

Impact of the western balsam bark beetle, *Dryocoetes confusus* Swaine (Coleoptera: Scolytidae), at the Sicamous Creek research site, and the potential for semiochemical based management in alternative silviculture systems

LORRAINE E. MACLAUCHLAN¹

**B.C. MINISTRY OF FORESTS, SOUTHERN INTERIOR REGION,
515 COLUMBIA STREET, KAMLOOPS, B.C. V2C 2T7**

LEROY HARDER

23392-16TH AVENUE, LANGLEY, B.C. V2Z 1K7

JOHN H. BORDEN

PHERO TECH INC., 7572 PROGRESS WAY, R.R. #5, DELTA, B.C. V4G 1E9

JULIE E. BROOKS

FOREST HEALTH MANAGEMENT, BOX 19, GRANTHAMS LANDING, B.C. V0N 1X0

ABSTRACT

Two pre-harvest baiting regimes were tested for their effect on *Dryocoetes confusus* in select stands at the Sicamous Creek Silviculture Systems Project. Single tree and two-tree bait treatments, in addition to a control area, were established in a grid format throughout the research area. There were significantly more new *D. confusus* attacks in the baited areas than in the control area. Eighty percent of mass attacks occurred within 9 m of single tree bait centres, while 75% of mass attacks occurred within 10 m of two-tree bait centres. Baiting appears to concentrate attacks into a discrete area and therefore could be used in single tree selection or patch cut systems (cuts generally less than 5 ha in size), two of the silviculture systems applied at the Sicamous Creek research area. Of 136 dead subalpine fir trees felled and examined, 105 (77%) showed clear evidence of *D. confusus* attack, making it the major cause of sub-alpine fir mortality at the Sicamous Creek research site. Naturally attacked trees had more advanced brood development and beetles utilized a greater percent of the total tree bole but had lower attack density (number of *D. confusus* galleries per unit area) than was observed on baited trees. In baited trees, the higher attack density resulted in indistinct gallery systems due to space competition of the brood. This suggested that there was a limited acceptable area for attack in these trees, which would not normally be susceptible. This study concludes it is possible to reduce resident populations of *D. confusus* by varying the number and placement of bait trees as a pre-harvest treatment.

Key words: *Dryocoetes confusus*, western balsam bark beetle, pheromone baiting, *Abies lasiocarpa*, subalpine fir

¹ Author to whom all correspondence should be sent.

INTRODUCTION

The western balsam bark beetle, *Dryocoetes confusus* Swaine (Coleoptera: Scolytidae), is the most destructive insect pest of subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., in British Columbia (Garbutt 1992; McMillin *et al.* 2001). Subalpine fir is also susceptible to a variety of other disturbance agents, including other insects, root and butt rots, stem rots and windthrow (Kneeshaw and Burton 1997). Cumulative mortality due to *D. confusus* may reach significant levels in chronically infested stands (Garbutt and Stewart 1991), however *D. confusus* outbreak dynamics appear to be very different from other tree-killing bark beetles. Over time, aerial overview surveys have established an average annual loss of 4.2 m³ per hectare in older affected stands. *D. confusus* can kill many trees in a single year but usually less than 5% of any given stand is attacked in one year (Garbutt 1992). Beetle populations can persist for many years in a stand slowly killing the entire mature and semi-mature component of sub-alpine fir (Garbutt 1992).

Subalpine fir comprises 12% of total timber volume (trees cut) in B.C. (B.C. Ministry of Forests 1993) and has typically been harvested in conjunction with higher valued spruce. As low elevation stands consisting of other tree species are depleted, the number of subalpine fir sites harvested has increased. In 1990, (B.C. Ministry of Forests 1992) subalpine fir comprised 8% of total volume harvested in the interior of B.C. compared to 10.9% volume in 2000-01 (B.C. Ministry of Forests 2001). As harvesting increases in subalpine fir sites, additional research is needed to develop more effective and ecologically sensitive management strategies.

In 1990, the B.C. Ministry of Forests established a silviculture systems project at Sicamous Creek near Salmon Arm, B.C., to address ecosystem responses to a wide range of disturbance levels created by harvesting. The Sicamous Creek site is located within the Engelmann Spruce- Subalpine Fir wet, cold subzone (ESSFw2) (Lloyd *et al.*, 1990), which is the largest of the seven ESSF subzones in the Kamloops Forest Region. This study was established at the Sicamous Creek research site to test how two baiting techniques could be used to manage *D. confusus* under different harvesting regimes.

