Comparison of Two Treatment Regimes for Managing Western Balsam Bark Beetle

Research Report

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Abstact

The efficacy of pheromone-baited, standing subalpine fir *Abies lasiocarpa* (Hook) Nutt. and felled green trap trees was tested in southern British Columbia as potential management techniques for containing western balsam bark beetle *Dryocoetes confusus* Swaine populations prior to logging. In the year treatments were deployed, standing trees in close proximity to baited trees had significantly higher levels of current attack than those near felled trap trees or in control blocks. The control blocks had the lowest level of current attack. Diameters of attacked trees were significantly greater than unattacked trees in all treatments. Naturally attacked, standing subalpine fir had high levels of occupation (number of nuptial galleries) along the full length of the bole. Baited trees had similar levels of occupancy up to six metres in height. Felled green trees had lower occupancy than the baited or naturally attacked trees. Although baited trees concentrated attack into a discrete area, they did not artificially trigger an outbreak or further population expansion in the year following treatment. Felled trap trees appeared less attractive to western balsam bark beetle than natural, susceptible, standing subalpine fir; they are more difficult to deploy and therefore not recommended as a means of containing western balsam bark beetle prior to logging.

Keywords: *Dryocoetes confuses*, felled trap tree, pheromone baiting

INTRODUCTION

The western balsam bark beetle (WBBB), *Dryocoetes confusus* Swaine (Coleoptera: Scolytinae), in association with its blue stain fungus, *Ceratocystis dryocoetidis* Kendrick and Molnar (Molnar 1965, Bleiker & Uzunovic 2004), is the most destructive native insect pest of mature and over-mature subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., in British Columbia (BC) (Garbutt 1992, Maclauchlan et al. 2003). It is the dominant disturbance agent in these high-elevation forests and is found throughout the range of its host (Bright 1963, Parish et al. 1999, Maclauchlan 2016). Beetle populations persist at fluctuating levels within a stand for many years until the majority of mature and semi-mature subalpine fir has been killed (Garbutt 1992). The outbreak dynamics of WBBB are closely linked to host suitability and susceptibility, with beetles preferring large, old, slow-growing subalpine fir

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(Stock 1991, Bleiker et al. 2003, Bleiker et al. 2005). Western balsam bark beetle selectively kills small groups of trees at a relatively low but constant level each year in infested stands (Stock 1991, Unger & Stewart 1992, McMillin et al. 2003). The selective and patchy distribution of mortality suggests that WBBB may be limited by the abundance and distribution of susceptible hosts, as well as by its harsh environment (Maclauchlan & Brooks 2017). Cumulative mortality from WBBB can reach significant levels in chronically infested stands (Garbutt & Stewart 1991, Maclauchlan 2016). It is expected to become even more aggressive as it responds to the effects of climate change on its host (Maclauchlan 2016). Provincially in 2016, close to 3.3 million hectares were impacted by WBBB, with 244,065 hectares occurring in southern BC where this trial was located (Maclauchlan & Buxton 2017, Westfall & Ebata 2017). The diffuse and patchy nature of tree mortality over long periods makes losses due to WBBB difficult to estimate. Annual levels of mortality of mature, dominant canopy subalpine fir are generally less than 2%; however, cumulative in-stand mortality can often exceed 60% (Maclauchlan 2016).

The impact of WBBB to forest resources such as harvestable volume is poorly quantified (BC FLNR 2015). Currently, BC has no coordinated management approach for addressing this impact. Minimal suppression of WBBB is indirectly achieved through the harvest of dead and dying trees (BC FLNR 2017). As the forest industry moves away from salvaging lodgepole pine killed by mountain pine beetle *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytinae) and the salvage focuses on spruce beetle *Dendroctonus rufipennis* (Kirby) infested forests in northern BC where subalpine fir and spruce often grow in mixtures, there has been increased awareness and interest in the impact of WBBB and how to manage BC's high-elevation ecosystems.

