Ten-Year Results of a Comandra Blister Rust Screening Trial in the Central Interior of British Columbia

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Abstract—Improved resistance to comandra blister rust (causal agent: *Cronartium comandrae*) can improve lodgepole pine (*Pinus contorta* var. *latifolia*) survival and growth, but we lack information about resistance structure in this pathosystem. Incidence of comandra and other diseases was monitored annually in a 130-seedlot trial designed to both characterize the resistance structure in lodgepole pine and identify resistant families for inclusion in the tree improvement program in British Columbia, Canada. By 10 years of age, incidence of new comandra infection had largely stabilized on all three trial sites, having reached 79, 70, and 22 percent, respectively. However, close proximity to the alternate host plant, bastard toadflax (*Geocaulon lividum*), resulted in an increased risk of infection by comandra, and relatively high family-level variation between sites. Although most families appeared to be highly susceptible, a few families exhibited a moderate level of resistance. Based on these results, it is recommended that future additional screening of a much larger number of families be conducted to identify a sufficient number of families for either augmenting existing orchards or establishing a comandra-resistant orchard.

INTRODUCTION

Comandra blister rust (caused by *Cronartium comandrae*) is one of the most lethal diseases of young lodgepole pine (*Pinus contorta* var. *latifolia*) (van der Kamp and Spence 1987; Woods et al. 2000). It occurs throughout the Canadian province of British Columbia (BC), but is most common in the Sub Boreal Spruce (SBS) biogeoclimatic zone, and alternates between bastard toadflax (*Geocaulon lividum*) and lodgepole pine (Ziller 1974). Management options include increased composition of nonhost species in reforestation, but some of the colder, drier, or more nutrient-poor ecosystems may not be well suited for these other species (Reich and van der Kamp 1993). Increased planting density of lodgepole pine (proportional to risk) is practiced in some areas, but this can be costly where risk to comandra is very high (British Columbia Ministry of Forests 1996). Hazard rating for comandra (Jacobi et al. 1993) identified several key variables including proximity to alternate host. Numerous other authors previously reported that infection is typically found in close proximity to alternate hosts (Andrews and Harrison 1959; Applegate and Seay 1971; Cordell et al. 1969). Although resistance to comandra has not been thoroughly investigated in the past, a formal disease assessment of a BC Ministry of Forests progeny field test in 2000 showed significant and large differences in family infection rates. Based on this result, a field trial was designed specifically to test comandra resistance of genotypes established in the Bulkley Valley low-elevation seed orchard (Orchard 219).

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METHODS

Three sites within established pine plantations in the central interior of BC were selected based on high incidence of comandra, and abundant cover of *Geocaulon lividum*, an alternate host of comandra. Each 2-ha site (about 100 m × 200 m) was prepared in fall 2003 by mechanically mulching the existing trees. In June 2004, seedlings from 130 seedlots were planted on a 1.5-m-square grid, in single tree plots, with 50 blocks per site (Alpha design). Most seedlots (hereafter referred to as "families") consisted of 50 seedlings, typically from open-pollinated families, though several controlled-cross families were included to evaluate specific putative resistant families. A total of 7,440 seedlings, including internal buffer seedlings, were monitored.

Two sites, Endako and Thompson, were assessed starting in 2006, 24 months after planting, and the third site, Holy Cross, was assessed starting in 2007, 36 months after planting. Detailed annual assessments were continued through 2014, representing 10 full growing seasons in the field. Disease assessments in 2006 through 2008 consisted of recording tree condition, and counting the number of individual infections (severity) by comandra, as well as by western gall rust (causal agent: *Endocronartium harknessii*), and stalactiform blister rust (causal agent: *Cronartium coleosporioides*). From 2009 to 2014, the tree condition and only the occurrence (not the count of infections) of a new rust species on a tree were recorded. Starting in 2012, an additional form or severity was also recorded to facilitate rust impact modeling. For all rusts, either the estimated percent stem encirclement (for stem-infected trees), or the distance of branch infections from the stem (for branch-only infected trees), was recorded for the most lethal-appearing stem or branch infection per rust per tree. In 2007, a count of the number of *G. lividum* stems was recorded within each 1.5-m × 1.5-m tree cell to evaluate the source of spread for comandra. A geographic information system (GIS) exercise was later used to calculate the distance, in 1-m intervals, from each tree to the closest *G. lividum* plant for determining the risk of infection based on proximity to the alternate host plant. For evaluating the source of spread of stalactiform, the presence of common red paintbrush (*Castilleja miniata*) was also assessed within the 1.5-m grid on all three sites in 2007. For stalactiform, the presence and general abundance of both yellow rattle (*Rhinanthus minor*) and cow wheat (*Melampyrum lineare*) were also noted at the site level.