Baiting trees with semiochemicals as a pre-harvest containment and concentration tactic is a well established pest management methodology for other bark beetles such as the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, (Borden 1990; Maclachlan and Brooks 1999) but has not been developed for *D. confusus*. Therefore, a trial was developed to test baiting systems that could be used in a single tree selection and patch cutting harvest scenarios.

Our objectives were to: assess past infestations of *D. confusus* at the Sicamous Creek Silviculture Systems Project; test the efficacy of pre-harvest baiting systems for *D. confusus* in different silviculture systems; and determine if pre-harvest baiting could concentrate more beetles for removal at harvest than no baiting.

METHODS

Pre- and post-harvest levels of D. confusus

The Sicamous Creek research site is dominated by subalpine fir and Engelmann spruce (*Picea engelmanni* Parry ex Engelm.). The harvest regimes, each on 30 ha, were: 1) control/no removal; 2) single tree selection in which 33% of the volume was removed over a 30 ha area by cutting every fifth tree using faller's choice; 3) 0.1 ha patch cuts; 4) 1 ha patch cuts; and, 5) 10 ha clearcut. Each of the harvest regimes removed 33% of the volume. The area was harvested without taking into account the presence or impact of *D. confusus*, even though there was significant mortality throughout the area.

Aerial photographs (1:5,000) of the Sicamous Creek silviculture systems project for the years 1993-1995 were used to map the location of red trees over a 200 ha area. Using

1993 photographs, groups of red trees were identified and mapped on an acetate overlay. For 1994, groups of red trees adjacent to the original clusters were identified and mapped. Each cluster was coded in relation to the eventual harvest regime conducted in the winter of 1994-1995. The red trees mapped from the 1995 photographs were used to compare the relative efficacy of the five cutting regimes in removing *D. confusus*. The uncut strips of trees between the 0.1 ha and 1.0 ha patch cuts were located on the photographs and assessed for red trees.

Infestation characteristics

Prior to adult emergence in the spring of 1995, 15 red, 31 grey and 90 older snags, were felled and examined for evidence of *D. confusus* activity. The following characteristics were measured or noted in the red and grey trees: diameter at breast height (d.b.h.) of the bole and distance from the ground for upper and lower limits of attack; resinosis typical of *D. confusus* attack; exit holes; and the presence of live adults, pupae and larvae. Because snags were usually quite degraded, only the presence or absence of *D. confusus* galleries, exit holes and associated resinosis were recorded and measured in those trees.

Pheromone baiting trial

In June 1995, a baiting trial was established at Sicamous Creek. Two treatments and a control area were laid out. The aggregation pheromone (\pm)-*exo*-brevicomin (released at 0.3 mg/24 hrs release rate) was used (Phero Tech Inc.). Baits were stapled at 1.5 m on the north side of large subalpine fir. In the single tree bait treatment, established in the single tree selection area, bait lines were 50 m apart, with baited trees at 25 m intervals in a grid pattern. In the two-tree bait treatment, established in the 0.1 ha patch cut area, bait lines were placed 33 m apart, with baits affixed every 66 m along the bait line, on two adjacent, large subalpine firs at each point. Baits on adjacent lines were offset by 33 m. In total, 86 single and 82 paired trees were baited. No baits were used in the control area. A chi square analysis was used to compare the number of green (live) trees to red (attacked) trees in the three treatment regimes.

In September 1995, a 100% ground assessment of all subalpine fir in the three study areas was conducted. Using Stock's (1991) criteria for "attack classes" in Table 1 a stem map was produced of the baited, attacked, mass attacked, red and grey trees. The d.b.h. of these trees was measured, and the number of snags in each area was counted. In each treatment, 10 randomly placed 15 m radius circular plots were established, to discern infestation characteristics. In each circular plot the d.b.h., species and tree class were recorded for each tree with minimum 9 cm d.b.h. Chi square analysis was used to compare the d.b.h. frequency distribution of red, grey and snags to unattacked trees.

Comparison of insect development on baited and naturally attacked subalpine fir

In late August 1996, 10 baited mass attacked trees in the single tree bait treatment area and 13 new mass attacked trees outside the study area were felled. Beginning at the stump (cut end of tree), gallery systems were dissected in 10×30 cm bark sections every 1.5 m along the bole. For each sample, the number of gallery systems and the occurrence of associated species were recorded. Within each gallery system, the presence or absence of *D. confusus* life stages and resin was recorded, and the length of each egg gallery was measured. Female *D. confusus* constructs the egg gallery away from the nuptial chamber where she mates and deposits eggs along the sides of these galleries. The upper bole of the tree was examined for secondary scolytid beetles and other associated insects. These scolytids are often referred to as secondary bark beetles as they do not typically kill trees but occupy trees infested by other tree killing species of the Scolytidae. Height limits for conspicuous resin flow was also noted. Foliage colour change was rated using a six point rating system (Table 2).

