Association of pitch moths (Lepidoptera: Sesiidae and Pyralidae) with rust diseases in a lodgepole pine provenance trial

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Abstract: A survey in a lodgepole pine, *Pinus contorta* var. *latifolia* Engelm., provenance trial showed that the western pine moth, *Dioryctria cambiicola* (Dyar) (Lepidoptera: Pyralidae), was the most prevalent pitch moth, and stalactiform blister rust, *Cronartium coleosporioides* Arth., the most prevalent stem rust. Also present were the Douglas-fir pitch moth, *Synanthedon novaroensis* (Hy. Edwards) (Lepidoptera: Sesiidae), comandra blister rust, *Cronartium comandrae* Pk., and western gall rust, *Endocronartium harknessii* J.P. Moore, and the stem canker *Atropellis piniphila* (Weir). Results from a likelihood ratio test indicated an association of western pine moth with stalactiform blister rust and of Douglas-fir pitch moth with both western gall rust and stalactiform blister rust. Western pine moth attacks are most commonly found along the active edge of stalactiform blister rust cankers, suggesting that the moth larvae derive some specific benefit from the fungus. The association of Douglas-fir pitch moth with the rusts appear to be a result of the physical wounding caused by the fungi, since attacks by this pitch moth are also frequently found at pruning wounds or other injuries.

Résumé : Un inventaire dans un test de provenance avec du pin lodgepole (*Pinus contorta* var. *latifolia* Engelm.) a révélé que la pyrale du cambium, *Dioryctria cambiicola* (Dyar) (Lepidoptera: Pyralidae), est le nodulier le plus fréquent et que la rouille-tumeur stalactiforme, *Cronartium coleosporioides* Arth., est la rouille la plus fréquente. On a également retrouvé le nodulier du Douglas, *Synanthedon novaroensis* (Hy. Edwards) (Lepidoptera: Sesiidae), la rouille-tumeur oblongue, *Cronartium comandrae* Pk., la rouille-tumeur autonome, *Endocronartium harknessii* J.P. Moore, et le chancre atropellien, *Atropellis piniphila* (Weir). Les résultats d'un test de rapport de probabilité a révélé qu'il y avait une association entre la pyrale du cambium et la rouille-tumeur stalactiforme ainsi qu'entre le nodulier du Douglas, la rouille-tumeur autonome et la rouille-tumeur stalactiforme. Les attaques de la pyrale du cambium surviennent le plus souvent à la limite des chancres causés par la rouille-tumeur stalactiforme, ce qui suggère que les larves de la pyrale tirent certains bénéfices spécifiques du champignon. L'association entre le nodulier du Douglas et les rouilles semble résulter de la blessure physique causée par les champignons étant donné que les attaques de ce nodulier sont aussi fréquemment observées autour des blessures d'élagage ou d'autres types de blessures.

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Introduction

Stem rusts and pitch moths of pine often occur in association (Coulson and Franklin 1970; Wong 1972; Furniss and Carolin 1977). For example, many species of *Dioryctria* (Lepidoptera: Pyralidae) are closely associated with various pitch cankers. *Dioryctria amatella* (Hulst.), *D. abietivorella* (Grote), *Dioryctria banksiella* Mutuura, Munroe, & Ross, *Dioryctria contortella* Mutuura, Munroe, & Ross, *Dioryctria okanaganella* Mutuura, Munroe, & Ross, *Dioryctria tumicolella* Mutuura, Munroe, & Ross, and *Dioryctria cambiicola* (Dyar) all attack parts of pine trees already infected with *Cronartium* spp., including comandra blister rust, *Cronartium comandrae* Pk., and stalactiform blister rust, *Cronartium coleosporioides* Arth. (Coulson and Franklin 1970; Wong 1972; Furniss and Carolin 1977). *Dioryctria banksiella* and *D. cambiicola* are also found in association with the western gall rust, *Endocronartium harknessii* J.P. Moore (Mutuura and Munroe 1969; Ives and Wong 1988).

