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Roger J. Whitehead and Glenda L. Russo

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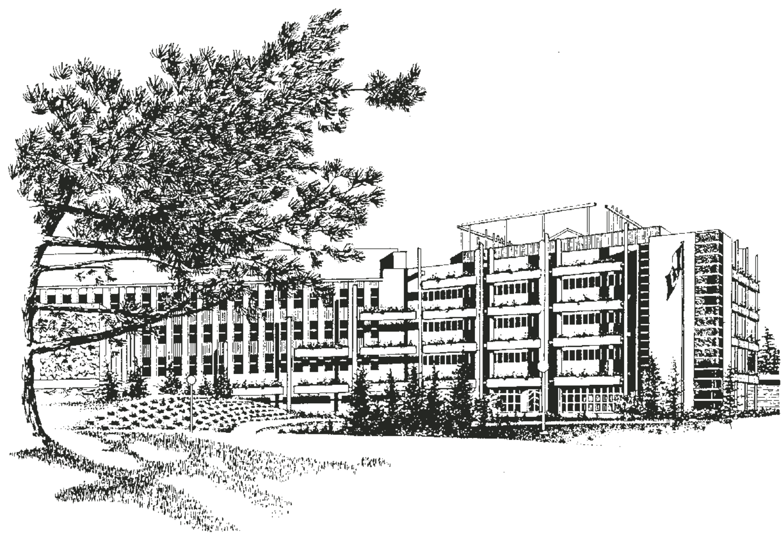

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Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, British Columbia
V8Z 1M5
Phone (250) 363-0600
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Contents

Abstract

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) activity was examined in untreated and "beetle-proofed" (thinned or spaced) portions of mature lodgepole pine (*Pinus contorta* Dougl. ex Loud. var *latifolia* Englm.) stands at five sites in central or southeastern British Columbia. Patch infestations requiring direct control were present in the untreated portions at all five sites. Number of attacked trees per hectare, mortality due to mountain pine beetle, and green to red attack ratios were much lower in treated portions. At the four sites where beetle pressure resulted only from the growth of resident populations during a period of favourable weather, no infestations requiring treatment developed in beetle-proofed stands. At the fifth site, extreme beetle pressure that resulted from immigration of beetles from an uncontrolled epidemic caused unacceptable damage to the beetle-proofed stand. The proportion of attacked trees where beetles successfully established and produced brood was high at all sites, regardless of treatment, suggesting that effect of treatment on ability to resist attack was not as important as the large reduction in frequency of attacks in beetle-proofed stands.

Résumé

On a étudié l'activité du dendroctone du pin ponderosa (*Dendroctonus ponderosae* Hopkins) dans des portions non traitées et « protégées contre le dendroctone » (éclaircies ou espacées) de peuplements mûrs de pins tordus (*Pinus contorta* Dougl. ex Loud. var *latifolia* Englm.) dans cinq sites du centre et du sud-est de la Colombie-Britannique. Des infestations localisées nécessitant des mesures de lutte directe étaient présentes dans les portions non traitées des cinq sites. Le nombre d'arbres attaqués par hectare, la mortalité due au dendroctone du pin ponderosa et la proportion d'arbres au stade vert et au stade rouge étaient beaucoup plus faibles dans les portions traitées. Dans les quatre sites où la pression exercée par le dendroctone ne provenait que de la croissance des populations résidantes durant une période de conditions météorologiques propices, aucun foyer d'infestation nécessitant un traitement n'est apparu dans les peuplements protégés contre le dendroctone. Dans le cinquième site, la pression extrême due à l'immigration de dendroctones provenant d'un foyer d'infestation incontrôlé a provoqué des dégâts inacceptables dans le peuplement protégé contre le dendroctone. La proportion d'arbres attaqués ou les dendroctones avaient pu s'établir avec succès et reproduire des nichées était élevée dans tous les sites, peu importe le traitement, suggérant que l'effet du traitement sur la capacité de résister à l'attaque n'était pas aussi important que la large réduction de la fréquence des attaques dans les peuplements protégés contre le dendroctone.

Introduction

The ecology of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and its relationship with lodgepole pine (*Pinus contorta* Dougl. ex Loud. var *latifolia* Englm.) has been intensively studied in western North America as resource managers have sought ways to avoid or reduce the impacts of periodic outbreaks. Carroll and Safranyik (2004) and Safranyik (2004) synthesize current knowledge of the biology of the insect and epidemiology of outbreaks in lodgepole pine. Amman and Logan (1998) review how management approaches to mountain pine beetle have changed with increasing knowledge from research and operational experience. Whitehead et al. (2004) discuss how to reduce the number and severity of future outbreaks through an emphasis on long-term planning to reduce landscape-level susceptibility and on silviculture to reduce stand-level susceptibility.

The first published account of stand-level silviculture intended to reduce mountain pine beetle damage described a crop-tree thinning experiment in ponderosa pine, based on the supposition that trees would be less likely to succumb to attack if their vigour was increased by removing competition (Eaton 1941). Thinning has been suggested for maturing lodgepole pine stands based on observations relating outbreak hazard to stand age, diameter distribution, and stand density (e.g., Hopping 1951). Variations on thinning treatments, including diameter-limit cutting (e.g. Cole and Cahill 1976; McGregor et al. 1987), thinning to reduce basal area (e.g. Amman et al. 1977; Cahill 1978; Bennett and McGregor 1980), and selective removal of trees with thick phloem (Hamel 1978) were tried initially, but produced variable results (e.g. Roe and Amman 1970). Thinning from above generally reduced the susceptibility of mixed or pure stands until residual trees grew to susceptible size, but it also left stands of reduced silvicultural value (Schmidt and Alexander 1985) that were often vulnerable to wind or snow damage. Although thinning from below left the most susceptible diameter classes, mortality was often reduced during outbreaks (e.g. Waring and Pitman 1980; Mitchell et al. 1983).

Reasons for the observed variability in results after thinning became a topic for discussion whenever research entomologists and forest managers met. As it became more and more apparent that tree vigour was not the only important factor, the roles that microclimate and inter-tree spacing played in the development of infestations were explored. Shepherd (1966) discussed the influence of heat and light intensity on how beetles locate and orient to host trees during attack. Geiszler and Gara (1978) described how inter-tree spacing affected the success of switching attacks from the first tree attacked to nearby trees during development of patch infestations. Amman et al. (1988) suggested that a change in microclimate was the principal factor responsible for reduced attack after thinning because the observed reduction of losses to mountain pine beetle often occurred immediately after thinning, while vigour responses might be delayed by “thinning shock” (McGregor et al. 1987; Amman et al. 1988). Bartos and Amman (1989) further discussed the role of stand microclimate in mountain pine beetle infestation.

