Severity of *Endocronartium harknessii* in Two Provenance Stands of *Pinus ponderosa* in Michigan

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ABSTRACT

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Transplants (2-1 stock) representing 73 seed sources of *Pinus ponderosa* were planted at two sites 74 km apart in 1968 in southwestern Michigan. Before being planted in Michigan, 0.5% or less of the stock became infected with *Endocronartium harknessii* at a Nebraska nursery. In 1982, disease severity (number of galls per tree) was recorded for each tree and mapped. *P. ponderosa* var. *scopulorum* was more severely diseased than *P. ponderosa* var. *ponderosa* ($P = 0.05$). Within *P. ponderosa* var. *scopulorum*, two southern ecotypes, Colorado Plains and Southern Rockies, were more severely diseased than others ($P = 0.001$). Resistant and susceptible seed sources occurred within ecotypes of both varieties.

Western gall rust (pine-pine rust), caused by *Endocronartium harknessii* (J. P. Moore) Y. Hiratsuka, is an important disease of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.). The rust causes severe damage on ponderosa pine grown on Christmas tree plantations, windbreaks, experimental plots, forests, and nurseries (4,12,13,20).

Previous studies have reported genetic resistance of pines to rust fungi (11,14). Ponderosa pine shows differences between varieties (*P. ponderosa* var. *ponderosa* and *P. ponderosa* var. *scopulorum* Engelm.) in susceptibility to several pests (2,6,8,18). However, differences in susceptibility between varieties or ecotypes to *E. harknessii* have not been documented for ponderosa pine. Individual Scots pine (*P. sylvestris* L.) (4,9) and ponderosa pine (12) have shown resistance to *E. harknessii*, but differences in susceptibility have not been reported at the varietal level.

The objective of this study was to determine if variation in susceptibility to *E. harknessii* exists among seedlings of ponderosa pine from different geographic sources. A preliminary report of this work has been published (19).

MATERIALS AND METHODS

In 1965, seeds from 80 geographic sources throughout the natural range of ponderosa pine were planted at the U.S. Forest Service Bessey Nursery, in Halsey, NE. While at the nursery, 0.5% or less of the stock became infected with *E. harknessii* from a nearby forest and from a windbreak (10,13). Transplants (2-1 stock) of 73 seed sources representing eight ecotypes as defined by Read (15) (Fig. 1) were shipped to Michigan for planting in early April 1968. A summary of the 10-yr growth and survival of trees from these seed sources was reported by Read (16).

The trees were used to establish provenance stands of *P. ponderosa* vars. *ponderosa* and *scopulorum* at two sites 74 km apart in southwestern Michigan. One stand was planted at Kellogg Forest, Augusta, MI (spacing of 2.44 × 2.44 m), on rolling glacial moraine with 2–30% slopes. The stand was planted in Oshtemo sandy loam and loamy sand. The other stand was planted at Russ Forest, Volinia, MI (spacing of 1.83 × 1.83 m), in a Brady sandy loam on flat terrain. All transplants were planted in six-tree, east-west plots in five randomized complete blocks at each site. When available, one or two replacement trees were planted between trees five and six of the corresponding provenance group.

In 1982, rust severity was recorded for each of 4,389 trees, using a disease scale of 0–4, where 0 = no infection, 1 = 1–5 galls,

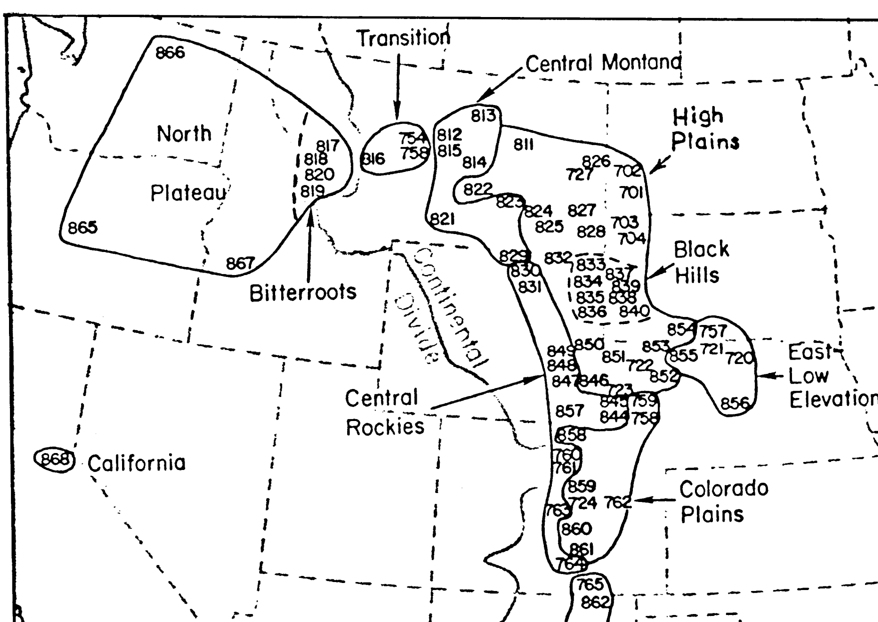

Fig. 1. Locations of 73 ponderosa pine provenance seed sources. *Pinus ponderosa* var. *ponderosa* includes California, North Plateau, Bitterroots, and Transition ecotypes. *P. ponderosa* var. *scopulorum* includes Central Montana, High Plains and Black Hills, East Low Elevation, Central Rockies, Colorado Plains, and Southern Rockies ecotypes (15).

