Predicted impacts of hard pine stem rusts on lodgepole pine dominated stands in central British Columbia; Were our Assumptions Valid?

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Abstract:

In 1997, 30 one-ha stem mapped plots were located in randomly selected juvenile lodgepole pine (*Pinus contorta* Dougl. Ex Loud.) leading stands aged 15-20 years. The growth and yield model TASS was then used to predict volume losses at rotation. The average loss at rotation due to hard pine rusts in lodgepole pine dominated stands was estimated to be 7.2%. In order to model rust impacts over a rotation three basic modelling assumptions had to be made. This study reviews those three basic assumptions by re-assessing all trees within the 30 plots seven years later. The first assumption was that rust incidence would have stabilized in stands aged 15-20 years. I found that the incidence of both comandra blister rust (*Cronartium comandrae* Peck) (CBR) and western gall rust (*Endocronartium harknessii* (J.P. Moore) Y. Hiratsuka) (WGR) continued to increase. The greatest increase in CBR incidence occurred in stands that already had a high incidence while increases in WGR incidence were universally distributed over all 30 plots. The second assumption was that the voids created by rust killed trees would not fill with merchantable sized non-host trees by the time the lodgepole pine crop was ready to harvest. I found that the mean height of interior spruce is just over 1/3 the height of the lodgepole pine crop trees. The mean stocking of interior spruce is 243.7 ± 102.0 sph while that of lodgepole pine was 968.2 ± 196.2 sph. (95% CI). It is unlikely these spruce trees will be of merchantable size prior to harvest of the lodgepole pine crop. The third assumption was that CBR infected trees would die at an annual rate of 5% between the ages of 20 and 40 years. I found that after approximately 1/3 of that time period elapsing, 1/3 of the CBR infected trees were dead. Very few WGR infected trees have died. I also examined the relationship between the abundance of alternate host and the number of CBR infected trees. I conclude from the reassessment of the three main modeling assumptions used to predict rust impact that the those assumptions were valid and that the impact of hard pine rusts in juvenile lodgepole pine dominated stands in central British Columbia is approximately 7.2%.

Introduction:

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is one of the most economically important tree species in western North American forests. In BC, it accounts for 27% of the total harvest and 41% of total planting in the province (BC Ministry of Forests 1997). The species grows over a wide range of site conditions and produces quality wood over relatively short rotations. Lodgepole pine is susceptible, however, to a wide array of pathogens. In western Canada, hard pine stem rusts such as comandra blister rust (CBR) caused by *Cronartium comandrae* (Peck), stalactiform blister rust (SBR) caused by *Cronartium coleosporioides* (Arth) and western gall rust (WGR) caused by *Endocronartium harknessii* (J.P. Moore)Y. Hiratsuka, can cause significant losses in young lodgepole pine stands (van der Kamp and Spence 1987, Woods et al. 2000).

Few impact estimates have been documented for hard pine stem rusts. Bella and Navratil (1988) estimated that 15% of total lodgepole pine volume was lost to WGR over a 20-year period in west-central Alberta. In BC, van der Kamp (1981) estimated volume losses to WGR and SBR blister rust at 5% and 0.5%, respectively. Woods et al. (2000) developed loss functions based on an intensive analysis of juvenile lodgepole pine stands in the Lakes TSA of central BC. They predicted that overall losses due to rusts totaled 7.2% over a rotation. Woods et al. (2000) suggested repeated surveys of their stem mapped stands to validate the loss functions they produced.

The objective of this study is to re-examine the assumptions that Woods et al. (2000) made in order to predict hard pine rust impacts. Those assumptions were as follows: 1) that the incidence of rusts had stabilized by stand age 15-20 and there would be few new infections, 2) that the voids created by dying trees would not be occupied by new trees of sufficient size to be harvested with the original stand, and 3) that the trees infected with comandra blister rust on the stem or on branches closer than 10 cm to the stem would die at an annual rate of 5% between stand age of 20-40 years.

Methods:

Study area:

This study was conducted in the Lakes Timber Supply Area (TSA) of central BC (Figure 1). The dominant biogeoclimatic subzones in this TSA are the sub boreal spruce dry cool (SBSdk) and the sub-boreal spruce moist cold (SBSmc) (Meidinger and Pojar 1991).