Table 1

Tree classifications assigned to subalpine firs attacked by *D. confusus*. These "Attack Classes" were developed by Stock (1991) and modified by L. Harder.

Attack Class	Description
attacked	streams of resin on bole (presumed unsuccessfully attacked)
mass attacked	frass and possibly resin on bole (presumed successful intense colonization of tree)
red	red foliage present (represents old attack from which new mature beetles emerge)
grey	needles mostly gone, but fine twigs present and bark generally intact (no beetles remaining in bark)
snag	a long dead tree; minimum height 2 m and d.b.h. 12 cm, with bark loose or absent and fine twigs gone

Table 2

Foliage colour classes used to classify colour changes in subalpine fir trees one year after mass attack by *D. confusus*.

Colour Class	Description
0	No colour change noticeable
1	Red needles on some tree limbs, usually on lower bole
2	Foliage on less than $\frac{1}{2}$ of the tree limbs starting to turn red, usually on lower bole
3	Half the foliage turned red
4	Most of the foliage turned red, some faded green left
5	Foliage completely red

Baited and naturally mass attacked trees were compared using a chi square test based on the number of trees containing different life stages of young brood. Samples without gallery systems, and gallery systems without brood, were classed as failed gallery systems and compared to other characteristics of attack by using a chi square test. Analysis of variance comparing naturally attacked trees and baited trees were done on gallery length, resin flow, number of egg galleries, and the total brood gallery length.

RESULTS AND DISCUSSION

Pre- and post-harvest levels of D. confusus

The mapped number of red trees decreased from 1993 to 1995 in both undisturbed and harvested areas (Table 3) indicating an overall decline in the *Dryocoetes* population. Because clearcut treatments (1 ha and 10 ha) remove all trees in an area, all *D. confusus* attacks were also removed in the harvested areas. Fewer red trees were observed in the 0.1 ha and single tree selection cut areas than in the 1.0 ha patch cut area (Table 3). The buffer strips between the 1.0 ha patch cuts were undisturbed by harvesting therefore, there was a similar level of attack there as in the undisturbed control areas. In the other two treatments, the 0.1 ha patch cut plus buffer strip and the single tree selection, there was so little area between the cuts that more attacked trees were removed at the time of harvest. Any dead trees within the narrow buffer strips, many of which were infested with *Dryocoetes*, were removed at the time of harvest. Thus, despite the lack of a conscious effort to manage for *Dryocoetes*, much of the resident beetle population was removed from these areas when harvested.

Table 3

Numbers of red subalpine fir per hectare in undisturbed and treated areas before and after treatment as seen in three consecutive years of aerial photographs.

Location of red trees	Sample Size(ha)	No. red trees per ha		
		pre-treatment 1993	post-treatment 1994 ^a	1995
Undisturbed control area	108	7.4	6.2	4.5
Within 10 ha clearcut	10	5.3	7.9	0
Within 1.0 ha patch cuts	9	10.1	9.7	0
In buffer strip between 1.0 ha patch cut	30	8.6	7.8	4.5
In 0.1 ha patch cut and buffer strip	18	5.5	8.9	1.3
In single tree selection area	21	4.0	3.6	0.7

^a Road right-of-way cut through research area in 1994.

Table 4

Evidence of past attack by *D. confusus* in felled red, grey and snag subalpine fir. The characteristics assessed included *D. confusus* brood (eggs, larvae, pupae), adult beetles, galleries, exit holes made by emerging beetles and resin flow on the bole of the tree caused by attacking beetles. The number of trees having all of the above-mentioned characteristics was also summarized.

Characteristic assessed	% subalpine fir with characteristic		
	Red (n=15)	Grey (n=31)	Snag (n=90) ^a
<i>D. confusus</i> brood	27	3	0
<i>D. confusus</i> adults	13	3	0
Galleries	100	90	70
Exit holes	80	87	63
Resin flow	93	94	56
Characteristics combined	100	97	76

^a Fewer snags were assessed for exit holes (n=87) and resin flow (n=72) than for other characteristics due to deterioration and loss of bark.