Many insects are associated with rust cankers (Powell et al. 1972). Conifer-infesting *Synanthedon* (Lepidoptera: Sesiidae) species, including the Douglas-fir pitch moth, *S. novaroensis* (Hy. Edwards), and the sequoia pitch moth, *S. sequoiae* (Hy. Edwards), preferentially attack trees at wounds (Furniss and Carolin 1977), and Douglas-fir pitch moth pitch masses are often found at rust canker wounds in natural stands of lodgepole pine (Lindgren, personal observations). Although the occurrence of these conifer-attacking pitch moths has not been previously correlated with canker disease, perennial stem cankers caused by *Cytospora cincta* Sacc. and *Cytospora leucostoma* (Pers.) Sacc. predispose peach (*Prunus persica* (L.) Batsch) trees to attack by the lesser peachtree borer, *Synanthedon pictipes* (Grote & Robinson), a congeneric species with a behavior similar to that of the Douglas-fir pitch moth (Swift 1986).

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There are three species of stem rust native to British Columbia: stalactiform blister rust; comandra blister rust; and sweet fern blister rust, *Cronartium comptoniae* Arth. There is also one species of gall rust, western gall rust (Hunt 1992). *Atropellis piniphila* (Weir), a canker-causing fungus, is also prevalent in the Prince George area (Hopkins and Callan 1992). Four of these fungi cause the formation of cankers ("sharply delimited necrotic patches of cortical tissues and malformation of the bark caused by recurring localized killing of the cambium layer" (Allen et al. 1996)) on the trunk or branches, while western gall rust causes branch or stem galls (Hiratsuka 1987).

Many lodgepole pine trees, *Pinus contorta* var. *latifolia* Engelm., in a provenance trial at the Prince George Tree Improvement Station (PGTIS) are infected with blister rust or canker fungi, all of which cause stem cankers. Larvae of western pine moth and Douglas-fir pitch moth may be associated with the canker wounds, which may predispose trees to pitch moth attack by providing attractive oviposition sites (Mutuura and Munroe 1969; Coulson and Franklin 1970; Wong 1972; Ives and Wong 1988). Wu and Ying (1997) found a strong correlation between infection by stalactiform blister rust and pitch moth attacks in the PGTIS provenance trial, where tree provenance and family had significant effects on apparent resistance to the disease and insect. In that and a related study (Wu et al. 1996), all pitch moth attacks (*Dioryctria* and *Synanthedon* spp.) were erroneously diagnosed as the sequoia pitch moth, and *Cronartium* rust cankers other than stalactiform blister rust were not included.

Although feeding by pitch moth larvae rarely kills trees, it can weaken them by partial girdling, which makes them more susceptible to wind breakage (Ives and Wong 1988; L.A. Rocchini, personal observations). Favoured attack sites are wounds that exude oleoresin, particularly on vigorous trees (Brunner 1915; Johnson 1993). Damage from stem rusts and cankers varies widely in intensity and depends on several factors including tree genotype, climate, and in the case of *Cronartium* spp., the proximity and abundance of secondary hosts (Hunt 1992). Seedlings and saplings are especially vulnerable as they are often girdled if infected. On pole-sized and larger lodgepole pine, stalactiform blister rust does not usually cause mortality, but may structurally weaken the tree, decrease the value of the wood, or make it more susceptible to insect attack. Western gall rust branch galls do not usually affect tree vigour, but stem galls often girdle trees, killing or causing structural weakening, which may lead to breakage (Hiratsuka 1987).

Our objectives for this study were to determine (*i*) the species of rust present, (*ii*) the relative abundance of rusts and pitch moths, and (*iii*) whether or not there is a species association between pitch moth species and stem rust or canker infections in the provenance trial at the PGTIS. We did not attempt to evaluate the effects of genetic parameters such as provenance or family, since this has been done previously (Wu et al. 1996; Wu and Ying 1997).