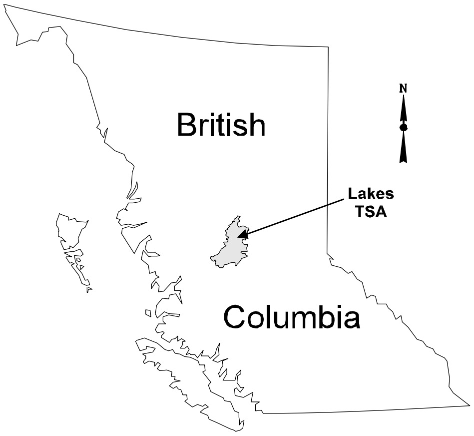

Figure 1. Map of British Columbia showing the location of the Lakes Timber Supply Area.

Lodgepole pine is the dominant commercial tree species in the Lakes TSA, covering more than 490 000 ha, or 77% of the operable timber harvesting area (Anon. 1995). The majority of the lodgepole pine is in mature (>100 years) age classes, with only about 75 000 ha less than 20 years old. Much of the mature volume is currently under attack by an unprecedented mountain pine beetle epidemic.

Initial stem-mapped-plot installation (1997):

This study builds directly upon the earlier work of Woods et al. (2000). They first defined their sample population of lodgepole pine stands within the Lakes Timber Supply Area (TSA) as all stands between the ages of 10-25 years, with > 80% lodgepole pine and <5000 stems/ha. Of the 339 potential candidate stands, they randomly selected without replacement 67 areas. Within these sample stands a low intensity (0.4% of the block area) transect survey was conducted to determine hard pine rust incidence. Stands were placed in three rust incidence classes; <10%, 10-20% and >20%. Ten stands were then randomly selected from each of the three incidence classes and a 100m X 100m (1ha) plot was established in each of the 30 selected stands.

In each plot the rust status of all trees > 1.5m in height was recorded. Tree were tallied as infected if they had stem infections or comandra and stalactiform blister rust branch infections within 60cm of the stem or western gall rust branch infections within 10cm of the stem. If a tree was infected by more than one rust species only the most lethal infection was recorded based on the following ranking from most to least lethal: CBR, SBR, WGR (Hiratsuka et al. 1988). Dead trees where the cause of death was obviously a rust infection were recorded as rust infected. Healthy trees were identified with blue log marking paint and infected trees with red-orange. The XY coordinates of all tallied trees was recorded to the nearest 3m by taking a minimum 30-second Global Positioning System (GPS) reading using a Trimbol Pro XL® GPS unit. All GPS data were differentially corrected.

Testing model assumptions by re-examining the 30 stem-mapped plots (2004)

Assumption #1 *Incidence of rusts had stabilized by stand age 15-20 (plot establishment) and there would be few new infections.*
I examined all lodgepole pine trees in each of the 30 plots for the following factors: former rust status, current rust status, and whether the tree was live or dead. Only lethally infected trees were recorded as rust infected applying the same standards as used in 1997. I determined the former rust status of trees by observing the colour of paint that had initially been applied in 1997. I found that blue log marking paint was particularly weather-resistant while the orange paint was not. If a tree had no obvious paint on it then it was assumed to have been marked with orange paint. All assessments were conducted during the rust sporulation period of late May-early July when bright orange rust aeciospores are released from cankers or galls on live infected trees. Trees that had been killed by CBR and SBR were identified as such by the characteristic pattern of damage (ie, stem swelling with extensively cracked bark and copious amounts of resin) while those killed by WGR were identified by the presence of large stem-girdling galls.

The total rust incidence by rust species was compared between the 1997 assessment and the 2004 assessment to determine if rust incidence had stabilized or changed substantially from the time of plot establishment.

Assumption #2) *The voids created by dying rust infected trees would not be occupied by new trees of sufficient size to be harvested with the original lodgepole pine stand.*
I assessed this assumption by comparing the total stocking of interior spruce and subalpine fir trees > 1.5m in height and lodgepole pine > 2.5m in height between the two plot assessments. Five 3.99m radius subplots were systematically located within each one-hectare plot to sample tree heights and diameters. In each subplot the five tallest, disease free lodgepole pine trees were measured for height to the nearest 0.1m using a Vertex Clinometer, and diameter at breast height (dbh) to the nearest 0.1cm with a dbh tape. All interior spruce and subalpine fir trees > 1.5m in height located within the subplots were also measured for height and diameter.