Spaced thinnings, to optimize the effects of microclimate, inter-tree spacing and vigour, were proposed as a method to “beetle-proof” some mature stands on timberlands. The beetle-proofing prescription now recommended requires thinning from below (to enhance individual tree vigour, which increases ability to produce resins that are the primary defense against attack), and wide inter-tree spacing to create stand conditions (including air and tree bole temperatures, light intensity, and within-stand winds) that inhibit beetle dispersal, attack behaviour or brood survival (Bartos and Amman 1989; Amman and Logan 1998). To optimize these effects, stands must be opened to an inter-tree spacing of 4 to 5 m (to increase wind penetration and solar radiation input), while retaining the largest and healthiest pine without logging damage (for vigour and windfirmness and to minimize stress). The range of stand characteristics (Table 1) and terrain features appropriate for such a heavy thinning entry into previously unmanaged stands is fairly narrow. However, when applied to mature stands with suitable characteristics, taking stand density down to between 625 trees/ha (4 m spacing) and 400 trees/ha (5 m spacing) usually removes enough volume of sufficient piece-size to ensure a commercially viable thinning operation[1], while leaving a stand that retains substantial value for timber, wildlife habitat, recreation or watershed protection.

1 Anon. 1999. A case study in adaptive management: beetle proofing lodgepole pine in southeastern British Columbia. B.C. Min. For. Extension Note EN-039. Nelson, B.C. 4 p.

Table 1. General stand characteristics appropriate for "beetle proofing" by thinning to uniform spacing

Stand Composition	Lodgepole pine-leading (> 80%)
Stand Age	60 – 110 years at breast height
Stand Density	750 – 1500 trees/ha (> 7.5 cm dbh)
Average Diameter	> 20 cm dbh
Elevation	< 1500 m ASL

In the early 1990s, researchers from the Canadian Forest Service, with forest health specialists and operations staff from the British Columbia Ministry of Forests and its licensees, established side-by-side comparisons of untreated and beetle-proofed stands at five locations in British Columbia (Figure 1). Early results from the most intensively monitored sites in the East Kootenays indicated that this beetle-proofing prescription was operationally feasible (Mitchell 1994), compatible with multiple land management objectives[1], and achieved the changes in stand and tree microclimate and tree vigour thought to reduce susceptibility to infestations[2]. However, efficacy for reducing mountain pine beetle attack remained untested until beetle populations rose significantly near all sites around 2000 - 2001 (Ebata 2004). In 2003, the Government of Canada's Mountain Pine Beetle Initiative[3] funded a re-visit to the sites to address the following questions:

2 Whitehead, R.J. 2001. Commercial thinning of mature lodgepole pine: results of "beetle proofing" research in the East Kootenays. On-line at: www.pfc.cfs.nrcan.gc.ca/cgi-bin/bstore/catalog_e.pl?catalog=18334 (February 17, 2005).

3 The Mountain Pine Beetle Initiative is a $40 million program administered by Natural Resources Canada, Canadian Forest Service. Additional information may be found at: mpb.cfs.nrcan.gc.ca

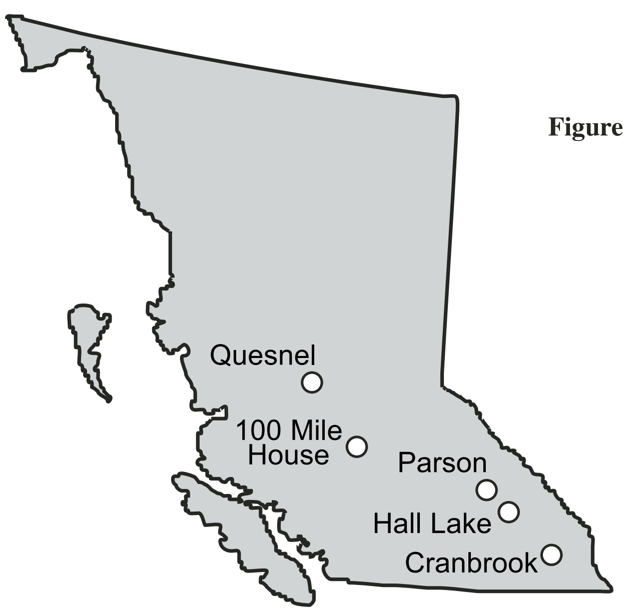

Figure 1. Study site locations.

- Is frequency of attack and of mortality since treatment (number and proportion of trees/ ha) the same in treated and untreated stands?
- Is the proportion of successful attacks (tree killed and/or beetle brood produced) the same in treated and untreated stands?
- Is the ratio of green attack to red attack (recent population growth trend) the same in treated and untreated stands?

This paper reports and discusses the results of these assessments.

Study Sites

Five sites, where beetle-proofed and untreated portions of mature pine forest had been maintained for research or demonstration purposes since establishment between 1989 and 1994, were re-visited for assessment of beetle activity since treatment. Treatments and layout vary with site, but in each case, portions of fire-origin, pine-leading stands were thinned or spaced for beetle-proofing while another portion was left untreated for comparison (Figure 2). All stands fit the profile for natural stands where outbreaks generally develop (Safranyik et al. 1974) and suitability for beetle-proofing (Table 1).

The Cranbrook study site is part of an 80-year-old stand in Galloway Lumber's Forest License, on level terrain in a broad valley at 1360 – 1390 m above sea level (ASL)[4]. This site has been classified as MSdk-04 (lodgepole pine/Oregon grape-pinegrass site series). A 10-ha and an 8-ha block were thinned from below to uniform 4-m and 5-m spacing, respectively, and an adjacent block was reserved as an untreated control. Mitchell (1994) described the harvest operations, which were completed in the winter of 1992/3. An additional 10.4 ha contiguous with the study area was thinned to a uniform 4-m spacing in 1997 during "PartCuts 97", a commercial thinning workshop and equipment demonstration. Green to red attack ratios reported from the surrounding area in 2001, 2002 and 2003 were 1.3 to 1, 1.9 to 1, and 3.0 to 1, respectively[5].

The Parson site is on a level terrace above the Spillimacheen River on Tembec's Tree Farm License (TFL No.14)[6] in two lodgepole pine-dominated stands with similar characteristics that regenerated after fires around 1892 and 1922. The site was classified as MSdk-01 (lodgepole pine/Menziesia-aster site series) and mechanically harvested in the winter of 1993/1994 when 9-ha blocks were thinned to uniform 4-m and 5-m spacing. Two untreated control areas were reserved adjacent to the thinned blocks. The green to red attack ratio reported for 2002 was 20 to 1, but aggressive control of patch outbreaks reduced the green to red ratio to 2 to 1 in 2003[7].