Methods

Study site

The study was conducted in the provenance trial at the PGTIS, located 10 km south of Prince George on the east side of the Fraser River. The provenance trial consists of 46 provenances from the interior of British Columbia, four from the Yukon Territory, and three from Alberta. Each provenance is represented by 15 wind-pollinated families, except for seven provenances with only 8–14 families (Wu et al. 1996). Each is also represented by three fully randomized replicates, with the provenance as the plot and each family within the provenance as the subplots. Each subplot consists of six trees planted in a grid of 3 × 3 m (Wu et al. 1996). All trees were planted in 1973.

Pitch moth identification

Species and pitch mass identifications were made by combining larval identifications (Stehr 1987), emergence-trap data, and visual observation of pitch masses that were caused by the collected specimens (Rocchini 1997). Identification to species of *Dioryctria* was made by R.G.B. based on dissection of about six adults (Sopow et al. 1996). Identification of *Synanthedon* was based on keying of one adult captured in emergence traps, and many additional sesiid moths captured in pheromone-baited traps (Eichlin and Duckworth 1988; Rocchini 1997). Voucher specimens of the insects have been deposited at the Pacific Forestry Centre, Natural Resources Canada, Victoria, B.C. All *Dioryctria* larvae were dug out of pitch masses that were oriented vertically on the tree. These pitch masses were approximately 1 cm in diameter in mid-June 1995 and up to 10 cm wide and 20 cm long in August 1995. Observations of several larvae and the capture of one moth in an emergence trap (Rocchini 1997) suggest that Douglas-fir pitch moth pitch masses often have both old and fresh pitch in one pitch mass. Active pitch masses of this species are usually large (>10 cm in diameter) in June, making them easy to distinguish from western pine moth pitch masses. Thus, pitch moth species determinations in this study were ultimately based on pitch mass morphology.

Rust identification

Atropellis cankers and western gall rust galls are easily differentiated from each other and from stalactiform and comandra blister rust cankers by obvious fungal signs and physical differences (Allen et al. 1996). Stalactiform and comandra blister rust are best identified during the sporulation period using aeciospore morphology, since canker morphology varies considerably (Allen et al. 1996). Aeciospores were scraped from each canker onto a microscope slide and examined with a ×10 magnification hand lens. At this magnification, the different shapes of the spores from the two species are obvious, i.e., round for stalactiform blister rust and pear shaped for comandra blister rust (Allen et al. 1996).

Survey

A survey of the provenance trial was carried out in late June 1996, when the rusts were sporulating. Fifteen trees were chosen randomly from each of the 53 provenances represented in the provenance trial for a total of 795 trees surveyed. The number and species of each type of stem rust fungus, canker fungus, and pitch moth were recorded up to a height of 2 m to maximize the number of trees samples while optimizing the potential for disease and pitch moth incidence. Most of the trees in the trial had branch infections of western gall rust, but for the purposes of this study, only stem infections were tallied since most branches were above 2 m on the tree and are generally of a diameter too small for pitch moth attack. Old and fresh insect pitch masses were differentiated: fresh pitch masses contained live larvae and contained flowing, noncrystallized resin. All active stem rust infections were considered fresh. Old (nonsporulating) rust cankers were not counted, because it was impossible to determine if bark damage was caused by rust fungi (and, if so, which fungus was responsible) or some other agent such as sun scald.

Table 1. Relative abundance of pitch moths, stem rusts, and Atropellis canker on 795 trees surveyed in a lodgepole pine provenance trial, Prince George Tree Improvement Station, Prince George, B.C., 1996.

Organism	No. of pitch masses, rust cankers, or galls	No. of trees infested	Trees infested (%)
Western pine moth	1723	210	26.42
Douglas-fir pitch moth	203	139	17.48
Total pitch moth	1926	349	35.22
Stalactiform blister rust	283	201	25.30
Comandra blister rust	1	1	0.13
Western gall rust (stem)	14	13	1.60
Atropellis canker	3	3	0.38
Total stem disease	301	218	27.17

Table 2. Chi-square and *P*-values resulting from the log-likelihood test (*G* test) for association between specific insect and disease pairs in a lodgepole pine provenance trial at Prince George Tree Improvement Station, Prince George, B.C.