Assumption #3) *Trees infected with comandra blister rust on the stem or on branches closer than 10 cm to the stem would die at an annual rate of 5% between stand age of 20-40 years.*
I assessed this assumption by determining the proportion of all CBR and SBR infected trees that are now dead. Whether an infected tree was live or dead was not recorded when the plots were established. A sub-sample of five one-hectare plots was examined in 1999 and at that time 68% of CBR and SBR infected trees were live.

Test of relationship between CBR incidence and alternate host abundance

I estimated the percent ground cover of the alternate host, bastard toadflax (*Geocaulon lividum*) for each one-hectare plot, using five 3.99m radius systematically located plots. The mean percent ground cover from the five subplots was correlated with the number of comandra infected trees in the larger one-hectare plot for all 30 plots.

Results:

Assumption #1

Hard pine rust incidence increased in all 30 plots over the seven-year period, 1997-2004 with a mean increase of 11.28% and a range of 0.8% to 24.6% (Table 1). The greatest rust incidence increase occurred with WGR rather than CBR. There was however, a significant relationship between total current rust incidence and the increase in CBR incidence ($r^2 = 0.522$, $f = 30.64$, $p < 0.001$). Generally, those plots that initially had high CBR rust incidence experienced the greatest increase in new CBR infections (Figure 2). There was no significant relationship between the change in WGR incidence and total current rust incidence ($r^2 = 0.0776$).

Table 1. Rust status of lodgepole pine trees in 30 stem-mapped stands located in randomly selected openings in the Lakes TSA, 1997 and 2004

Plot	Healthy'97	Infected'97	%Inf.'97*(-notinf)	Heathy'04**	Current%inf	Change%Inf	%Chng in CBR
E090-16	1063	118	7.79	950	19.52	11.73	3.11
E099-520	894	351	22.73	741	40.86	18.13	6.53
F062-20	992	199	14.44	837	30.17	15.73	1.97
F062-25	1889	394	15.16	1521	33.79	18.64	13.89
F062-29	879	113	7.46	789	19.92	12.46	0.78
F063-03	1221	197	11.50	1074	24.30	12.81	2.48
F063-22	717	349	31.52	476	56.06	24.55	13.19
F063-23	614	606	47.79	464	63.73	15.94	12.91
F081-25	899	109	8.83	819	17.02	8.19	0.97
F083-10	1877	537	20.26	1595	34.23	13.97	2.51
F093-06	1110	194	11.89	1034	12.66	0.77	-9.48
K012-02	835	164	14.41	695	30.05	15.64	2.97
K012-32	604	232	27.03	487	42.52	15.49	5.68
K025-07	927	239	15.44	841	28.40	12.96	1.53
K031-12	285	511	64.07	284	68.91	4.84	3.94
K032-13	1804	421	15.91	1704	23.05	7.13	2.52
K032-47	1326	215	8.18	1326	14.11	5.93	1.42
K032-48	1336	658	30.39	1250	38.48	8.09	4.57
K032-63	2323	484	13.64	2267	19.39	5.74	0.26
K033-25	1777	942	33.54	1382	50.68	17.14	6.03
K033-34	1024	1140	51.48	828	64.59	13.11	8.89
K033-53	846	98	6.67	837	11.41	4.73	0.48
K033-56	559	679	52.18	434	66.94	14.76	9.72
K043-12	320	484	58.96	283	68.64	9.69	7.57
K043-13	926	885	47.43	770	60.25	12.82	8.05
L30-033	1777	249	9.18	1772	11.73	2.55	-0.78
L030-39	955	106	9.05	874	17.44	8.39	1.40
L030-44	623	120	12.25	613	17.86	5.61	2.00
L030-49	911	795	44.78	892	51.93	7.15	3.38
L039-552	526	59	8.38	457	21.96	13.58	2.58
Average			**24.08**		**35.35**	**11.28**	**4.04**

*some trees recorded as infected in '97 were not and have been removed from this value

** trees that had dead branch cankers were considered healthy and were combined with uninfected trees

The 9.48 % reduction in CBR incidence in stand F093-06 (Table 1) was due to a low initial CBR incidence and a relatively large amount of young healthy pine ingress.