In the southern interior of BC, the WBBB normally requires two years to complete development (Mathers 1931, Garbutt 1992). Male beetles initiate attack in mid-late June when daily maximum temperatures exceeded at least 15ºC (Stock 1991, Hansen 1996, Gaylord et al. 2008, Stock et al. 2013, Maclauchlan & Brooks 2017). They locate a suitable host tree through primary attraction (Stock & Borden 1983) and then excavate a nuptial chamber beneath the bark (Bright 1976, Garbutt 1992). There, they release the aggregation pheromone, *exo*-brevicomin, which attracts females to the tree (Borden et al. 1987, Stock et al. 1994). Female beetles typically overwinter in the host tree after establishing one brood and may extend their galleries and lay additional eggs the following spring before emerging to attack a new host. It has been observed that new or recent windthrow are sometimes used as host material (Allen et al. 2003, McMillin et al. 2003), but to what extent and how successfully is unclear. WBBB and other bark beetles such as spruce beetle and Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, attack low-vigor, stressed, or downed hosts (Rudinsky 1962).

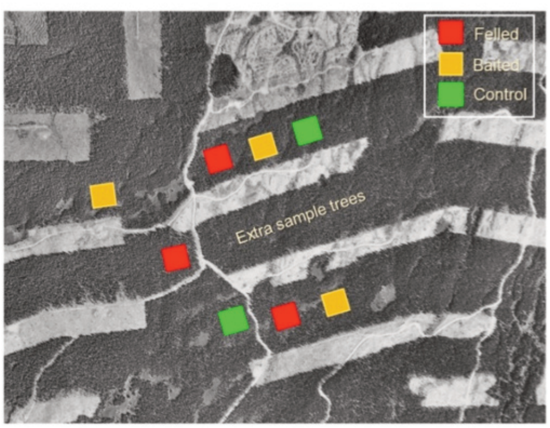
Spruce beetle and Douglas-fir beetle will exploit recent windthrow, thereby potentially increasing their population density (Dyer 1973, Gray et al. 1990, Ross & Daterman 1997). The utilization of fresh windthrow by these two bark beetles led to developing the successful management technique of deploying freshly cut, large host species trees, called "trap trees," to manage outbreaks of spruce and Douglas-fir beetle (Maclauchlan 2016). Deployment of attractive pheromone baits is another tool that can be used to manage spruce beetle and Douglas-fir beetle under certain infestation conditions in stands planned for harvest. Baiting standing, live trees will attract and concentrate beetles in stands prior to harvesting but the use of trap trees (felled, unbaited trees) is the preferred and recommended management tactic for spruce and Douglas-fir beetle (FLNR 2016, FLNR 2018).

The objectives of this study were to:

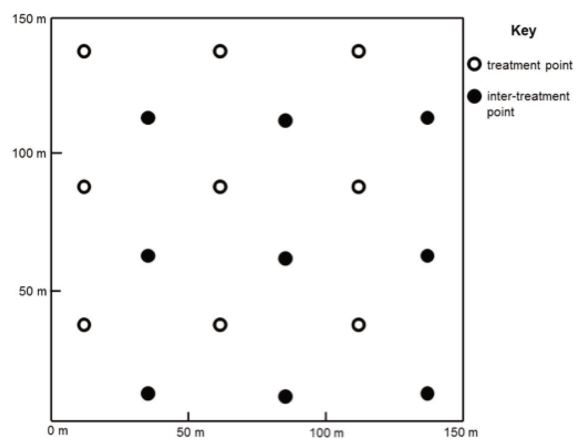
1. assess the efficacy of baiting standing trees and falling trap trees in containing WBBB pre-harvest; and
2. determine occupancy (WBBB attack density) in standing baited trees, felled trap trees, and naturally attacked subalpine fir.