RESULTS

Comandra Occurrence by Site

Although the three sites were selected to maximize risk to comandra infection, only two of the three sites were infested with a sufficiently high incidence to allow reliable screening for comandra resistance (fig. 1). The two sites with the highest infection, Endako (79-percent incidence of infection) and Thompson (70-percent incidence), were located about 12 km apart. They apparently had very similar weather conditions, based on the similarity of the timing and incidence of comandra on an annual basis. The third site, Holy Cross, which was more than 100 km southeast of the other two sites, recorded significantly less comandra (22-percent incidence), and its timing was very different from that of the other two sites. By 2006, both of the western sites had about 35-percent comandra, with close to 0 percent noted at Holy Cross. By 2007, both of the western sites had about 50-percent cumulative comandra incidence, compared to only 2 percent at the Holy Cross site. Given that it takes 2 to 3 years for infections to become noticeable, this difference probably indicates very different weather, both in 2004 and 2005, between these two geographic regions. The incidence of comandra at all three sites had apparently stabilized by age 10, with very little new infection occurring. The vast majority of infections by comandra on lodgepole pine in BC are typically restricted to a zone less than 0.5 m above ground, so it is reasonable to assume that the lack of new infections is related to the development of age-based resistance.

Ranking Resistance to Comandra

The primary interest in this trial is the structure of resistance in the lodgepole pine population, and whether there are any resistant families that can be used to increase the resistance of the improved tree orchards for BC. Sorting families by increasing comandra incidence at the Thompson site allows a systematic evaluation of the family variation due to site (fig. 2). After 10 growing seasons, the vast majority of the