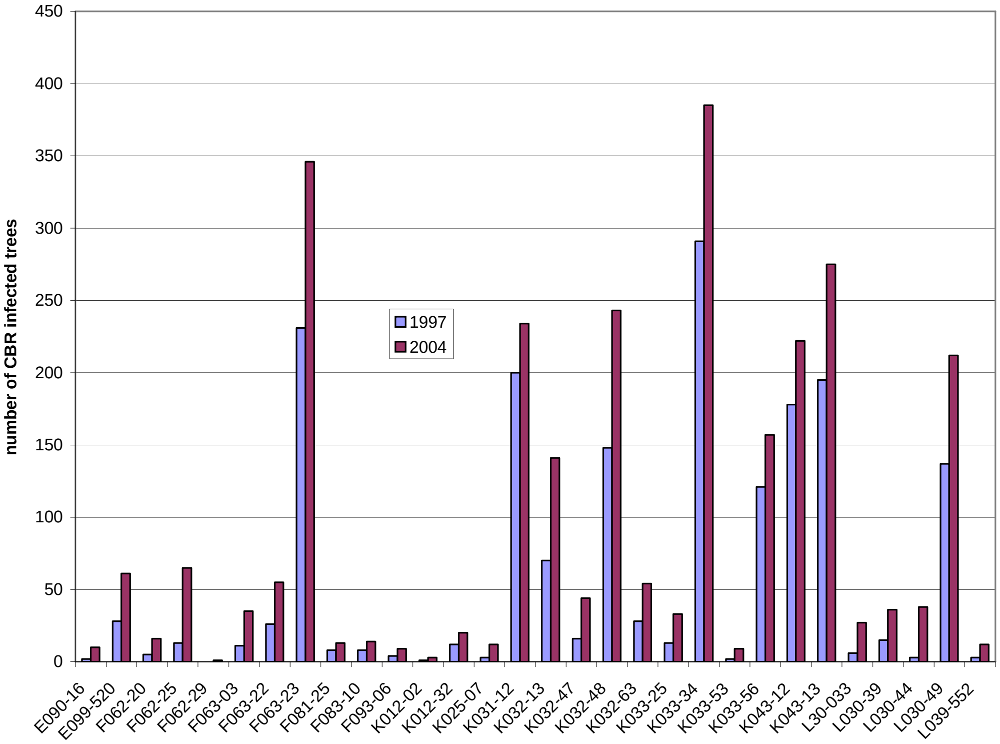

Figure 2. Number of comandra blister rust infected trees in 1997 and in 2004 in 30 one-hectare plots .

Assumption #2

There was considerable variability in the amount of ingress of interior spruce and sub-alpine fir among plots (Table 2). All 30 one-hectare plots contained some interior spruce and 24 of the plots also contained some sub-alpine fir. The systematically located 3.99m radius sub-plots used for height sampling contained at least one spruce tree in 22 of the one-hectare plots. Only seven of the 24 one-hectare plots that contained sub-alpine fir had subplots that captured sub-alpine fir sample trees.

Table 2. Stocking of lodgepole pine, interior spruce and sub-alpine fir in 30 one-ha stem-mapped plots and the mean tree heights for each species based on five 3.99m radius sub-samples per plot.

	Stocking (sph)					**Height (m)**				
Species	N	mean	±95% CI	Max	Min	n	Mean	±95% CI	Max	Min
Pl*	30	968.2	196.2	2305	221	149	9.40	0.282	14.4	3.3
Sx	30	243.7	102.0	1131	22	56	3.94	0.582	10.7	1.6
Bl	30	65.9	56.9	781	0	15	4.01	1.155	8.4	1.8

* rust free stocking only

Assumption #3
Only those five stands that had been re-examined in 1999 to confirm whether infected trees were dead or not could be directly compared with the current rates of mortality. The percentage of CBR infected trees that were dead averaged 33.3% in 2004 up from 25.2% in 1999. (Table 3).

Table 3. Comparison of proportion of rust infected trees that are dead between the 1999 and 2004 assessments for five of the 30 stem-mapped plots.