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2 = 6–25 galls, 3 = 26–50 galls, and 4 = >50 galls. Gall rating, dead trees, and topography were mapped for each stand.

To verify the identity of the rust, peridermoid teliospores were collected in 00 gelatin capsules from one gall on each of 30 trees on 20 May 1982 at the Kellogg stand and from one gall on each of three trees at the Russ Forest stand on 21 May 1983. The fungus was identified as *E. harknessii* on the basis of germ tube morphology as described by Anderson and French (1).

RESULTS

Because infection within each stand was spotty, we chose to average the five plots (six trees each) within each site to obtain a more stable gall rating. Analysis of variance was performed with the experiment (site) as the blocking variable in a randomized block design. Mean gall ratings for provenance groups showed similar rankings at each forest stand. Variances at each stand were similar. The mean gall rating at Kellogg Forest (0.56) was significantly higher than that at Russ Forest (0.36, $P = 0.001$). The mean gall rating of *P. ponderosa* var. *scopulorum* (0.48) was significantly higher than that of *P. ponderosa* var. *ponderosa* (0.35, $LSD_{0.05} = 0.12$). Mean gall ratings for eight ecotypes indicated more disease in southern ecotypes ($P = 0.05$) (Table 1).

Resistant and susceptible provenance groups occurred within the same ecotype of either variety (the higher the percentage of infection of each provenance group, the higher the gall rating [$r = 0.91$]) (Table 1). Provenance groups were considered very resistant if no tree had more than five galls when at least two adjacent trees in different provenance groups had more than five infections. Four provenance groups were consistently very resistant (828, 866, 760, and 827). Mortality was low (2.5–9%) for all of these except 760 from Colorado (30.5%), which was the southernmost source. Michigan's climate may have been too cold and moist for trees from this seed source because they died of winter injury. Four provenance groups were consistently very susceptible (849, 762, 850, and 863). These eight sources represent a conservative estimate of very resistant and very susceptible provenance groups. For instance, although 764 had a low mean gall rating (0.11), two trees from this seed source had a gall rating of 2. The above definition of highly resistant provenance groups eliminates groups such as 764 as well as groups that had low mean gall ratings caused by escape from inoculum.

Infection centers were identified when 80% of the trees had ratings of 3 or higher. Infection centers appeared to be distributed throughout the stand at Russ Forest. At Kellogg Forest, infection centers occurred on the east side of the stand surrounding four initially infected trees (as indicated by basal galls). Spread of the rust appeared to have been restricted initially to the east side of the stand by a north-south ridge. A few galls were found on trees on the west side of the stand but were the result of more recent infections because they were located only in the upper portion of the crown. Gall rating was not closely associated with a tree's distance from the nearest low area at Kellogg Forest ($R^2 = 0.03$). The western gall rust fungus has not spread to other pine plantations from these two stands.

DISCUSSION

This study is the first to document differences in susceptibility to *E. harknessii* between *P. ponderosa* vars. *ponderosa* and *scopulorum*. It is also the first to document differences in susceptibility of ponderosa pine ecotypes within a variety. Differences in susceptibility to western gall rust among individual trees have been observed in ponderosa pine (12) and in Scots pine (4). In both cases, heavily infected trees were adjacent to trees of the same species with no infection. Hutchinson (9) detected differences among individual Scots pine trees in susceptibility to *E. harknessii* in inoculation tests.

Ponderosa pine has shown varietal and individual tree differences in susceptibility to other pests. Callahan (6) reported varietal differences in susceptibility of ponderosa pine to the pine reproduction weevil (*Cylindrocopturus eatoni* Buch.). *P. ponderosa* var. *ponderosa* was moderately susceptible; however, *P.*

Table 1. Severity of western gall rust caused by *Endocronartium harknessii* in 73 *Pinus ponderosa* provenance groups representing eight ecotypes planted in Michigan

Ecotype[v]		Provenance group[x]		
Name	Mean gall rating[w]	Identification number[y]	Percent infection	Gall rating[w]
North Plateau	0.33 a[z]	866	9.5	0.10
		865	34.0	0.47
		867	29.0	0.42
Bitterroots and Transition	0.36 a	754	20.0	0.23
		818	35.5	0.40
		819	33.5	0.46
		820	30.5	0.39
		817	27.5	0.32
Central Montana	0.39 a	814	21.5	0.18
		815	16.0	0.19
		813	25.5	0.27
		829	26.0	0.35
		812	35.0	0.55
		821	31.0	0.48
		823	41.5	0.72
East Low Elevation	0.36 a	855	18.0	0.29
		757	22.5	0.30
		856	15.5	0.27
		720	38.0	0.57
High Plains and Black Hills	0.42 a	828	3.0	0.03
		827	11.5	0.13
		722	15.5	0.21
		825	14.0	0.17
		853	19.0	0.21
		835	16.5	0.25
		832	16.0	0.18
		840	27.0	0.30
		851	22.0	0.38
		852	30.0	0.39
		723	25.0	0.40
		811	20.5	0.33
		838	15.0	0.33
		833	44.0	0.49
		826	27.5	0.45
		824	26.0	0.32
		701	50.5	0.78
		839	26.0	0.38
		704	13.5	0.20
		822	26.0	0.43
		836	40.5	0.81
		703	33.5	0.54
		727	40.5	0.75
		850	48.5	0.88
		702	37.5	0.75
		846	43.5	0.80
		834	31.5	0.63

