan sources the gall rust dominated, while for the Wisconsin sources suppression was the cause of most of the mortality. The redheaded pine sawfly killed few trees. The percent mor-

Table 8.—*Estimated cause of death for trees in the three plantations by seed source*
(In percent)

Source number	Unknown	Suppression	Cause of death Eastern pine shoot borer	Pine-oak rust fungus	Redheaded pine sawfly	Miscellaneous[1]
			MINNESOTA SOURCES			
1589	18	22	30	20	10	0
1590	49	18	6	19	2	6
1591	33	31	8	25	0	3
1592	23	9	2	62	2	2
1593	35	10	10	43	0	2
1594	21	10	13	44	6	6
1595	33	21	21	10	2	12
1596	29	12	9	32	0	18
1597	31	8	15	35	3	8
1600	32	11	13	13	9	22
1601	15	23	15	39	2	6
1602	26	8	5	54	0	7
					11	
Local	39	22	7	12	9	
Average	29	16	12	31	4	8
			WISCONSIN SOURCES			
1604	65	11	8	8	5	3
1605	39	19	21	9	2	10
1606	55	21	1	14	5	4
1607	37	20	8	18	2	15
1608	35	16	14	23	4	8
1609	47	21	3	15	3	11
1610	44	15	4	30	0	7
1611	45	27	12	6	0	10
Average	46	19	9	15	3	8
			MICHIGAN SOURCES			
1612	46	11	3	29	6	5
1613	34	11	6	34	2	13
1614	26	15	13	39	2	5
1615	31	8	8	38	2	13
1616	60	16	8	13	0	3
1617	48	21	7	15	9	0
1618	29	29	6	19	2	15
1620	44	17	7	17	0	15
1621	25	16	2	57	0	0
Average	38	16	7	29	3	7

[1]Miscellaneous causes include porcupine and pocket gopher feeding, snow-breakage, windthrow, etc.

tality due to the eastern pineshoot borer and the pine-oak rust were regressed on the logarithms of the susceptibilities to these pests. The percent of mortality caused by the eastern pineshoot borer was not related to the percent infestation ($r = 0.098$, $p > 0.5$). In sharp contrast the percent mortality caused by the pine-oak rust was significantly related to the percent infection ($r = 0.852$, $p << 0.001$).

Affect of Pest Damage on Average Height Growth, 1958 to 1964

The heights of all trees were measured in 1958 and 1963 in the Cloquet plantation and in 1958 and 1964 at the Pillsbury plantation (table 9). The height

Table 9.—*Average height growth of jack pine from 1958 to 1963 for the Cloquet plantation and from 1958 to 1964 for the Pillsbury plantation as related to pest attach*

(In meters)

State of seed source	None	Eastern pine shoot borer	Pine-oak rust	Northern pitch twig moth	Whitepine weevil
CLOQUET PLANTATION					
Minnesota	2.8	2.6	2.5	2.8	2.6
Wisconsin	2.7	2.6	2.8	2.8	2.6
Michigan	2.9	2.6	2.7	2.8	2.3
Average	2.8	2.6	2.7	2.8	2.5
PILLSBURY PLANTATION					
Minnesota	3.7	3.3	3.6	3.6	—
Wisconsin	3.8	3.5	3.7	4.0	—
Michigan	3.9	3.5	3.8	—	—
Average	3.8	3.4	3.7	3.8	—

increase of uninfested trees was not significantly different from that of trees attacked by the pine-oak rust fungus and the northern pitch twig moth. For the eastern pine shoot moth and the white pine weevil, however, the differences were significant. The average height increase of shoot borer-damaged trees was 0.2 meter less than that for the pestfree trees at Cloquet and 0.4 meter less at Pillsbury. The weevil-infested trees also grew about 1/3 meter less than the pestfree trees.