	Stand #	**K043-12**	**F062-25**	**K032-48**	**L030-49**	**K033-56**
	Live 99	299	53	378	555	225
	Dead 99	99	4	95	233	77
CBR	**Live 04**	324	66	367	461	208
	Dead 04	121	34	188	254	116
	New Inf	47	43	82	-73	22
	%Dead 99	24.87	7.02	20.08	29.57	25.50
	%Dead 04	27.19	34.00	33.87	35.52	35.80
	Live 99	99	154	155	149	331
	Dead 99	1	2	1	5	2
WGR	**Live 04**	160	299	284	285	646
	Dead 04	0	5	3	6	1
	New Inf	60	148	131	137	314
	%Dead 99	1.00	1.28	0.64	3.25	0.60
	%Dead 04	0.00	1.64	1.05	2.06	0.15

Although this proportion follows the prediction of an annual rate of mortality of 5%, this result does not account for the fact that some of the trees recorded as infected in 1997 were already dead. In addition, an average of 22.7% ± 7.7% of the trees identified as infected in 1997 over all 30 plots had dead branch infections and were thus no longer considered infected in 2004. Conversely, there was an average increase of 48.4 ± 7.8% in the number of CBR infections over 1997 plot tallies for all 30 plots combined. Of those newly found infected trees 11.4 ± 2.7% were already dead (i.e, the trees had become infected and died in the seven year period between plot establishment and the 2004 re-assessment).

Very few WGR infected trees have died thus far but there has been a large increase in the number of "lethally" infected trees (Table 3).

Relationship between alternate host abundance and CBR incidence

There was a significant relationship between the proportion of the ground covered in alternate host and the number of CBR infected trees ($r^2 = 0.412$, $f = 19.64$, $p < 0.001$). The one-hectare plots with the greatest number of infected trees also tended to have the highest proportion of ground covered in alternate host (Figure 3).