Infestation characteristics

All 15 felled red trees and 30 of 31 grey trees showed evidence of past attack by *D. confusus* (Table 4). Twelve of 15 red trees had exit holes, while only 4 of 15 had juvenile life stages, and two had adults. There was less evidence of beetle attack in snags due to deterioration and loss of bark. This is strong evidence that most of the dead subalpine fir in the study area had been attacked by *D. confusus*.

Attacked subalpine fir can retain their red foliage for a number of years prior to shedding needles and being termed grey. The examination of red and grey trees revealed that few *D. confusus* adults were still present (Table 4), suggesting that adult beetles leave red trees before trees become grey.

Successful completion of development by *D. confusus* occurred primarily along the lower portion of the bole. In general, exit holes occurred within the upper and lower limits of the gallery systems (Figures 1, 2). In 32 trees that had visible resinosis, resin flow usually overlapped the exit hole zone and in 28 trees, extended above the exit holes a few metres. There was less variation in the lower height limit for gallery systems and exit

holes than in the upper height limit. Exit holes associated with other beetles in the Family Scolytidae occurred throughout the resin flow zone extending past it in both directions. Secondary scolytids found in the lower bole were identified as *Pityokteines minutus*, and those in the upper bole as *Pityophthorus sp.*

The narrow variance in height of the lower limit of *D. confusus* galleries and exit holes, and the broader variance in diameter (Figure 2) suggest that height was of greater importance than diameter in limiting *D. confusus* occupation at the lower end of the bole. Poor gallery development between 1 and 2 m may be related to cooler nighttime summer temperatures close to the ground, typical in the ESSF (Farnden 1994). Gallery systems close to the ground at or below the lower limit of exit holes had short egg galleries. Bark in this area of the bole is often wet, encouraging the growth of decay fungi that overgrow *D. confusus* galleries. In contrast, the upper limit was characterized by wide variation in

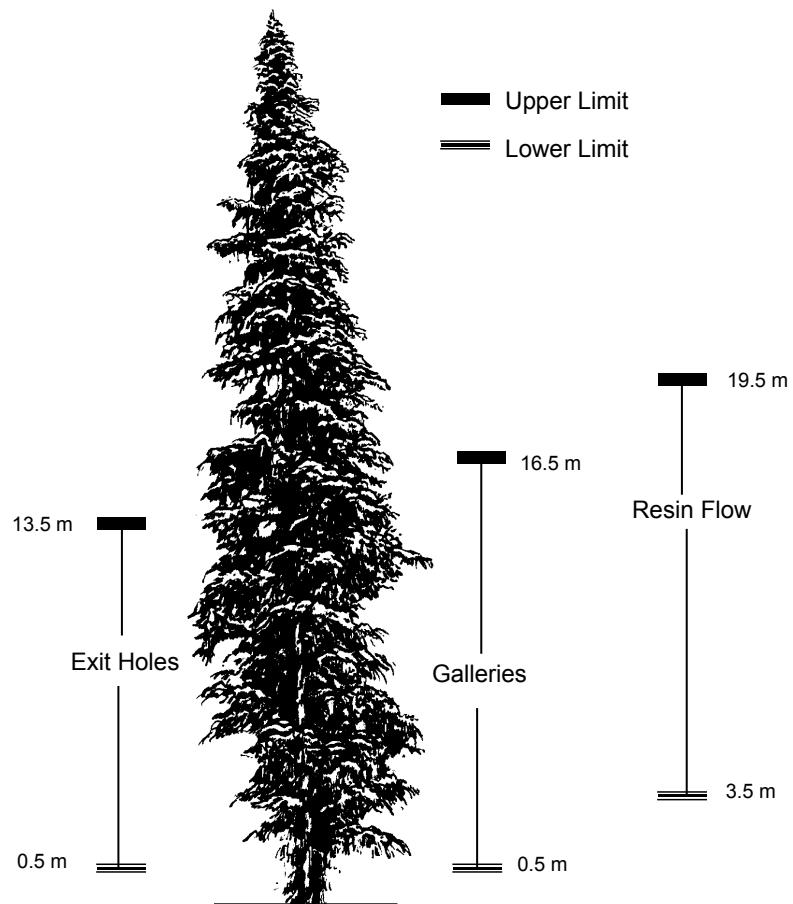


Figure 1. Upper and lower height limits for the majority of *D. confusus* galleries, exit holes, and resin flow observed on felled red and grey subalpine fir.