	No. of trees with					
Organisms	No insect or disease	Insect only	Disease only	Insect and disease	χ^2	*P*
Western pine moth – stalactiform blister rust	539	55	46	155	335.20	<0.001
Douglas-fir pitch moth – stalactiform blister rust	503	91	153	48	7.24	0.007
Douglas-fir pitch moth – western gall rust	652	130	4	9	17.29	<0.001

Analyses

Each tree was classified as attacked or not attacked by rust and pitch moths. Results were analysed using the likelihood-ratio test (*G* test), which measures goodness of fit using more than one variable, and is set up in a similar fashion to the chi-square contingency table (Zar 1984). The *G* statistic was calculated for three associations: (*i*) western pine moth with stalactiform blister rust, (*ii*) Douglas-fir pitch moth with stalactiform blister rust, and (*iii*) Douglas-fir pitch moth with western gall rust. The null hypothesis for each case was that the rust and insect occur independently. The *G* statistic was not calculated for (*i*) associations of insect attacks with comandra blister rust or Atropellis canker because of the very limited occurrence of these diseases in the provenance trial and (*ii*) for association of western pine moth with western gall rust, since these organisms were never observed in association with each other. Statistical analyses were performed using SYSTAT®, version 7.0, for Windows® (SPSS Inc. 1996).

Results

Species identification and relative abundance

Results from the survey indicated that western pine moth is more prevalent than Douglas-fir pitch moth in the provenance trial, since there were 1723 and 203 pitch masses from each insect, respectively (Table 1). There were 210 trees infested with western pine moth and 139 trees infested with Douglas-fir pitch moth. The former insect had 8.2 pitch masses per attacked tree and the latter had 1.5 pitch masses per attacked tree. No sequoia pitch moths were found.

Observation of cankers, galls, and spores revealed that the stem diseases present in the provenance trial are Atropellis canker, western gall rust, comandra blister rust, and stalactiform blister rust, with the latter accounting for 94% of all cankers or galls tallied (Table 1). No sweet fern blister rust was found.

Association between diseases and insects

The results of the likelihood-ratio test indicated that, in all three tests of insect–rust association, the presence or absence of pitch moth attacks is not independent of the presence or absence of the disease ($P < 0.05$). Thus, stalactiform blister rust and western pine moth, stalactiform blister rust and Douglas-fir pitch moth, and western gall rust and Douglas-fir pitch moth are associated with one another to some degree (Table 2). However, the number of western gall rust-infected trees was very small (1.64% of trees sampled), which greatly increased the probability of the occurrence of a type I error when interpreting that result. Therefore, although the calculated chi-square value leads to rejection of the null hypothesis, for the western gall rust – Douglas-fir pitch moth pair, the test may not be valid (Zar 1984).

Discussion

Results from this study indicate the presence of a species complex in the provenance trial that differs from other areas at the PGTIS. In the provenance trial, western pine moth damage is considerably more prevalent than Douglas-fir pitch moth damage, whereas the reverse is true in four lodgepole pine seed orchards surveyed by Rocchini (1997). Similarly, the provenance trial had a much greater incidence of stalactiform blister rust (25% of all trees infected) compared with the seed orchards, where this disease does not appear. Therefore, the relatively high levels of western pine moth in the provenance trial may result from to the high

incidence of stalactiform blister rust, because results indicated that the two species are highly associated. Although Douglas-fir pitch moth is also associated with stalactiform blister rust, this association is not as strong as with western pine moth (Table 2).