The B.C. Ministry of Forests established the Hall Lake study area in 1990 about 30 km north of Radium Hot Springs at the entrance to the Hall Lake Recreation Area[8]. The treated area was thinned to 500 trees/ha in 1990, and a nearby block was reserved as an untreated control. The site is classified as MSdk04 (lodgepole pine/Oregon grape-pinegrass site series). Green to red attack ratios for 2002 and 2003 were 1.1 to 1 and 3.4 to 1, respectively[9].

4 For. Lic. A19042, C.P. 42, Opening # 82G042-002; Can. For. Serv. Research Project No. P5-8001

5 pers. comm. Elizabeth Goyette, Forest Stewardship Tech., Rocky Mountain Forest District B.C. Min. For.

6 Tree Farm License 14, Cutting Permit 24, Block 915; Can. For. Serv. Research Project No. P5-8001

7 pers. comm. Paul Frasca, TFL Forester, Tembec Inc. Parson, B.C. Extracted from GIS-based record of green attacks within 2 km of study area boundary.

8 pers. comm. Emile Begin, BCTS Planning Forester, Prince George, B.C.

9 pers. comm. Vivian Jablanczy, Canadian Forest Products Ltd. Radium Hot Springs, B.C.

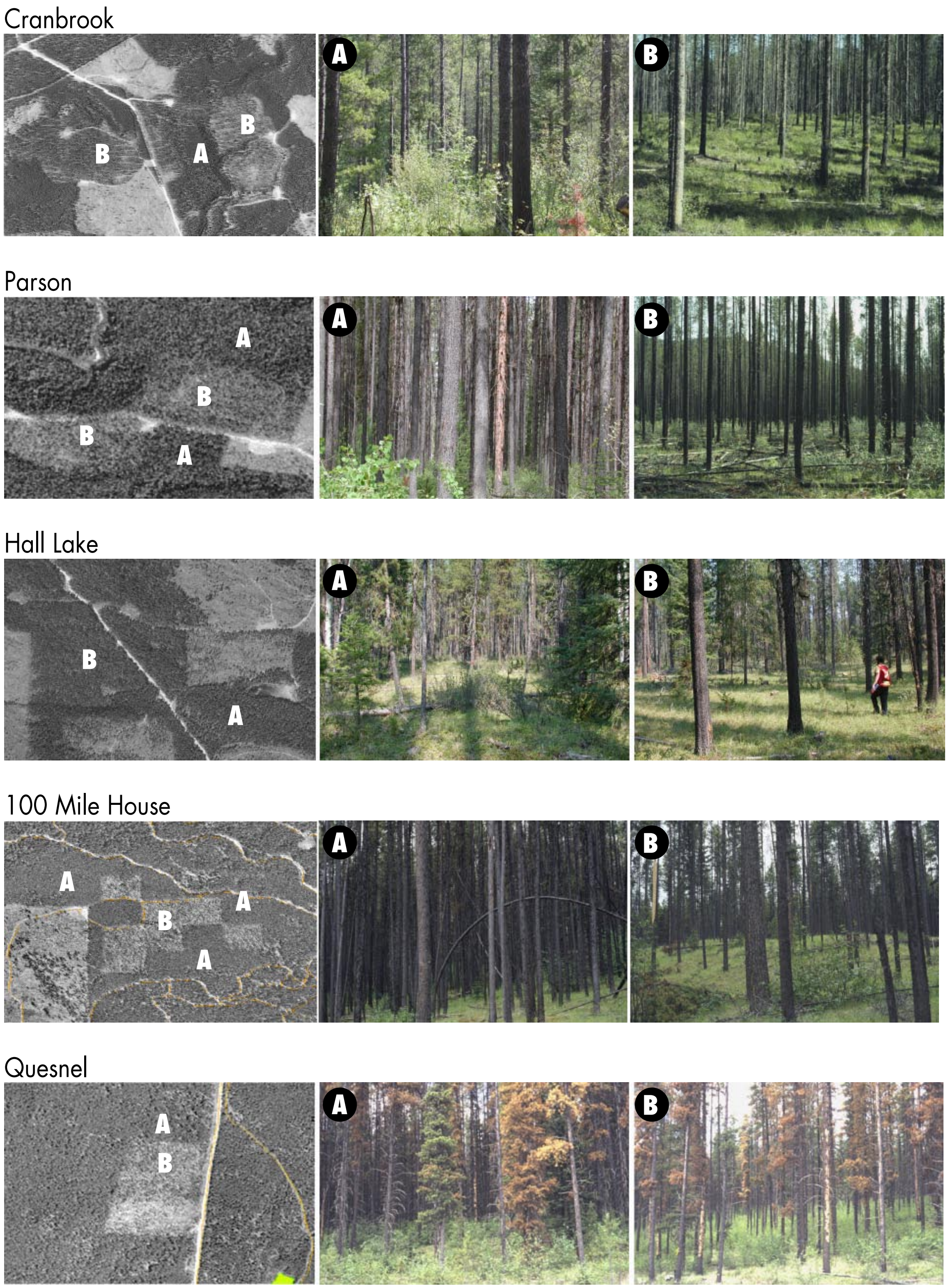

Figure 2. Aerial overview and untreated (A) and treated (B) stand photos for each site.

The 100 Mile House site was established by the B.C. Ministry of Forests and Canadian Forest Service just south of 100 Mile House[10] in 1994. The site is classified as IDFdk3-01 (Douglas-fir-lodgepole pine/pinegrass-feathermoss site series). Six 1-ha control blocks were left untreated while six 1-ha blocks were beetle-proofed by thinning to uniform 4-m inter-tree spacing in a fully randomized block design. We intended to assess all blocks in both treatments; however, due to high mountain pine beetle activity, portions of the unspaced blocks were harvested early in 2003 to remove green attacked trees before the dispersal flight. Green to red attack ratio in the surrounding area was 2 to 1 in 2001, 4 to 1 in 2002, and 6 to 1 in 2003[11].