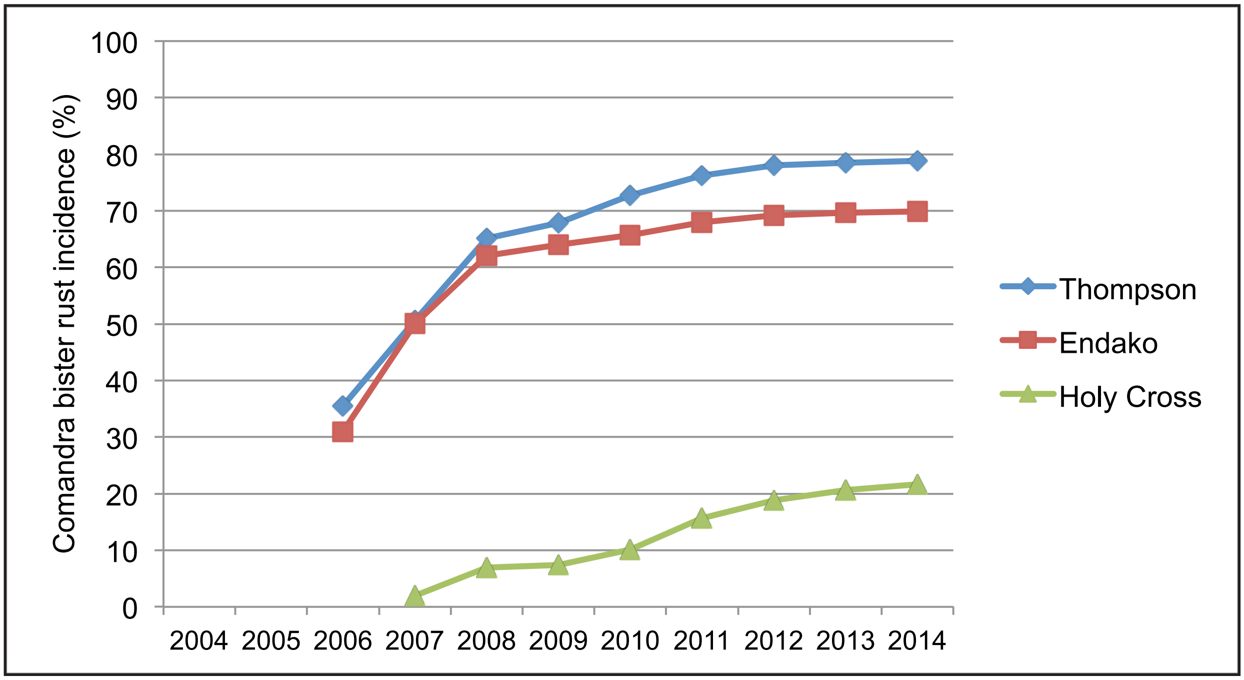

Figure 1—Cumulative comandra incidence at all three sites monitored annually.

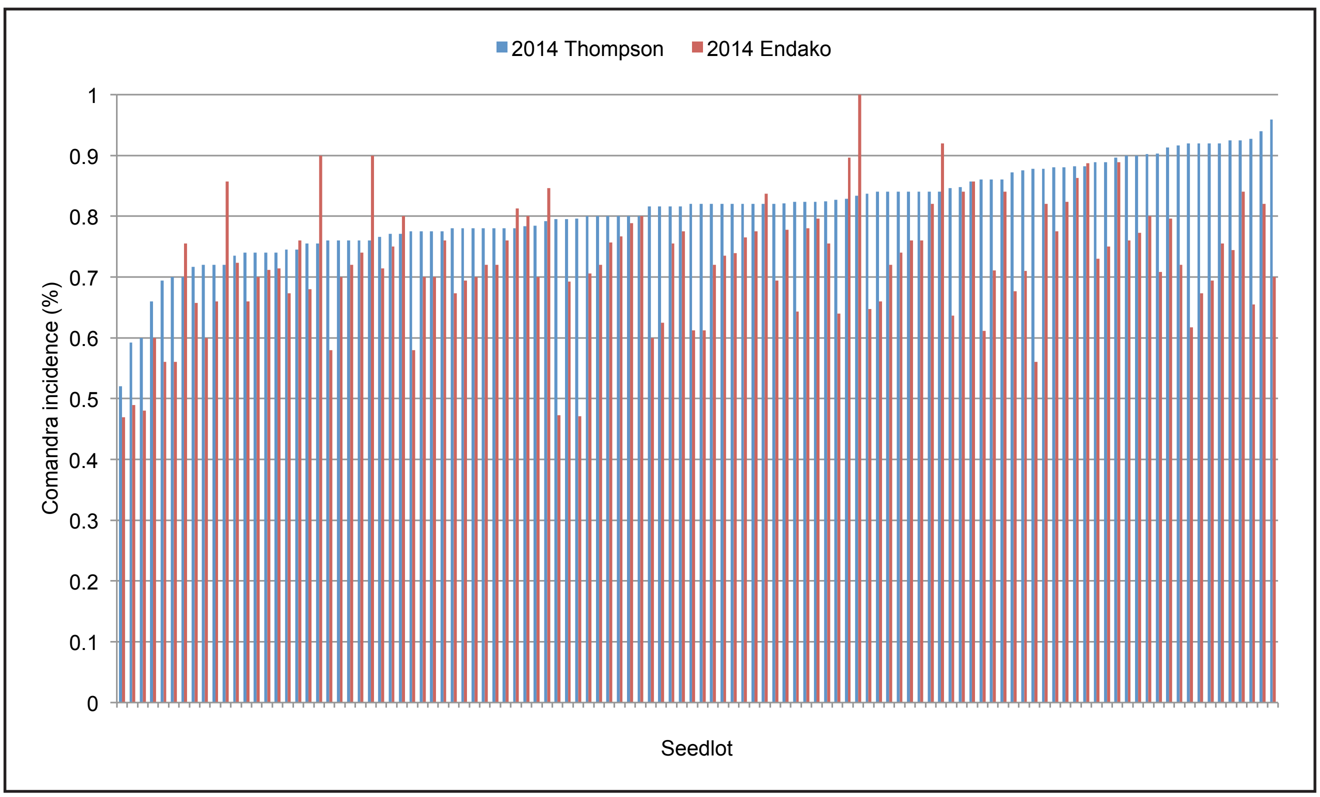

Figure 2—Cumulative mean family comandra incidence at Thompson and Endako, sorted by Thompson comandra incidence.