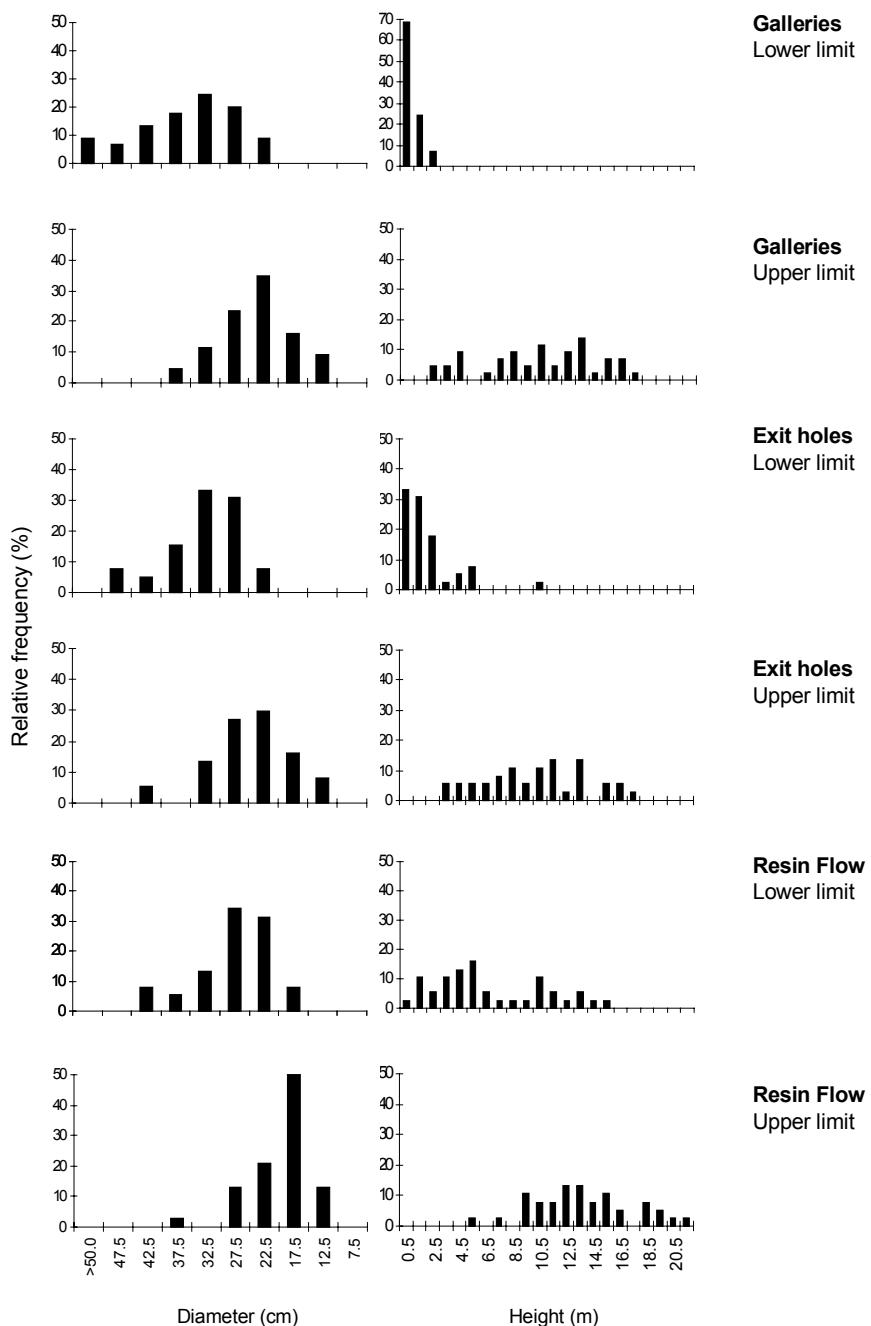


Figure 2. Frequency distributions for upper and lower limits for *D. confusus* galleries, exit holes and resin flow, based on bole diameter and height.

height, indicating a weak influence. The upper limit for resin flow, however, was tightly clustered around 17.5 cm diameter (Figure 2), indicating a possible influence related to diameter that limits *D. confusus* attack. The 17.5 cm upper limit diameter peak for resin flow was greater than the average 10 cm upper limit for attack on trees that were

previously assessed by Stock (1991). This difference may indicate a different diameter limit preference by *D. confusus* on standing trees versus downed trees.