Affect of Pest Damage on Average Height Growth, 1958 to 1968

The effects of insect attack and rust infection are somewhat different for ths longer period of time than those presented above (table 10). For all three plantations, trees with leaders killed by the shoot moth had a smaller average height increase than the pestfree trees. The trees infected with pine-oak rust also grew less than those not infected in the Cloquet and Pillsbury plantations. Healthy and infected trees in the General Andrews plantation grew at approximately the same rate. The growth of trees infested by the northern pitch twig moth was consistently greater than that for the pestfree trees, which suggests that this species might have been attracted to the taller trees. Redheaded pine sawfly defoliation caused by far the greatest reduction in height growth, probably because this pest destroys much more than just leaders.

Table 10.—*Average height growth of jack pine from 1958 to 1968 as related to pest damage*

(In meters)

State of seed source	None	Eastern pine shoot borer	Pine-oak rust	Northern pitch twig moth	Redheaded pine sawfly
CLOQUET PLANTATION					
Minnesota	4.5	4.2	4.0	4.4	—
Wisconsin	4.2	4.4	4.3	4.5	—
Michigan	4.5	4.2	4.3	4.3	—
Average	4.4	4.3	4.2	4.4	—
GENERAL ANDREWS PLANTATION					
Minnesota	5.2	5.0	4.9	5.5	4.7
Wisconsin	5.5	5.3	5.5	5.4	4.9
Michigan	5.4	5.4	5.8	5.5	5.1
Average	5.4	5.3	5.4	5.5	4.9
PILLSBURY PLANTATION					
Minnesota	5.9	5.1	5.7	6.4	4.6
Wisconsin	5.8	5.7	5.6	6.5	—
Michigan	5.9	5.4	5.4	7.4	—
Average	5.9	5.4	5.6	6.8	—
AVERAGE FOR THE THREE PLANTATIONS					
	5.2	5.0	5.1	5.6	—

Affect of Pest Damage on Diameter and Form of Trees

In the fall of 1978 all the living trees in the three plantations were measured for diameter and rated for form (table 11). The average figures for diameter were consistent irrespective of the State from which seed was obtained but trees in the Pillsbury plantation had a greater average diameter. Overall, attack by the eastern pineshoot borer and redheaded pine sawfly caused the greatest reduction in diameter. Trees infected by the pine-oak rust had the same average diameter as noninfected trees.

The form ratings for the three plantations and the seed sources from the three States were remarkably constant. The effect of much earlier infestations by the shoot borer, sawfly, and the weevil is evident by the much higher ratings for all three than for the pestfree trees. As was noted for diameter, the form of trees infected by pine-oak rust was as good as that of noninfected trees.

SUMMARY AND CONCLUSIONS

The susceptibility to attack by insect and disease pests of jack pine grown from seed collected in 13

Table 11.—*Diameter and form of trees in the three plantations as related to pest damages, 1978*

Type of damage	Diameter by plantation			Form rating[1] by plantation		
	Cloquet	Andrews	Pillsbury	Cloquet	Andrews	Pillsbury
MINNESOTA SOURCES						
None	11.4	10.7	13.5	2.0	1.9	2.2
Eastern pine shoot borer	9.9	10.2	13.5	2.5	2.4	2.7
Pine-oak rust	11.4	10.4	14.2	1.9	2.0	2.2
Redheaded pine sawfly	7.9	9.6	—	3.0	2.2	—
White pine weevil	9.6	12.7	—	3.5	3.0	—
WISCONSIN SOURCES						
None	11.9	11.2	12.9	1.9	2.1	2.1
Eastern borer	10.4	10.7	13.4	2.6	2.3	2.6
Pine-oak rust	10.7	11.2	13.4	2.1	1.8	2.2
Redheaded pine sawfly	—	9.4	—	—	2.2	—
White pine weevil	11.4	12.4	11.9	2.9	3.0	3.0
MICHIGAN SOURCES						
None	11.4	10.7	12.9	1.9	2.0	1.9
Eastern pine shoot borer	10.2	10.2	12.7	2.7	2.5	2.7
Pine-oak rust	10.9	10.7	13.7	2.0	1.8	2.3
Redheaded pine sawfly	—	8.6	—	—	2.6	—
White pine weevil	—	13.4	—	—		

[1]Straight-boled trees were rated 1, somewhat crooked trees were rated 2, the crookedest trees were rated 3, and forked and stag-headed trees were rated 4.