The Quesnel study site is located on level terrain at 970 m ASL, 55 km north on the 1200 Road and has been classified as SBSdw2. The BC Ministry of Forests and Canadian Forest Service jointly established four contiguous 3-ha plots for study in 1989[12]. One plot was left untreated; the other three were spaced to 4-, 5- or 6-m spacing by a horse-logging contractor. The area with 6-m spacing was not assessed in this study because it had suffered heavy loss to windthrow since treatment. Green to red attack ratios in the surrounding area were approximately 1 to 1 in 2000, 6 to 1 in 2001, and >50 to 1 in 2002.[13]

Cranbrook, Parson and Hall Lake are located in the Rocky Mountain Trench, where an epidemic in the early 1980s greatly reduced the amount of overmature pine at mid-elevation. However, infestations have appeared at higher elevations or in stands that have matured since then as local beetle populations increased in response to several recent years of favourable weather. Cranbrook and Parson are surrounded by extensive tracts of pine that have matured since the last epidemic, and forest managers responsible for these areas have maintained an aggressive approach to monitoring and taking direct action to control patch infestations nearby. The Hall Lake site is a relatively isolated patch of mature pine in the midst of young stands established after salvage harvesting following the last outbreak. Some firewood cutting permits have been granted at the Hall Lake study site to remove beetle-kill since treatment, but there was little effort targeted specifically at mountain pine beetle control in the immediate area.

The sites near 100 Mile House and Quesnel are part of extensive overmature pine forest that was not as heavily impacted by the last outbreak. At 100 Mile House, an aggressive approach to control infestations since the research area was treated has kept beetle pressure under control in the surrounding area. In contrast, beetles from the expanding current epidemic in the north central interior (Ebata 2004) have inundated the Quesnel area recently and control efforts have been unable to keep beetle populations low.

Methods

At four of the five sites (Cranbrook, Parson, Hall Lake, and 100 Mile House), cruise lines were established at right angles to starting points every 50 m along a baseline situated on one side of each treatment unit. Variable radius (prism) plots were then systematically centred along each cruise line at 50 m intervals (three plots per hectare on average) for stand description. Diameter at breast height was recorded for each tree, and increment cores (to pith) and height were measured on a subset of trees at each plot.

In each 50-m-wide rectangular strip between the prism cruise lines, we examined every living or dead lodgepole pine tree with dbh > 10 cm (100% sample by area) for evidence of attack by mountain pine beetle including faded crown, pitch tubes, boring dust (frass), entry and exit holes, and parental and larval galleries. If present in the sample area, stumps cut since beetle-proofing were also examined for evidence of blue stain or mountain pine beetle galleries, and if found, stump diameter was recorded.

10 TSL #A49244, BC Min. For. Silviculture Trial No. SX94401C

11 pers. comm. Rick Stock, Forest Stewardship Tech, 100 Mile House Forest District, B.C. Min. For.

12 Can. For. Serv. Research Project No.PC5269

13 pers. comm. Charles von Hahn, Operations Supervisor, Canadian Forest Products, Quesnel, and Mike Pelchat, Stewardship Officer, Quesnel Forest District, B.C. Min. For.

At the fifth site (Quesnel), similar measurements were taken, but the sampling design was modified. Each 100 m × 200 m rectangular treatment plot was divided into a 25 m grid , which yielded 21 interior grid intersections, eight 25 m × 100 m strips and thirty-two 25 m × 25 m grid-cells (Figure 3). In the untreated control and in areas with 4 m spacing, prism sweeps were conducted at six randomly chosen interior grid-points (i.e. three per hectare) for stand description and each tree or stump in four 25 m × 100 m strips (50% sample by area) was assessed for evidence of mountain pine beetle activity as described above. In areas with 5 m spacing, no prism plots were established nor strips assessed. Instead, diameter was measured on every tree found in eight randomly selected 25 m × 25 m grid-cells (25% sample by area) and each pine tree or stump was assessed for mountain pine beetle activity as described above. Heights and increment cores were measured on a sub-sample of trees in each grid-cell assessed.

In all cases, trees with evidence of attack were tallied and then divided by the area surveyed to calculate frequency of attack (attacked trees/ha). Trees with evidence of mountain pine beetle attack were assigned to 'level of attack' categories (Table 2). Attacks were classified as 'successful' if a) mountain pine beetle galleries or blue stain fungi[14] were present in stumps of trees removed since treatment, b) there was any evidence that brood had been produced in standing dead trees, or c) mountain pine beetles present in freshly infested trees had established galleries without being pitched out. Success rate was calculated as the proportion of attacked trees in the 'mass' and 'partial' attack categories. 'Age of attack' (Table 3), was assigned to each infested tree and summarized graphically by treatment for comparison of trends in mountain pine beetle activity within each stand since treatment. The green to red attack ratio[15] was calculated for each stand to estimate the most recent trends in population growth.

To assist with interpretation of results, background information related to beetle activity and control efforts within a 2-km radius surrounding each study site, was synthesized from available BC Ministry of Forests and Licensee sources (geo-referenced maps of annual forest health overview flights, beetle probes and logging history) and personal communication with local land managers.

14 We assumed that only dead trees were harvested and all blue stain was introduced by mountain pine beetle attack.

15 As used here, the "Green to Red attack ratio" is a ratio of the total number of trees attacked (whether successful or unsuccessful) in the most recent year to the total number of trees attacked in the preceding year. Some trees may have been attacked in both years.

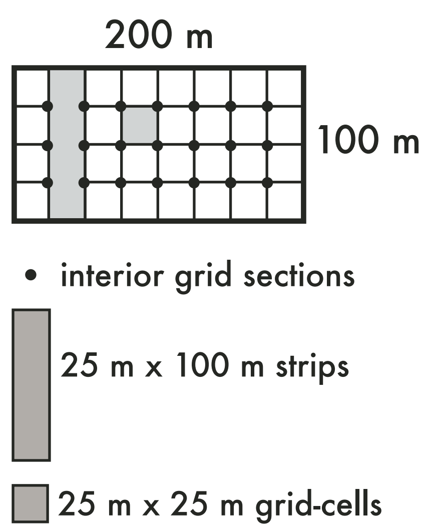

Figure 3. Sampling layout at Quesnel.

Table 2. 'Level of attack' categories used in this study.

Level of Attack	
Mass	Dead or dying tree with successful mountain pine beetle attack; or fresh pitch tubes or entry holes found on the entire circumference of the tree - living beetles present
Partial	Tree successfully attacked by mountain pine beetle in previous years but not dead or dying as a result; or fresh pitch tubes or entry holes found on one side of tree only – living beetles present
Unsuccessful	Tree was attacked this year but the beetle was pitched out – no living beetles present; or, tree attacked in previous years, but evidence of larval galleries and exit holes not present.

Table 3. Age of attack categories used in this study.

Age of attack	
Green	Attacked in most recent flight year
Red	Attacked in year previous to most recent flight
Grey	Attacked more than 2 years previous to most recent flight

Results and Discussion

Stand Characteristics

Table 4 summarizes the areas we surveyed, showing mean stand density, diameter and breast-height-age at time of assessment, by site and treatment. Figure 4 shows mean breast-height ring width vs. time for dominant and co-dominant trees, by site and treatment. In all cases, trees exhibited the typical pattern of unmanaged, single-cohort stands until treatments were applied (Oliver and Larson 1996), i.e., a marked decline in ring width after crown closure, followed by an extended period of slow growth during the stem exclusion phase of stand development. At Cranbrook, Parson, and Quesnel, there was a marked increase in annual radial growth soon after spacing that is not evident in the adjacent untreated stands, suggesting that tree vigour increased after thinning in response to reduced competition for limited site resources. At 100 Mile House, the treated stand shows a similar increase in ring width shortly after spacing but there are no data from the untreated stand for comparison. At the Hall Lake site, there is no obvious difference between treatments.