(*continued on next page*)

Table 1. *(continued from preceding page)*

Ecotype[v]		Provenance group[x]		
Name	Mean gall rating[w]	Identification number[y]	Percent infection	Gall rating[w]
Central Rockies	0.46 ab	760	10.0	0.10
		763	27.5	0.32
		764	11.0	0.11
		857	19.0	0.32
		831	28.5	0.40
		845	39.0	0.51
		830	23.5	0.35
		761	30.5	0.40
		848	35.5	0.52
		849	64.0	0.94
		844	42.5	0.80
		847	44.0	0.80
Colorado Plains	0.67 b	861	25.5	0.43
		759	37.5	0.64
		858	32.0	0.55
		860	40.0	0.55
		859	48.0	0.72
		758	39.0	0.74
		762	50.0	0.92
		724	35.5	0.84
Southern Rockies	0.65 b	869	19.0	0.30
		767	49.0	0.69
		765	42.5	0.67
		862	38.5	0.68
		864	46.0	0.82
		766	18.5	0.51
		863	45.0	0.88
LSD 0.05			23.4	0.43

[v] *Pinus ponderosa* var. *ponderosa* includes North Plateau and Bitterroots and Transition ecotypes. *P. ponderosa* var. *scopulorum* includes Central Montana, East Low Elevation, High Plains and Black Hills, Central Rockies, Colorado Plains, and Southern Rockies ecotypes.

[w] Gall ratings were based on number of galls per tree: 0 = none, 1 = 1–5, 2 = 6–25, 3 = 26–50, and 4 = >50.

[x] Values reported as a mean of two forest stands. Each forest stand was planted in five randomized complete blocks of six-tree, east-west plots. Two extra trees were planted when available between trees five and six.

[y] Identification numbers are those used by Read (15). Detailed forest stand information about seed sources is available for gall rating, mortality, and percentage of infection from the first author.

[z] Numbers followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's new multiple range test.

ponderosa vars. *scopulorum* and *arizonica* (Engelm.) Shaw were highly susceptible. Ponderosa pines with resinous new shoots were highly susceptible to resin midge (*Retindiplosis* sp.), whereas trees with glaucous or glabrous new shoots were highly resistant (2). Glabrous shoots were common for southern ecotypes of ponderosa pine (15). *Arceuthobium vaginatum* (Willdenow) Presl. occurs on *P. ponderosa* vars. *arizonica* and *scopulorum* but not on *P. ponderosa* var. *ponderosa* (8). This, however, is due to the limited geographic extent of the mistletoe because inoculations show that *P. ponderosa* var. *ponderosa* is susceptible to this mistletoe (F. G. Hawksworth, *personal communication*). Rabbits and porcupines preferred to feed on *P. ponderosa* var. *ponderosa* rather than *P. ponderosa* var. *scopulorum*, but the opposite was true for deer (18).

The bases of resistance are unknown. The southern ecotypes initiate shoot elongation much later than other ecotypes (15). Because spores infect new shoots as they elongate, the southern ecotypes may be exposed to more inoculum or to conditions more suitable for efficacy of inoculum.

Ponderosa pine populations became discontinuous and isolated several times in the recent geological past (3). During the Tertiary period, large-scale volcanism was followed by arid periods (7). During the Pleistocene period, alpine glaciation disrupted the continuous mixed mesic forests. As the glaciers advanced, the high altitudes became colder and the low altitudes became dryer. Occasionally, as the cold and dry regions merged, pine was eliminated from some slopes (3,5). Microcyclic rusts could have evolved from macrocyclic rusts caused by the selection pressure of short summers (17). *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *banksianae* may have been divided by the advancing glaciers and in the west evolved into *E. harknessii*. *P. ponderosa* var. *ponderosa* was diverging in this region as well. Because *P. ponderosa* var. *ponderosa* is the least susceptible to *E. harknessii*, it could be that the fungus has coevolved longer with this variety than with other varieties of ponderosa pine.

In the western United States, frequency of natural infection is greatest in the Black Hills and East Low Elevation ecotypes, much less in the Colorado Plains and Central Rockies ecotypes, and least in the Southern Rockies ecotype (F. G. Hawksworth, *personal communication*). If *E. harknessii* is less adapted to the more southern climates or if it spread to those areas last, there would be less selection pressure for resistance to western gall rust. This may be the case because the southern ecotypes have the highest mean gall ratings in Michigan.

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