A large percentage of subalpine fir basal area consisted of dead trees, totaling 31%, 28% and 25% for the single tree bait treatment, two-tree bait treatment and the control area, respectively, at the time of baiting. These proportions are similar to those documented by Unger and Stewart (1993) and Stock (1991). Parrish (1997) determined that losses take place over a long period in subalpine fir stands, with some existing snags having been dead for over 45 years. This slower, but continuous tree mortality affects stand structure very differently than the devastation caused by mountain pine beetle to mature pine stands.

D. confusus is likely the major mortality causing agent for standing dead trees at the Sicamous Creek research area. The d.b.h. distribution of red and grey trees contained more trees in the larger d.b.h. range (>20 cm d.b.h.), ranging in size between 19 and 49 cm, while the d.b.h. distribution of snags contained on average smaller trees, between 9 and 39 cm, similar to unattacked trees. Direct observation also confirmed *D. confusus* activity in all felled red trees, 97% of the grey trees and 76% of snags examined (Table 4). The greater percentage of small diameter trees among snags (Figure 3), suggests that the smaller trees were killed by *Armillaria ostoyae*, a common root disease of conifers. Merler (1997) found that *A. ostoyae* killed mostly subdominant balsam and spruce at this site.

Pheromone baiting trial

Baiting trial assessment. The ratio of mass attacked to red attacked trees in the single tree and two-tree bait treatments was similar, and was significantly higher than in the

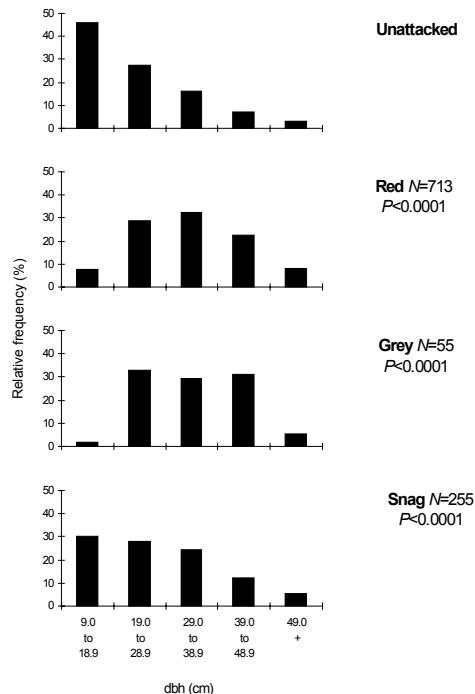


Figure 3. Frequency distribution by diameter class of unattacked, red, grey and snag subalpine fir. The DBH distribution of red, grey and snag trees were significantly different from non-attacked trees (chi square analysis).

control area (Table 5), despite differences in the numbers of red trees per hectare among the three areas in the pheromone baiting experiment. Trees in the two-tree bait treatment area were more frequently mass attacked than those in the single tree baiting area (Table 5).

Table 5

Comparison of numbers and ratios of grey, red and newly mass attacked subalpine fir in baited and control areas.

Treatment area	Number of affected subalpine fir/ha			Mass attacked: Red ^a	Red: Grey ^a
	Mass attacked	Red	Grey		
Control	4.4	18.5	15.5	0.24a	1.19a
Single tree baited	4.9	8.7	23.6	0.56b	0.37b
Two-tree baited	14.2	27.3	19.6	0.52b	1.40c

^a Proportions followed by the same letter are not significantly different, χ^2 , $P < 0.001$

Single-baited trees were consistently mass attacked. Spillover attack (attack on trees directly adjacent to a baited tree, resulting from the bait treatment) was highest out to 1 m away from the bait centres (Figure 4), and decreased at greater distances. Eighty percent of mass attacks occurred within 9 m of single tree bait centres.

In the paired bait treatments, mass attacks peaked within 3 to 4 m of the bait centre, apparently corresponding to half the distance between two bait trees (Figure 4). Cumulative mass attacks increased to 60% of total mass attacks within 5 m of the bait centre. At 10 m, 75% of all cumulative attacks had been recorded.

The aggregation pheromone (\pm)-*exo*-brevicomin used in the baiting trial successfully concentrated *D. confusus* attacks on and around bait centres (Figure 4). However, it was unclear whether the higher ratios in the baited vs. control areas were caused by retaining dispersing beetles within the baited areas, attracting beetles into those areas (Table 5) or spreading the same number of beetles among more trees. Baits used for spruce beetle seem to have a limit of 25 meters efficacy (Shore *et al.* 1990), and Gray and Borden (1989) found that the influence of pheromone baiting for mountain pine beetle extended up to 75 m from grid-baited stands. Stock *et al.* (1994) observed consistently higher mass attacked to red ratios within baited blocks than in 50 m wide buffer strips surrounding the blocks. This suggests at least a 50 m range of influence on *D. confusus*.