Mountain Pine Beetle Attack

Total number of trees attacked since treatment, attack density (number of attacked trees per hectare), and green to red attack ratio are shown in Table 5, by site and treatment. Table 6 summarizes corresponding figures for mortality due to mountain pine beetle. Cumulative attack since study establishment is shown as a line graph in Figure 5 to emphasize differences in attack history and rate of increase over the last 2 years at the four sites where data is available for all treatments. Tables 7 and 8 provide a breakdown of attack by level (mass, partial or unsuccessful) and age (grey, red or green) by site and treatment.

Table 4. Stand descriptions, by site and treatment

Location (year established)	Treatment	Area assessed (ha)	Mean density (trees/ha)	Mean DBH (cm)	Mean age (years)
Cranbrook	Not Treated	3.9	1380	22.7	90
(1993)	Spaced to 4 m	5.3	443	25.3	90
	Spaced to 5 m	2.4	383	24.5	90
Parson	Not Treated 1	1.9	770	28.2	90
(1994)	Not Treated 2	1.7	1089	24.1	90
	Spaced to 4 m	2.9	386	22.3	110
	Spaced to 5 m	2.5	258	25.3	90
Hall Lake	Not Treated	3.8	1169	22.3	109
(1991)	Thinned to 500 trees/ha	4.7	701	22.7	109
Quesnel	Not Treated	1.0	1300	21.5	83
(1990)	Spaced to 4 m	1.0	484	25.1	83
	Spaced to 5 m	0.5	296	23.9	83
100 Mile House	Not Treated	6.6	n/a [a]	n/a [a]	n/a [a]
(1994)	Spaced to 4 m	7.7	549	22.1	124

a Patches of green attack were harvested at 100 Mile House in June 2003 before the survey was completed. All removals were from untreated plots.

Table 5. MPB attack since treatment, by site and treatment

Site	Treatment	Proportion of stand attacked (%)	Number of attacks [a] Total	Number of attacks [a] per ha	Green:red ratio
Cranbrook	Not Treated	1.6	88	22	1.8
	Spaced to 4 m	0.5	12	2	0.3
	Spaced to 5 m	1.8	16	7	0.5
Parson	Not Treated 1	7.3	98	56	2.9
	Not Treated 2	1.4	24	15	0.3
	Spaced to 4 m	0.0	0	0	0
	Spaced to 5 m	0.4	1	0	0
Hall Lake	Not Treated	13.5	579	158	1.8
	Thinned to 500 trees/ha	5.3	161	37	1.4
Quesnel	Not Treated	34.8	453	453	3.3
	Spaced to 4 m	34.5	167	167	1.2
	Spaced to 5 m	37.8	56	112	1.4
100 Mile House	Not Treated	n/a [b]	433 [b]	67 [b]	n/a [b]
	Spaced to 4 m	0.0	0	0	--

a Includes unsuccessful attacks. Some trees were attacked in more than one year.

b Patches of green attack were harvested at 100 Mile House in June 2003 before the survey was completed. All tree removals were from untreated plots. Untreated stand data are from British Columbia Ministry of Forests pre-harvest beetle probe.

Table 6. Mortality caused by mountain pine beetle by site and treatment

Site	Treatment	Proportion of stand killed (%)	Trees killed		Green:red ratio (killed trees)
			Total	Per ha	
Cranbrook	Not Treated	1.4	78	20	1.4
	Spaced to 4 m	0.5	9	2	--
	Spaced to 5 m	1.0	10	4	--
Parson	Not Treated 1	5.5	79	42	4.0
	Not Treated 2	0.9	17	10	1.0
	Spaced to 4 m	0.0	0	0	--
	Spaced to 5 m	0.0	1	0	--
Hall Lake	Not Treated	9.8	434	114	4.7
	Thinned to 500 trees/ha	3.1	102	22	3.0
Quesnel	Not Treated	27.9	363	363	3.3
	Spaced to 4 m	23.3	113	113	1.2
	Spaced to 5 m	26.3	38	76	1.4
100 Mile House	Not Treated	n/a [a]	n/a [a]	n/a [a]	n/a [a]
	Spaced to 4 m	0.0	0	0	--

a Patches of green attack were harvested at 100 Mile House in June 2003 before the survey was completed.

Table 7. Attack Levels (attacked trees/ha) for three levels of attack.

Site	Treatment	Level of attack		
		Mass	Partial	Unsuccessful
Cranbrook	Not Treated	20.0	1.0	1.5
	Spaced to 4 m	1.7	0.2	0.4
	Spaced to 5 m	4.2	2.5	0.0
Parson	Not Treated 1	41.6	8.9	4.7
	Not Treated 2	10.0	4.7	0.6
	Spaced to 4 m	0.0	0.0	0.0
	Spaced to 5 m	0.4	0.0	0.0
Hall Lake	Not Treated	114.2	32.9	12.1
	Thinned to 500 trees/ha	21.7	9.1	5.7
Quesnel	Not Treated	363.0	8.0	82.0
	Spaced to 4 m	114.0	17.0	36.0
	Spaced to 5 m	76.0	12.0	24.0

Table 8. Trees attacked, by age (green, red, and grey) and level of attack (mass, partial, and unsuccessful).

Site	Treatment	Grey attack			Red attack			Green attack		
		Mass	Partial	Unsuccessful	Mass	Partial	Unsuccessful	Mass	Partial	Unsuccessful
		trees/ha								
Cranbrook	Not Treated	8.7	0.5	0.3	4.6	0.0	0.0	6.7	0.5	1.3
	Spaced to 4m	1.5	0.0	0.0	0.0	0.4	0.2	0.2	0.0	0.0
	Spaced to 5m	3.8	1.7	0.0	0.4	0.4	0.0	0.0	0.4	0.0
Parson	Not Treated 1	12.1	1.6	0.0	5.8	4.7	0.0	23.7	2.6	4.7
	Not Treated 2	7.6	2.4	0.6	1.2	2.4	0.0	1.2	0.0	0.0
	Spaced to 4m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Spaced to 5m	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hall Lake	Not Treated	99.2	20.5	7.6	2.6	5.5	3.4	12.4	6.8	1.1
	Thinned to 500 trees/ha	16.6	5.7	3.6	1.3	1.5	1.7	3.8	1.9	0.4
100 Mile	Not Treated	na	na	na	na	na	na	na	na	na
	Spaced to 4m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quesnel[a]	Not Treated	18.0	na	na	69.0	na	na	276.0	na	na
	Spaced to 4m	21.0	na	na	41.0	na	na	52.0	na	na
	Spaced to 5m	8.0	na	na	28.0	na	na	40.0	na	na

a At Quesnel, date of attack was not identified for partial and unsuccessful attacks; however, in the untreated area 8 trees/ha of partial and 82 trees/ha of unsuccessful attack were identified, 17 trees/ha of partial and 36 trees/ha of unsuccessful attack was identified in the areas with 4-m spacing, and 12 trees/ha of partial and 24 trees/ha of unsuccessful attacks were identified in the areas with 5-m spacing.