The high incidence of stalactiform blister rust in the provenance trial may be caused by factors such as an abundance of susceptible genotypes (Wu and Ying 1997), the occurrence of "wave years" of infection following planting, and a prevalent secondary host, common red paintbrush (*Castilleja miniata* Dougl.), which is necessary for stalactiform blister rust to complete its life cycle (Allen et al. 1996). A wave year of western gall rust occurred in the Prince George area in 1976 (van der Kamp 1988), 3 years after the provenance was planted. Wave years of *Cronartium* species infections are more difficult to determine, and those of stalactiform blister rust tend to be more localized than those of western gall rust (B.J. van der Kamp, University of British Columbia, Vancouver, B.C., personal communication). The absence of sweet fern blister rust is likely a result of the absence of its secondary host *Myrica gale* L., a wetland shrub (Pojar and MacKinnon 1994).

The provenance trial is mowed to remove weeds only in spring and fall. This practice curbs the growth of perennial shrubs that would outcompete red paintbrush but allows paintbrush to complete a season of growth. Common red paintbrush is absent from the four lodgepole pine seed orchards (Rocchini 1997), presumably because of their more intensive management regimes, which includes some herbicide application and regular mowing. Airborne rust spores can be spread considerable distances, however, and it would be possible for basidiospores from the paintbrush in the provenance trial to infect trees in the seed orchards hundreds of meters away. Therefore, although presence or absence of secondary host in the immediate vicinity of pine trees probably contributes significantly to rust infection levels, other factors are involved. The provenance trial was established before the seed orchards, so infections in the provenance trial may have occurred before seed orchard trees were planted.

Host trees vary widely in their susceptibility to rust fungi (Bingham et al. 1971). The large number of families and provenances in the provenance trial may provide a higher proportion of susceptible genotypes than is found in the seed orchards. Some of the resistance mechanisms are controlled by many genes (horizontal resistance), whereas others are single- or few-gene mechanisms that correspond directly with genes or pathogen virulence in the host (vertical resistance) (Hoff 1984). Horizontal resistance includes mechanisms such as timing of shoot elongation to avoid high concentrations of basidiospores. Planting provenances in areas outside of where they evolved can lead to disruption of these mechanisms.

The majority of pitch masses, particularly those caused by the western pine moth, occur on the live periphery of the stalactiform blister rust cankers (L.A. Rocchini and B.S. Lindgren, personal observations). In two studies of insect–rust associations in natural stands, pitch moths were not found in association with stalactiform blister rust (Powell et al. 1972; Beard and Martin 1981), perhaps indicating that genotype or off-site planting stress is responsible for the high incidence of this disease in the provenance trial. No studies have been conducted on the feeding habits of pitch moths associated with rust cankers, but it is possible that they feed in part on fungal hyphae, utilizing their higher nutritional potential in a manner similar to many other phloeophagous insects, e.g., bark beetles (Paine et al. 1997).

The few stem galls of western gall rust that were present were often infested with Douglas-fir pitch moth larvae. This association may be more physical in nature or associated with increased metabolic activity by the tree in response to the wound itself. Douglas-fir pitch moth attacks in the provenance trial at PGTIS are also frequently found where large-diameter branches have been pruned off (B.S. Lindgren, personal observations). Thus, the wound response of trees to any cause of local necrosis may provide an optimal microhabitat for sesiid pitch moth larvae.

Disease-induced openings in the bark may reduce the bark's ability to act as a physical barrier against mining larvae. Pitch moths usually lay their eggs in cracks or fissures in the bark, and one probable reason for this is to enable the newly hatched larvae to burrow into the bark with ease (Duncan 1996). Both *Synanthedon* and *Dioryctria* spp. prefer bark wounds for attack sites (Weidman and Robbins 1947; Coulson and Franklin 1970; Powers and Sundahl 1973; Duncan 1996). Rust cankers cause the bark to blister, and in the case of stalactiform blister rust, the active edges of the rust canker usually have open, fresh wounds.

The results from this study show that there is an association between pitch moth attacks and stem rusts in the lodgepole pine provenance trial. The exact nature of the association is not known, and further studies concerning insect attraction to host volatiles, and larval development and fecundity in trees with and without rust cankers, are recommended to clarify this association.

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