Minnesota, 8 Wisconsin, and 9 Michigan localities was investigated in three Minnesota plantations. Significant differences in susceptibility to both insects and fungi were evident among the trees grown from the various seed sources. One striking feature was the high positive correlation between the latitude of sources and the percentage of trees attacked by the eastern pineshoot borer and the pine-oak rust—trees from the northern sources suffered the most severe injury. In sharp contrast and in spite of its common occurrence, the susceptibility of the various seed sources to infestation by the northern pitch twig moth was not affected by latitude.

The seed sources with the highest and lowest incidence of attack by the shoot borer and the rust were almost identical with those reported from similar plantations established in Wisconsin and Michigan. Jeffers and Jensen (1980) found that the northern Minnesota sources, which had the highest gall rust incidence, also exhibited the poorest survival and slowest growth. These sources—1592, 1593, 1594, and 1602—also were among the most severely damaged by the pineshoot borer in the three plantations in our study.

Suppression and infection by the pine-oak rust were by far the most important causes of death in these plantations. Also, the percentage of trees infected by the rust was highly correlated to the mortality caused by this fungus. This was not the case for the eastern pineshoot borer. However, the shoot borer, the white pine weevil, and the redheaded pine sawfly significantly reduced height growth, stem form, and diameter increment of the trees they infested. On the other hand, the growth of trees infested by the northern pitch twig moth was consistently greater than that for pestfree trees.

The occurrence of attack by all of the pest species included in this study was greatest in the early stages of tree growth. The maximum infestation by the shoot borer occurred when the trees were from 1 to 3 meters tall and for the pine-oak rust when the trees were from 1 to 6 meters tall.

The results of this study indicate that it may be difficult to find seed sources of jack pine that would produce trees reasonably free of the many pests that attack this host. For example, the sources that showed the least susceptibility to shoot borer and rust damage were among those with the highest incidence of attack by the white pine weevil, the redheaded pine sawfly, and the pine tortoise scale.

LITERATURE CITED

Alm, A. A.; Jensen, R. A. Results of a Lake States seed source test ineast-central Minnesota. MN For. Res. Note 200, 4 p; 1969.

Arend, J. L.; Smith, N. F.; Spurr, S. H.; Wright, J. W. Jack pinegeographic variation—five-year results from Lower Michigan tests. Proc. MI Academy of Sci., Arts and Letters 46: 219-238; 1961.

Batzer, H. O. Jack pine from Lake States seed sources differ in susceptibility to attack by the white-pine weevil. Tech. Note 595. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station; 1961. 2 p.

Fienberg, S. E. The analysis of cross-classified categorical data. Cambridge, Massachusetts: Massachusetts Institute of Technology Press; 1977.151 p.

Jeffers, R. M.; Jensen, R. A. Twenty-year results of the Lake States jack pine seed source study. Res. Pap. NC-181. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, 1980. 20 p

Jensen, R. A.; Schantz-Hanson, T.; Rudolf, P. O. A study of Jack pine seed source in the Lake States. MN For. Note 88, 2 p., 1960.

King, J. P. Pest susceptibility variation in the Lake States Jack pine seed sources. Res. Pap. NC-53. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1971. 10 p.

King, J. P.; Nienstaedt, H. Variation in needle case susceptibility among 29 jack pine seed sources. Silvae Genetica 14: 194-198; 1965.

Hodson, A. C.; French, D. W.; Jensen, R. A.; Bartelt, R. J.
The susceptibility of jack pine from Lake States seed sources to insects and diseases. Res. Pap. NC-225. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 12 p.

Describes the susceptibility to insect and disease pests of jack pine grown in three Minnesota plantations from seed collected in Minnesota, Wisconsin, and Michigan.

KEY WORDS: Eastern pineshoot borer, pine-oak rust, white pine weevil, redheaded pine sawfly, northern pitch twig moth, jack pine genetics.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication August 27, 1982
1982

U.S. GOVERNMENT PRINTING OFFICE:1982-665-450/161