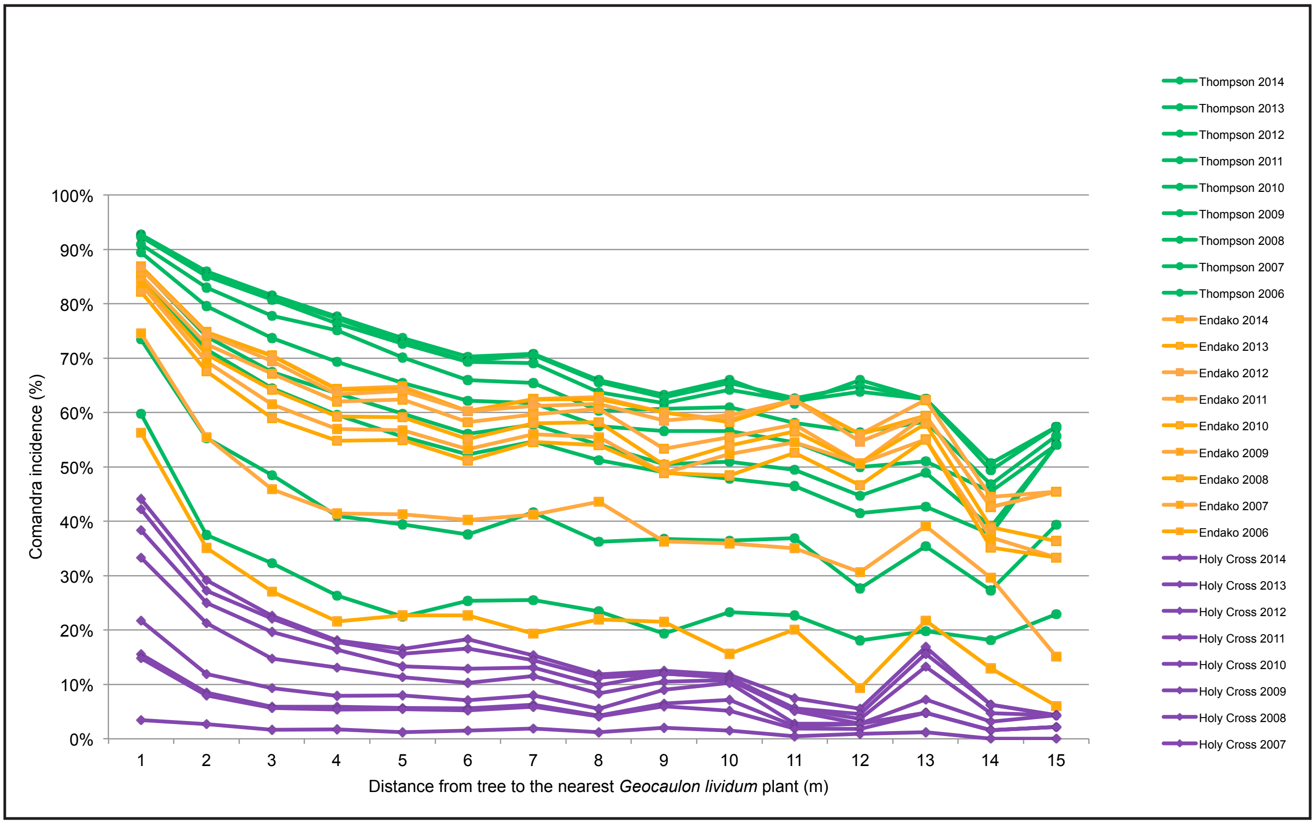

Figure 3—Cumulative comandra incidence by proximity to alternate host for all three sites, monitored annually.

families appear to be highly susceptible, with only a few showing somewhat lower comandra incidence. Especially given the large number of families in this trial, this result may suggest that there exists very low natural resistance in the lodgepole pine population as a whole. This would be reasonable to expect, especially if most of the pine population is not normally exposed to challenge by comandra on a regular basis.