METHODS

The study site, es tablished in a stand approximately 100 years old, was located at Buck Mountain (UTM Zone 11, Northing: 5548600, Easting: 360500), south of Lumby, BC, in a very dry, cold subzone (ESSFxc) of the Engelmann Spruce Subalpine Fir ecosystem (Meidinger & Pojar 1991). Treatment blocks were placed throughout the stand, which had a low-level scattered WBBB infestation (Figure 1a). The three treatments were: baited (three replicates), felled (three replicates), and control (two replicates) (Figure 1 a, b). Only two control replicates were established due to the lack of suitable, accessible locations in the stand. All treatment trees (baited and freshly felled trap trees) were similar in size and age. Each replicate consisted of nine trees arranged in a grid pattern covering a 150 m x 150 m area, to ensure that each treatment tree (either baited or felled) was separated from all other treatment trees by 50 m. The authors established nine treatment points per block and nine inter-treatment points per block for a total of 18 sampling points per replicate (Figure 1b). An inter-treatment point was a pre-determined point located mid-way between treatment points to assess attack in the stand beyond the treatment point. Inter-treatment points were created by running a line at the 25 m mark between treatment points and establishing plots staggered from adjacent lines at 50 m intervals (Figure 1b). At each treatment and inter-treatment point, a 10 m radius plot was established. In total, 144 plots were established and assessed.



a.



b.

Figure 1. a) Layout of treatment and control blocks for the felled/baited trial at Buck Mountain; and, b) diagram of the nine treatment points and nine inter-treatment points within the blocks.

The trial was established from June 13 to 18, 2001, prior to the onset of WBBB flight. The first attack assessment occurred from August 24 to 26, 2002 and the second from October 6 to 8, 2003.

The baited trees had one pheromone bait attached to the north side of the tree bole at approximately 2 m height. The baits contained (±)-*exo*-brevicomin (release rate of 0.4 mg/24 h) (supplied by PheroTech Inc., Delta, BC, Canada). The trap trees were felled at approximately 30 cm stump height. Designated control trees were left in their natural state.

Plot centres were clearly marked as to treatment and sampling point. All live and dead trees greater than 12.5 cm at DBH within the 10 m radius plot were assessed. Assessments included tree species; tree status (live/dead); DBH (cm); and WBBB attack status.

Windthrow (i.e., subalpine fir > 20 cm at DBH, with a minimum 3 m length, not felled for the trial) was also measured. Windthrow was assessed in mid-July 2002. Very decayed windthrow was ignored. The windthrow assessment involved two steps:

1. estimating the length of time the tree had been on the ground: new (fallen within the past year: green foliage intact); recent (fallen within 1–2 years: bark intact); and older (> 2 years: snag); and,
2. determining the presence or absence of WBBB attack (Figure 2).

Figure 2. Old subalpine fir windthrow with evidence of WBBB attack (left) and stand of subalpine fir showing recent and old WBBB attack (right).

All assessed windthrow were marked with paint. The same survey protocol was followed for all treatments (baited, felled, and control) in 2003, with the exception that only new unmarked windthrow was assessed.

Western balsam bark beetle attack success was measured for each treatment one year after the trial was established. To assess attack success in baited trees, we felled baited trees that comprised part of a long-term study in an adjacent stand of similar age and WBBB population level. These surrogates were used because at the assessment time, safety issues were identified within parts of the baited tree blocks. Eleven baited subalpine firs were felled post-attack to assess brood development success. The 27 felled trees in the felled treatment were assessed and 25 naturally attacked trees were felled post-attack in the control treatment and assessed. Three 20 cm x 20 cm bark samples were obtained along the bole at 2 m, 6 m, and 10 m for all treatments. Samples were collected from the top or side of the bole, for ease of access. The number of nuptial chambers (full and partial) and egg galleries were compared among treatments. Full nuptial chambers were defined as attacks originating within the (20 cm x 20 cm) sample, with all radiating female egg galleries visible. Partial nuptial chambers were defined as attacks occurring on one of the four boundaries of the (20 cm x 20 cm) sample, with only some of the egg galleries extending into the sample area. ANOVA, Tukey's, and *t*-tests ($p < 0.05$) were performed using the statistical computing package SYSTAT 10.2 for Windows (SPSS Inc., Chicago, IL.).