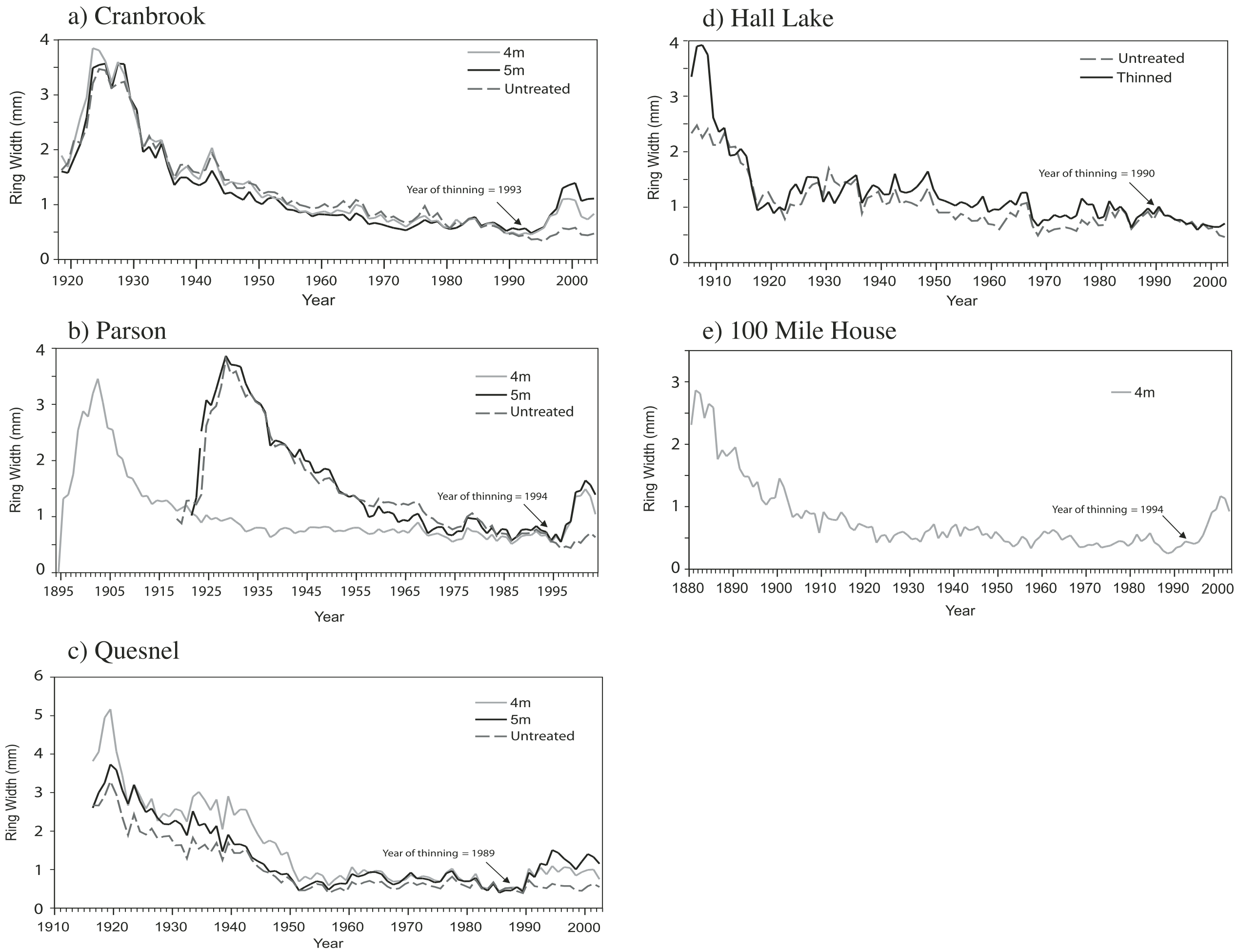

Figure 4. Radial growth increment (ring width), by site and treatment. The arrow points to year of "beetle-proofing".

Total number and density of trees attacked, mortality due to beetle attack, and green to red attack ratio are much lower in beetle-proofed treatment units than in corresponding untreated units at every site, although the magnitude of that difference varies between sites. Grey attacks at all sites were generally found irregularly dispersed throughout the stand as expected with endemic beetle activity (Safranyik 2004). Red and green attacks were often found in small groups or patches in the untreated stands at Cranbrook, Parson and 100 Mile House, a pattern typically seen when resident populations respond to several years of favourable weather (Safranyik 2004).

Variation between sites in overall amount of attack and proportions of partial or unsuccessful attacks appears to be related to differences in availability of nearby suitable habitat for local dispersal, level of immigration from other sites, and effectiveness of recent control efforts in the surrounding area. Relative to the other sites, Hall Lake had much more grey attack, a lower green to red attack ratio, and a high proportion of partial attacks in both units (with the same trees often attacked in several successive years) and of unsuccessful attacks in the treated unit. Because this study site is isolated from other mature pine stands in a matrix of young stands, it may be that the local dispersal of a resident population has been restricted to this small area and has been cycling at low levels since the 1980s outbreak. At Quesnel, there was very little grey attack and recent attacks were distributed throughout the treatment units (and in the surrounding area). This likely reflects very high numbers of beetles entering the area over the last 2 years as long-range dispersal from the uncontrolled epidemic to the north and west rather than local dispersal of resident beetles from within the stand.

At 100 Mile House there was no evidence of any attack in the spaced areas since treatment in 1994. In contrast, several patch infestations that developed in the untreated areas in 2002 were logged in the spring of 2003 as part of normal beetle control operations in this area. Raw data obtained from the beetle probe conducted prior to harvest[16] indicated approximately 433 trees (67 per ha) were attacked in 2001 or 2002 in the 6.6 ha of unspaced area that fell within the study boundaries and that the "current red- and green-attack" to "non-current red-attack" ratio was 9.8 to 1.