The difference between the moderately resistant families and the highly susceptible ones is more distinct when comparing the severity of infection (count of infections per tree) rather than the mean incidence at the family level (Feng et al. 2013). The most susceptible families may be almost twice as susceptible as the least susceptible when basing the comparison on incidence, whereas the most susceptible families are close to six times more susceptible when using severity as the basis for comparison.

Although variability in family-level comandra incidence between sites should have been minimized through the robust trial design (50 open-pollinated seedlings planted in single-tree plots within 50 blocks per site), the family rankings varied considerably between sites. A correlation R^2 calculated annually for the two most highly infested sites never rose much higher than about 0.50. This would generally indicate that only about 50 percent of the variability was accounted for by genotype, which is considerably lower than expected for this type of study.

Spatial Correspondence of Comandra and its Alternate Host

At an early stage in the monitoring of this trial it became apparent that the highly clustered distribution of comandra incidence may be related to the highly clustered spatial distribution of the alternate host, and that this factor may affect the outcome of ranking families for resistance. In particular, ranking families using the average family incidence of all sites may introduce error, as trees within the same site may be exposed to dramatically different levels of challenge. Combining trees that are challenged at a low level with trees challenged at a high level is unlikely to yield reliable rankings, unless their proportions are similar.

A visual inspection of the mapped distribution and intensity of comandra incidence, in relation to the distribution and clustering of the alternate host, exhibited a distinct spatial correspondence on all three sites. Results of using the GIS technique to display the cumulative risk of infection by comandra in relation to the proximity to the nearest alternate host plant at each annual measurement show a sharp decrease in risk over a very short distance from the alternate host (fig. 3). The shape of this function appears to be relatively independent of the incidence or the site. This proximity relationship is explored in greater detail through the development of a flexible semi-parametric generalized additive model to reduce ranking error (Feng et al. 2013). This approach was used in an expanded, but unpublished, study by the same authors to more reliably rank families by modeling the effect of proximity to alternate host, abundance of alternate host, and other factors such as site topographic effects (e.g., slope, elevation, and aspect).

Other Rusts and Forest Health Factors

Several observations were made regarding the other two rusts. Western gall rust occurred at a lower than expected frequency and incidence on all three sites. Stalactiform blister rust occurred at a much higher than expected incidence at only one of the three sites. Stalactiform incidence at the Endako site appeared to follow a rapid and widespread invasion in 2004 or 2005 by *R. minor*, a known transient annual (Westbury 2004). *Rhinanthus minor* was not observed until 2010 at the Holy Cross site and not until 2012 at the Thompson site. Although *C. miniata* was highly clustered and somewhat abundant on all three sites, it did not appear to result in distinctly clustered stalactiform infection. It may not be as effective an alternate host for stalactiform as *R. minor*, though the trial was not designed to evaluate this factor. *Melampyrum lineare* was present only on the Holy Cross site, and was very abundant and widespread. It did not appear to cause widespread stalactiform on pine, though the weather may not have been suitable for infection by stalactiform.

Trial Design, Assessment Schedule, and Tree Condition

The results of this trial demonstrated the importance of careful site selection, the need for replication of test sites, and the dependence on suitable weather for successful screening using field trials. This trial also demonstrated the need for detailed annual monitoring given both the rapidly changing annual rate of new infection, and the rapid rate of mortality of trees infected at a very young age. Further, it demonstrated the value of mapping the alternate host distribution in climates where spatial infection gradients may develop over very short distances from the alternate host.

CONCLUSIONS

Detailed annual monitoring and subsequent analysis have shown that after 10 growing seasons, the comandra incidence has both stabilized and reached an adequate threshold for reliable screening on two of three sites. Although very few families demonstrated resistance in relation to the large number of families tested, this result may possibly indicate that the lodgepole pine population as a whole may contain a relatively low level of resistance to an endemic pathogen. Screening of additional lodgepole pine families to further bolster the number of comandra-resistant families is highly recommended.

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