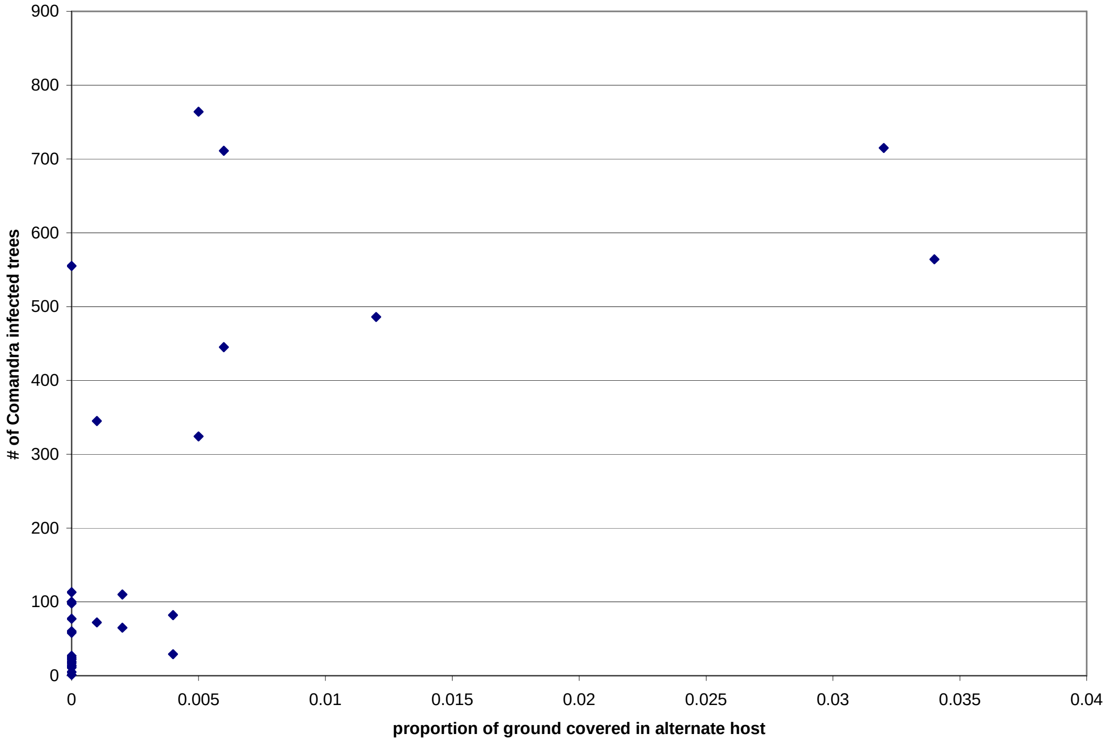

Figure 3. Scatterplot of the relationship between the proportion of ground covered in alternate host (*Geocaulon lividum*) based on a sample of five 3.99m radius sub-plots/one-hectare plot and the number of CBR infected trees in those 30 one-hectare plots.

Discussion:

The Woods et al. (2000) study provides an approach to estimating the impacts of hard pine rusts that can be used by silviculture foresters in individual stand applications. Forest managers in the central interior of BC have used the loss functions developed by Woods et al. (2000) to help guide their decisions regarding stand management treatments and hard pine rusts. Those same loss functions could be applied on a larger extent in BC provided there was more confidence in the modeling assumptions. The results of this current study provide that confidence.

Assumption #1 *Incidence of rusts had stabilized by stand age 15-20 (plot establishment) and there would be few new infections.*

I found that hard pine rust incidence had not stabilized and that it has continued to increase over the seven years since plot establishment. The greatest increase in rust incidence occurred with WGR but it is the increase in CBR incidence that has a greater influence on future stand productivity. Woods et al. (2000) stated that CBR incidence alone controlled much of the variability in volume loss at rotation based on juvenile stand growth projections. Lodgepole pine trees are most susceptible to CBR when they have live needles on or close to the stem within 1.5-2.0 m of the ground. Basidiospores released from the alternate host infect lodgepole pine hosts through needle stomates and require cool damp conditions out of direct sunlight for survival and germination (Johnson 1986). These conditions are most often met within that range of 1.5-2m of the ground. Environmental conditions that favour aeciospore germination on the alternate host also include moderate temperature, high humidity and lack of direct sunlight (Powell 1974). The increase in CBR incidence occurred despite the fact that most of the trees had now grown out of this most susceptible stage.

The environmental conditions favouring CBR infection are thought to occur during cool damp periods in both early summer when the relatively robust aeciospores are released from infected pines, and again in late summer when the more fragile basidiospores are released from the alternate host. It is possible that the trend towards cooler, wet summers that has been experienced over the period since plot establishment in 1997 (Woods unpublished data) has favoured continued spread of CBR. Increased summer precipitation could also help explain the marked increase in WGR incidence. New WGR infections are also favoured by cool wet early summers. If the extension of the period of host tree susceptibility to CBR and the overall increase in WGR incidence are related to climate change, these results raise concerns about the future productivity of managed lodgepole pine stands.

The results of this study indicate that the assumption regarding rust incidence stabilizing by age 15-20 was optimistic.

Assumption #2) *The voids created by dying rust infected trees would not be occupied by new trees of sufficient size to be harvested with the original lodgepole pine stand.*

There was considerable variability in the amount of natural ingress of interior spruce and sub-alpine fir among the 30 plots. In two of the plots interior spruce stocking now outnumbered healthy lodgepole pine. This natural ingress will augment the timber supply eventually but these trees were on average just over 1/3 the height of the lodgepole pine crop trees. In addition, the average stocking of interior spruce in these pine plantations was 243.7 ± 102.0 sph compared to 968.2 ± 196.2 for lodgepole pine crop trees. The loss functions developed by Woods et al. (2000) were based on the assumption that the voids created by rust infected trees dying would not be filled with natural ingress of sufficient size by rotation. This assumption does leave open the question of what is sufficient size. If rotation length was extended past the optimal for lodgepole pine, the interior spruce and sub-alpine fir ingress would contribute more to timber supply and the losses due to hard pine rusts would be of less concern. Lengthening rotations would in itself have a negative influence on timber supply.

Whether or not this assumption in the original loss function was optimistic or overly pessimistic depends on harvest scheduling. The unprecedented mountain pine beetle epidemic in central BC places more emphasis on shorter rotations for managed stands in order to minimize timber supply shortfalls in the mid-term. The juvenile stands represented by the 30 stand sample in the Lakes TSA could well be harvested before the interior spruce and sub-alpine fir natural ingress reach sufficient size to be considered merchantable.