Comparison of insect development in baited and naturally attacked subalpine fir.

There was great variation in the utilization of both baited and naturally attacked trees by western balsam bark beetle, ranging from trees with few gallery systems and little brood to those having long galleries occupying a large proportion of the bole with advanced brood development. Naturally mass attacked trees had more advanced brood development (Table 6) and a greater percentage of the bole was occupied (Harder 1998).

The average meters of egg galleries and average density of egg galleries were less in the naturally mass attacked trees than in the mass attacked, baited trees (Figure 5). Mean egg gallery length however was not different between natural and baited trees (Fig. 5) indicating more egg galleries constructed in baited trees. Some trees with low attack density had high numbers of *D. confusus* parent adults per gallery system (up to 10).

These gallery systems were stained black, evidence of the fungus *Ophiostoma dryocoetidis*. Western balsam bark beetle is closely associated with this pathogenic fungus (Garbutt 1992; Bleiker *et al.* 2003). Initial beetle attacks may be pitched out and *O. dryocoetidis* introduced, which in facilitates successful subsequent attack by the

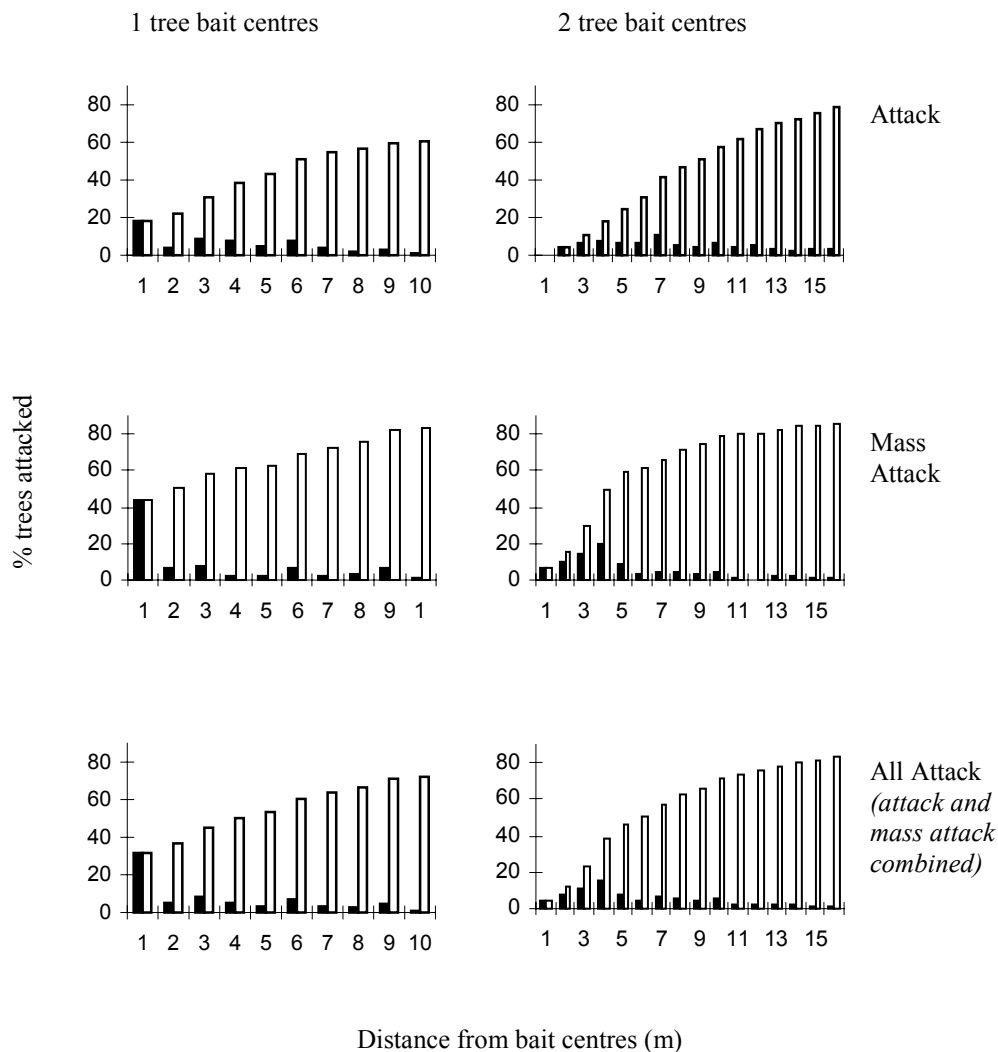


Figure 4. Distribution of attacked trees (% trees) at one bait and two bait tree centres. Solid bars indicate % attack at 1m intervals. Clear bars indicate cumulative attack.