In the 10 years since treatment was completed at Parson, only one tree (grey attack) was attacked in the 5.9 ha of spaced area assessed; in contrast, 122 trees were attacked in the 3.6 ha of untreated areas examined (42 grey; 26 red; 61 green). Most attacks were concentrated in a single patch, which was part of a 4-ha infestation harvested by Tembec in the winter of 2003/2004 as part of their normal operations to control growth of beetle populations[17].

Evidence of some attack was found in all treatment units at the Cranbrook, Hall Lake and Quesnel sites. At Cranbrook, where the overall number of attacks was lowest, cumulative attack density in the untreated stand was 3 to 11 times higher than in the treated stands since the trial was established. Only one green mass attack was found in 7.4 ha of spaced area in contrast with 26 green mass attacks within the 3.9 ha unspaced area we assessed. The newest attacks were mostly concentrated in one patch, which was cut the following winter as part of normal beetle control efforts that also included harvest of one 2-ha and two <1-ha patch infestations just across the spur road which defined the boundary of our study area.

At Hall Lake, cumulative attack density was 4.2 times higher in the untreated area than in the thinned area and the number of grey attacks per hectare was much higher in the untreated portion of the stand than in the thinned portion, suggesting that beetles consistently selected trees and initiated attack more often in the untreated part of the stand. Treatment at the Hall Lake site differed from all other sites in that the prescription specified thinning to 500 trees/ha, rather than spacing to a minimum inter-tree distance. Our surveys indicated considerable variation in stand density after thinning (142 – 2059 trees/ha), and a higher mean density than prescribed. When thinning to a target density, patches of higher density are often left to compensate for natural stand openings or removal of damaged trees along skid trails. Our methods of data collection did not allow testing the influence of density on attack frequency; however, we noted that attacks seemed to occur in patches within the treatment area where there were no stumps. It is important to remember that "beetle-proofing" requires thinning to minimum inter-tree spacing to optimize the desired effect on microclimate. Small, untreated patches may still provide good microclimate for host selection and initiation of attack. Similarly, retaining a high proportion of full-crowned species such as spruce or dense intermediate layers may compromise the desired microclimate change.

At Quesnel, almost all attacks occurred in the two years preceding our assessment, but attack density was much higher than at other sites. In the untreated area, attack density was 2.7 to 4.0 times higher than in the spaced plots, more than 80% of trees over 20 cm diameter at breast height (dbh) were dead at time of assessment and new attacks were occurring in smaller-diameter trees. Although the green to red attack ratio is much lower in the treated stand, about half of trees over 20 cm dbh have also been attacked in spaced plots and this level of mortality (already unacceptable for commercial timber management) is expected to increase.

At the time of assessment, the epidemic in north-central British Columbia had been on-going for several years and there had been frequent reports of extended or multiple dispersal flights per season. This behaviour can result in portions of the population losing synchrony with local weather patterns and an increase in mortality for those beetles that over-winter in life stages that are not cold-hardy (Carroll

16 pers. comm. Rick Scott, Stewardship Tech., 100 Mile House Forest District, BC Min. For.

17 pers. comm. Paul Frasca, TFL Forester, Tembec Inc. Parson, BC.

and Safranyik 2004), which may explain the relatively high proportion of attacked trees that successfully resisted attack in all treatments at Quesnel (Table 9). Alternatively, it may be that immigrant beetles were unsuccessful because they indiscriminately attacked trees at Quesnel whose vigour was higher than those normally selected by resident populations at other sites.

Although increased primary resin production in response to wounding has been observed in lodgepole pine trees after spacing[18], the proportion of attacked trees where mountain pine beetle overcame tree resistance and produced brood was high at all sites with no consistent difference between treatments. Similarly, higher numbers of scolytid bark beetles have been trapped in lodgepole pine stands after thinning (Hindmarch and Reid 2001; Safranyik et al. 2004), yet we observed far fewer attacks initiated by mountain pine beetle in the beetle-proofed stands at all sites. This suggests that increased ability to produce resin to resist attack was not as important in reducing damage at stand level as the large reduction in number of attacks actually initiated, which is more likely associated with the effects of treatment on microclimate or inter-tree spacing.

18 Safranyik, L., Linton, D. and Carroll, A.L., Canadian Forest Service, Victoria, BC (unpublished data), cited in Whitehead et al. 2004.