RESULTS AND DISCUSSION

Western balsam bark beetle attack incidence (number of subalpine fir attacked) was summarized for each replicate in all treatments. There were no significant differences. Mortality of subalpine fir ≥ 12.5 cm DBH averaged across replicates within a treatment ranged from 39% to 41% in the baited replicates, 38–40% in the felled replicates, and 32–33% in the two control replicates. The data for replicates within each of the three treatments were pooled for analysis.

The mean DBH of the remaining live subalpine firs was significantly less than WBBB-killed trees in all treatments (Table 1), supporting other reports that demonstrate larger diameter trees are preferentially colonized by WBBB (Stock 1981, 1991, Greenwood & Borden 2000, Bleiker et al. 2003, Maclauchlan 2016). There were no significant differences in the mean DBH of live and dead subalpine fir among treatments (Table 1).

Table 1. Stand structure of the felled, baited, and control treatments sampled at Buck Mountain in 2002

Attribute	Felled (3 replicates)	Baited (3 replicates)	Control (2 replicates)
Total number of live subalpine fir	783	752	542
Number of trees measured	324	351	221
DBH range (cm)	12.5–42.9	12.0–55.3	12.5–50.1
Average DBH (cm) ± SE	22.5 ± 0.4a*	22.1 ± 0.4a	22.0 ± 0.5a
Total number of dead subalpine fir	663	728	399
Number of trees measured	340	369	154
DBH range (cm)	12.5–70.0	11.8–54.1	12.0–50.0
Average DBH (cm) ± SE	26.9 ± 0.4b	25.4 ± 0.4b	26.7 ± 0.6b
Total number of live interior spruce	257	334	260
Stand density (sph)	619	646	716

Notes: cm, centimetre; DBH, diameter at breast height; SE, standard error; sph, stems per hectare.
*Means followed by the same letter are not significantly different ($p > 0.05$)

In July 2002, one year after the trial was established, the natural windthrow located in each treatment was tallied and assessed for WBBB attack. The amount of available and suitable host material on the forest floor of natural stands is possibly an attractive yet scarce resource for WBBB. Some species of *Dendroctonus* bark beetles (e.g., spruce beetle and Douglas-fir beetle) will build up their populations in windthrow and then move to standing green trees (Lejeune et al. 1961, Schmid & Frye 1977, Humphreys & Safranyik 1993, Humphreys 1995, Oregon Department of Forestry 2017), thereby potentially triggering or exacerbating an infestation. Observational data on current and past attack levels in all treatment blocks were collected and summarized. Current attack levels in recent windthrow was highest in the baited treatment (Table 2), likely due to the influence of tree baits attached to the centre trees of each replicate in 2001. The two other treatments had lower levels of current attack on natural windthrow. The felled treatment had the lowest level of current attack in natural windthrow, probably due to the freshly felled subalpine firs being a stronger competing influence (larger trees than natural windthrow) for beetles searching for hosts. Incidence of past attack in windthrow (Figure 2) ranged from 27% to 51% among treatments, while approximately half the windthrow showed no evidence of WBBB attack (Table 2). McMillin et al. (2003) found similar levels of utilization. This could indicate that trees died of other causes and then fell over, WBBB did not attack the trees even though they were acceptable hosts, or there were very low populations of WBBB in the stand when the windthrow occurred. Also, we cannot ascertain for certain whether the presence of WBBB galleries in old windthrow means the tree was attacked as a live standing tree and then fell or was attacked as fresh windthrow on the ground. Although WBBB will colonize windthrow, it is not as successful in this host type and does not appear to have the same influence on outbreak dynamics as observed with spruce beetle and Douglas-fir beetle. Subalpine fir have a narrow, dense crown that sheds snow and are fairly wind-firm. Therefore, windthrow may be only a host of opportunity for this insect.