Assumption #3) *Trees infected with comandra blister rust on the stem or on branches closer than 10 cm to the stem would die at an annual rate of 5% between stand age of 20-40 years.*

Seven years have elapsed since the 30 stem-mapped plots were established. If the annual mortality rate for CBR infected trees was 5% as predicted by Woods et al. (2000) then approximately 1/3 of the infected trees should be dead. That is what I found, however, this result does not exactly follow the scenario modeled by Woods et al. (2000). In that scenario all infected trees were assumed to be alive in 1997 and would then die at an annual rate of 5% so that between the ages of 20 and 40 years 100% of the infected trees would succumb. In 1997, 25% of the infected trees were already dead. Woods et al. (2000) found that the annual rate of mortality had an insignificant influence on volume loss over a rotation provided all CBR infected trees eventually died.

Since 1997, new infections have occurred, old branch infections have died and small lodgepole pine trees have grown sufficiently to now be included in the sample. Despite all of these factors, the incidence of mortality in CBR infected trees is 33.3%.

I expect that live trees with stem infections will continue to succumb. I also expect that some of the current branch cankers will lead to lethal stem infections while some will kill the individual branch and cease to be a threat to host trees. Coupling these likely scenarios with the fact that new CBR infections are continuing to be formed leads me to conclude that this assumption was not overly pessimistic.

Lethality of WGR infections

Although the testing of lethality assumptions for WGR was not one of the objectives of this study I have been able to draw some conclusions. Very few of the WGR infected trees died over the seven year period between assessments. The scenario Woods et al. (2000) used to predict hard pine rust impacts estimated that 50% of the lethally WGR infected lodgepole pine trees would die between age 20 and 40. This assumption appears to be overly pessimistic. Stem galls do cause serious defects and many eventually result in stem failure in lodgepole pine trees but WGR is not an effective tree-killer. The marked increase in WGR incidence that has occurred since the stem-mapped plots were established will have more of an impact on wood quality than on timber volume.

In stands where WGR and not CBR is the dominant rust species, the loss functions developed by Woods et al. (2000) may over-estimate impacts.

Relationship between alternate host abundance and CBR incidence

The positive relationship between the proportion of ground occupied by alternate host and the number of CBR infected trees was significant. Even very small amounts of alternate host are sufficient to support a considerable number of CBR infected trees. Five 3.99 m radius sub-plots/one-ha plot (sampling intensity of 2.5%) were used to estimate ground cover of *Geocaulon lividum*. Although this intensity of survey is five times the accepted standard for Ministry of Forest silviculture surveys, the distribution of the alternate host tends to be much more clumped than the distribution of host trees. It appears that in the study area the amount of alternate host on site could be used as an indicator of future stand risk from CBR.

Conclusion and Forest Management Implications:

The unprecedented mountain pine beetle epidemic in central BC will have catastrophic impacts on the timber supply of the region. The loss of vast areas of mature and over-mature lodgepole pine trees will place a much greater reliance on the productivity of second growth stands in order to lessen the impacts of the fall-down in timber supply. With a greater reliance on second growth stands comes the need for improved estimates of the impacts of agents that negatively affect juvenile stand productivity. This study provides greater confidence regarding loss estimates of one of the most damaging forest health agents affecting juvenile lodgepole pine stands.

The results of the Woods et al. (2000) study were incorporated into the current Timber Supply Analysis for the Lakes TSA. Through consultation with senior timber supply analysts within the Ministry of Forests it was decided that the 7.2% impact due to rusts would be incorporated as an increase in Operational Adjustment Factor (OAF 1) from the provincial default of 15% to 20%. The results of this study confirm the earlier rust impact estimate. All three major modelling assumptions were valid. If anything, the impact estimates for hard pine rusts may have been underestimated due to the fact that the incidence of both CBR and WGR has continued to increase. This possible underestimate of impacts is tempered by the slow rate of mortality in WGR infected trees. This validation of the modelling assumptions made by Woods et al. (2000) will hopefully lead to wider application of their approach to estimating losses due to hard pine rusts in managed lodgepole pine stands in British Columbia.

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