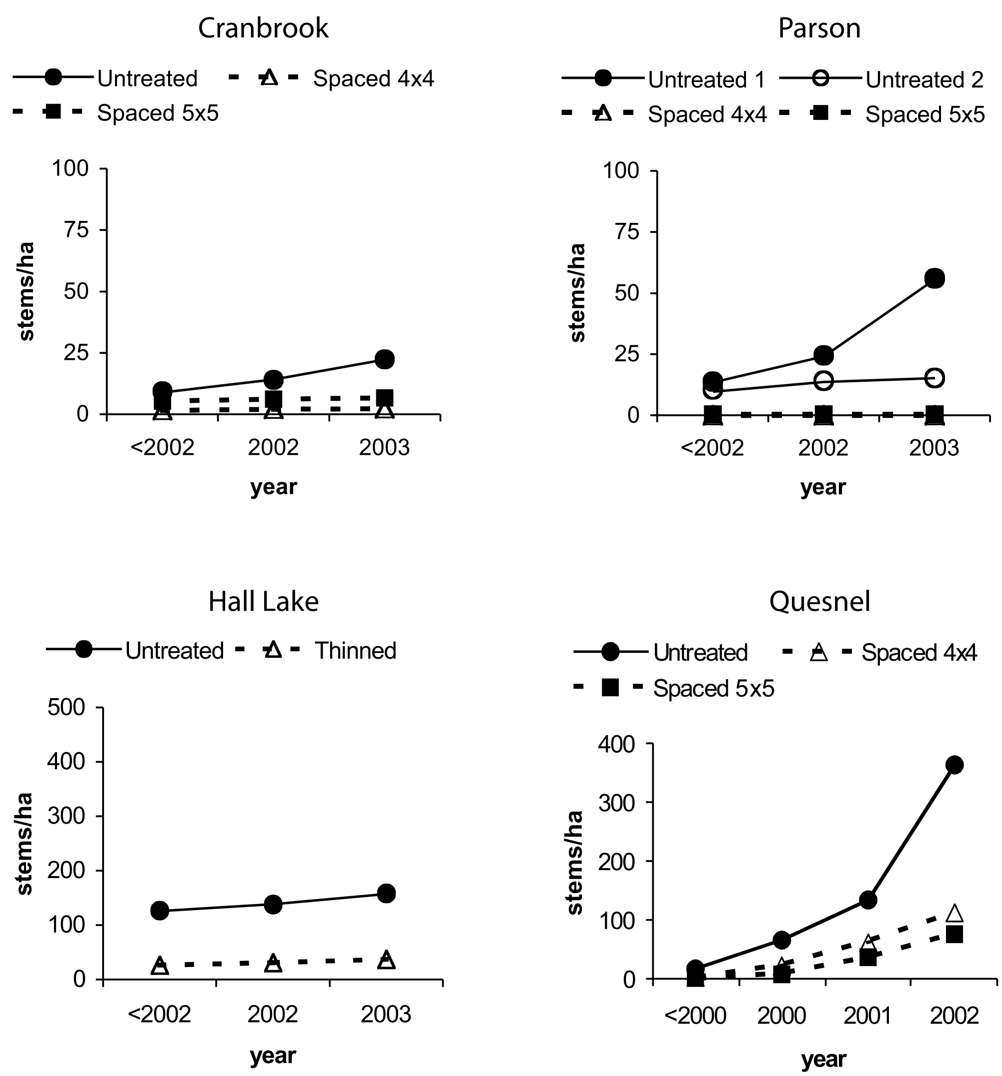

Figure 5. Cumulative Mountain Pine Beetle attack by site and treatment

Table 9. Success rate of attack

Site	Treatment	Trees attacked (trees/ha)	Unsuccessful attacks (trees/ha)	Unsuccessful attacks (percent)
Cranbrook	Not Treated	22.4	1.5	7%
	Spaced to 4 m	2.3	0.4	17%
	Spaced to 5 m	6.6	0.0	0%
Parson	Not Treated 1	56.0	4.8	9%
	Not Treated 2	15.3	0.6	4%
	Spaced to 4 m	0.0	0.0	.
	Spaced to 5 m	0.4	0.0	0%
Hall Lake	Not Treated	158.1	12.0	8%
	Thinned to 500 trees/ha	36.7	5.8	16%
Quesnel	Not Treated	453.0	82.0	18%
	Spaced to 4 m	167.0	36.0	22%
	Spaced to 5m	112.0	24.0	21%

Summary and Conclusions

Thinning mature pine stands from below to a uniform inter-tree spacing of at least 4 m (beetle-proofing) is an effective stand-level treatment to prevent outbreaks in specific stands when weather conditions favour expansion of resident mountain pine beetle populations. This prescription is best suited to single-layer pine-leading stands when retention of mature forest cover is required to meet management objectives on that site and should only be applied within a landscape-level strategy focused on keeping beetle populations low in surrounding areas and reducing landscape susceptibility through planned stand replacement.

At Cranbrook, Parson, and 100 Mile House, the prescribed spacing treatment produced the intended result. When untreated stands in all three areas developed incipient infestations that required direct control intervention, the beetle-proofed stands did not. At Hall Lake, the prescription called for thinning to a target stand density, rather than spacing to a minimum inter-tree distance. Although there was much less attack in the thinned portion of the area than in the untreated portion, attack density in the treated area at Hall Lake was higher than at Cranbrook, Parson or 100 Mile House. Many of these attacks appeared to occur in small pockets of the stand left unthinned to reach the target stand density (to compensate for natural stand openings and skid trails).

Our observations suggest that an increase in an individual tree's ability to resist attack through increased capacity to produce primary resins as a result of enhanced vigour after thinning does not have as much effect on reducing mortality at stand-level as the reduction of attack frequency achieved in response to increasing inter-tree spacing to at least 4 m. Increasing inter-tree spacing to at least 4 m appears to be the key to achieving the desired results. Unspaced patches or leave strips within beetle-proofed units provide conditions that favour successful initial attack and may serve as centres for initiation of patch infestations.

At every site we examined, some or all of the untreated areas developed infestations that required management intervention to prevent expansion of the outbreak. Unacceptable damage occurred in a beetle-proofed stand only at the Quesnel site, where there was immigration of very high numbers of beetles from an uncontrolled landscape-level outbreak. Although effective in preventing transition between endemic and incipient phases of the outbreak cycle by resident beetle populations, beetle-proofing will not save a stand from damage caused by a huge influx of immigrant beetles during an epidemic outbreak.

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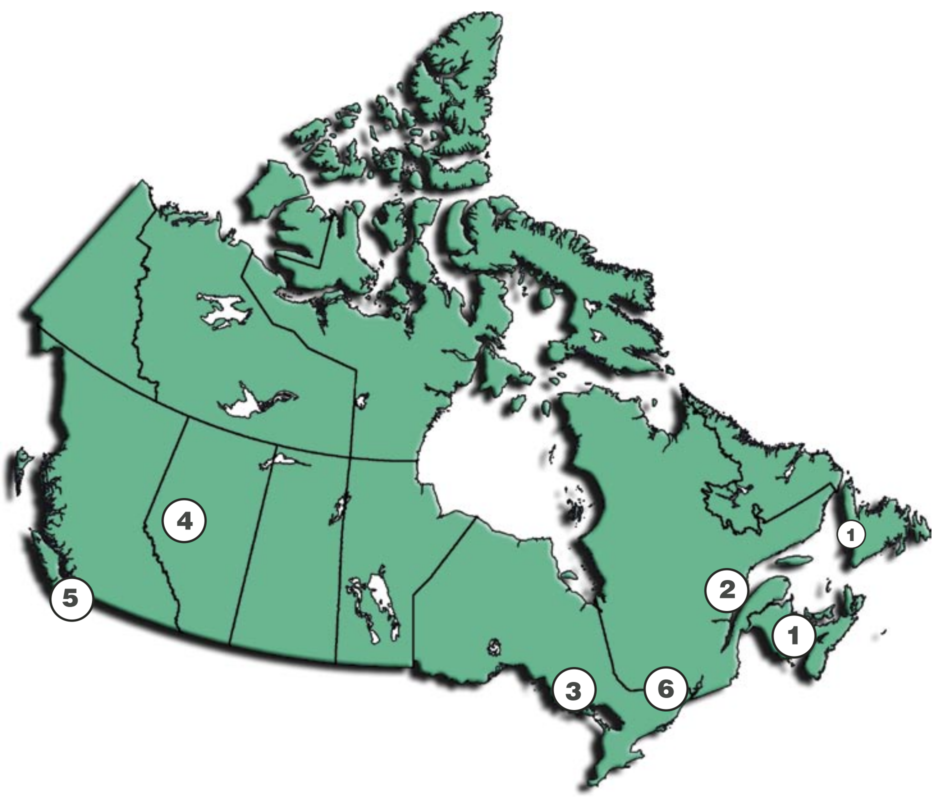

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