Table 2. Summary of WBBB activity in windthrow subalpine fir assessed in 2002

	Treatment (all blocks combined)	Number of windthrow	% with current attack	% with evidence of past attack	% with no WBBB activity
Windthrow	Felled	150	1.3	40.0	58.7
	Baited	144	6.3	51.4	42.4
	Control	52	3.8	26.9	69.2

In 2002, one year after the trial was established, the baited treatment had a significantly higher incidence of current attack (16.1% in the treatment plots), than the felled and control treatments (7.9% and 7.3%, respectively) (Table 3). There were lower levels of attack in the inter-treatment areas, suggesting that the baits were effective in containing attacking beetles. Our results demonstrate that subalpine fir stands can be baited to contain and concentrate WBBB populations in delineated blocks prior to harvest, without increasing the intensity or area of infestation beyond the application of treatments. This result supports Stock et al. 1994 who report baiting susceptible subalpine fir altered the distribution of attack in a stand and therefore had the potential to manipulate WBBB populations within a patch or selection logging system. There was no significant difference in percent current attack in the treatment and inter-treatment plots of the felled and control treatments.

In 2003, all treatments were re-assessed for current attack. Beetles were attracted to baited trees, especially in the first year; however, there was a significant decline seen in Year 2. The average percent current attack decreased from 16.1% to 7.0%, while attack rates in the baited inter-treatment plots remained unchanged at 5.6% (Table 3). Attack rates in both the control and felled treatment and inter-treatment plots declined, except for the felled inter-treatment, where there was a slight but insignificant increase compared with 2002. There was no significant difference in the percent incidence of unsuccessful WBBB attack (i.e., tree was attacked, but beetles were pitched out) among treatments (Table 3) in either 2002 or 2003. There was significantly lower unsuccessful attack in the inter-treatment control plot in 2002, perhaps illustrating that when WBBB is not influenced by human intervention (trap trees or baits), they may be very discerning in the trees that are selected for colonization.

Table 3. Comparison of percent current attack in 2002 and 2003 in the felled, baited, and control treatments

		% current attack		% unsuccessful attack	
Treatment	Total number of live subalpine fir	2002	2003	2002	2003
Felled	683	7.9 ± 1.31a	5.9 ± 1.28a	7.6 ± 1.33a	4.1 ± 1.11a
Baited	757	16.1 ± 1.81b	7.0 ± 1.47a	7.3 ± 1.40a	6.1 ± 1.43a
Control	490	7.3 ± 1.50a	2.4 ± 0.99b	8.2 ± 1.64a	2.5 ± 1.01a
Inter-treatment					
Felled	763	8.5 ± 1.35a	10.1 ± 1.60a	6.2 ± 1.22a	2.2 ± 0.82a
Baited	723	5.6 ± 1.10a	5.6 ± 1.28b	5.6 ± 1.14a	1.0 ± 0.57a
Control	451	9.0 ± 1.69a	4.1 ± 1.34b	0.4 ± 0.38b	1.4 ± 0.82a

*Means followed by the same letter are not significantly different ($p > 0.05$)

Fifty-three 20 cm x 20 cm bark samples were obtained from 11 baited trees. The average number of full nuptial chambers varied significantly among sampling heights (Table 4). Attack density was significantly higher in samples from the lower bole (2–6 m), closer to where the baits were attached (average of 150 full nuptials/m^2). The 10 m sample had significantly lower attack density, with an average of 75 full nuptial chambers/m^2. The same trend was seen when partial nuptial chambers were counted (Table 4). However, the average number of egg galleries excavated per full nuptial chamber did not vary significantly and ranged from 2.8 to 3.3 galleries. Baiting appears to influence the number and distribution of attacks (number of nuptial chambers initiated) (Maclauchlan et al. 2003), but not the number of females responding to the male in each nuptial chamber.

Table 4. The average number of full and partial nuptial chambers/m^2 from 20 cm x 20 cm bark samples collected at multiple heights on sample trees

			Average ± SE*	
	Sample height (m)	N trees	No. full nuptial chambers/m^2	No. partial nuptial chambers/m^2
Felled	2	27	91 ± 12.1*a*	34 ± 6.6*a*
	6	27	106 ± 8.9*ab*	47 ± 6.2*b*
	10	27	118 ± 9.8*b*	44 ± 6.2*b*
Baited	2	11	150 ± 19.7*a*	64 ± 19.18*a*
	6	10	150 ± 36.5*a*	52 ± 17.98*a*
	10	7	75 ± 12.7*b*	30 ± 10.01*b*
Control	2	25	167 ± 12.2*a*	72 ± 10.1*a*
	6	24	181 ± 20.2*a*	56 ± 10.6*a*
	10	20	148 ± 22.8a	27 ± 6.3*b*

Notes: m, metres; N, number; SE, standard deviation *Means in columns followed by the same letter are not significantly different (Tukey's)

Samples collected from the felled trees at 2 m, 6 m, and 10 m on the bole of 27 sample trees (81 samples in total) revealed higher numbers of full and partial nuptial chambers at the 6 m and 10 m sampling sites (Table 4). However, the average attack density was lower than in either the baited or the naturally attacked trees (Table 4). Although felled trees attracted beetles into the treatment area, they were less attractive than the baited or naturally attacked trees and this treatment of felling trees in a short window of time (after snowmelt and prior to beetle flight) required much more cost and effort to deploy (Tables 3 and 4).

Seventy-five bark samples were collected from 25 naturally attacked red trees, which were felled and sampled along the bole (2m, 6m, and 10m) (Table 4). There was no significant difference in the average number of full nuptial chambers recorded at the different heights. Overall, naturally attacked trees had the highest attack density (number of full nuptial chambers) (Table 4) and utilized a greater total percent of the bole (Maclauchlan et al. 2003). Grid baiting increased the number of trees attacked by WBBB in the short term (Year 1), including attack on recent windthrow (Table 2). Baits may spread beetles over more trees than in a natural setting, where beetles tend to maximize use of optimal natural host trees. Baiting concentrated attack into a discrete area but did not artificially trigger an outbreak or population expansion the following year (Table 3). Greenwood and Borden (2000) had similar results. Although baits attract many beetles to the tree and adjacent trees, and a mass attack is initiated, the trees selected for baiting in this study may not be as susceptible or suitable for brood success as those chosen by the beetle itself (Bleiker et al. 2003, Maclauchlan et al. 2003, Bleiker et al. 2005). Only 11 of the 20 baited trees were attacked the first season. The following year, six of the 11 trees had no successful brood, re-confirming that baits may attract beetles initially, but human-selected trees may be less suitable for WBBB production (pers. comm. Lorraine Maclauchlan). The greatest attack density occurred in the vicinity of the bait itself, leaving the higher portion of the tree much less utilized compared to naturally attacked trees (Table 4). Although the management focus may be different for WBBB than for other bark beetles, maximizing the number of beetles that are removed from a stand at harvest is still a viable and proactive strategy. Maximizing the number of beetles that are removed in harvest operations will further reduce potential mortality and should remain a management priority. Depending on the logging system (e.g., small patch or clearcut harvest), using tree baits to contain and concentrate beetles flying into the stand, or already present in the stand, will achieve this goal.

The results of this study have important management implications. Harvesting creates stand edges that are very susceptible to increased windthrow. Our results demonstrate that windthrow and/or felled trees may temporarily increase beetle populations but will not significantly disrupt natural population fluctuations and host selection mechanisms of WBBB. Maclauchlan and Buxton (2002) found that attack rates increased shortly after harvest due to windthrow on cutblock edges but then leveled off and decreased over time as the stand edges equilibrated, with fewer trees falling as the edges became more windfirm. In summary, the use of felled trap trees as a management tactic to attract and contain WBBB prior to logging is not recommended. Baiting is a useful tool in aggregating beetles within a defined area scheduled for harvest (Tables 2 and 3). Baiting for WBBB concentrates attack within 10 m of the bait centre. Other studies have seen similar results (Stock et al. 1994, Maclauchlan et al. 2003). Unlike some *Dendroctonus* species, stands can be baited in the short term without a high risk of spread if there are enough suitable hosts. Operational trials to develop baiting protocols in a range of infestation levels under a variety of harvesting regimes, such as patch cuts or clear cuts, should be encouraged.

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