beetle. Coalescing lesions caused by the fungus may also girdle and kill the trees without any further beetle activity (Garbutt 1992). Egg galleries were so close together in baited trees that the centre of the gallery system was completely excavated, and the nuptial chamber and brood galleries were no longer distinguishable. This high density of gallery construction and subsequent brood activity make certain characteristics of the gallery system obscure. It is possible then, that *D. confusus* was confined to a limited area in some baited trees because the tree would not have been susceptible to attack had it not been baited (Bleiker *et al.* 2003).

In 1995, colonization by secondary scolytids was limited to *Crypturgus borealis* and *P. minutus*. The year following mass attack, *P. minutus* was present in much larger numbers in half of the baited trees examined (Harder 1998). *Rhizophagus dimidiatus* and *C. borealis* were found primarily in trees with advanced western balsam bark beetle brood development (Table 6). *R. dimidiatus* is a bark beetle predator and may use *D. confusus* pheromones to locate its prey.

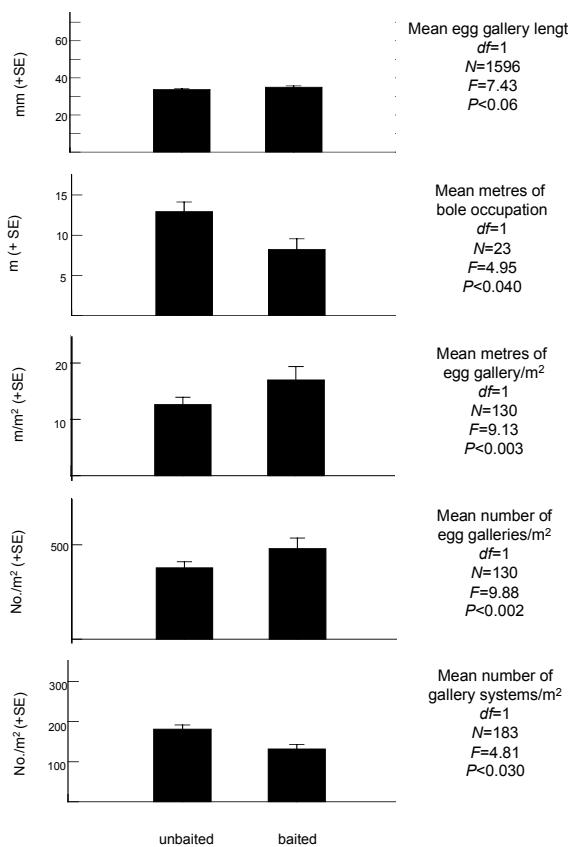


Figure 5. Comparison of mean *D. confusus* egg gallery length (cm), bole occupancy (m), and number of egg galleries per m² in non-baited and baited subalpine fir.

Signs and symptoms (Dissections of mass attacked trees).

Trees classified as mass attacked in 1995 were divided into those turning red and those that remained green. Fourteen trees with red foliage had larvae, evidence of successful attack, while four of the eight trees that were still green had parent adults only. Only one of these trees also had larvae, suggesting a delayed or partially successful attack. The four other green trees had no successful adult activity or brood development. In one-year-old attacks with green foliage, gallery systems from the previous year were generally abandoned, with few surviving brood. New, vigorous gallery excavation often began some distance from old gallery areas. The affected trees likely responded to pathogenic infection by producing traumatic resin at the sites of inoculation (Berryman and Ashraf 1970). New attacks were initiated elsewhere to avoid the toxic areas. The trees that were mass attacked in 1995 went through a rapid colour change between June and August 1996, from green to bright red. Because foliage does not change to red until August, aerial surveys should not be done until late summer or early fall.

The changes in foliage colour and the continued production of frass in mass attacked, baited trees one year after baiting is consistent with their original classification. Foliage colour change, frass production and renewed resinosis in trees originally classified as light-attack, indicates that adults were able to survive, while allowing a year for associated pathogenic fungi to overcome tree defenses. Lightly attacked trees could still be attractive to attacking beetles one year after baiting. In an operational setting, all mass attacked trees

Table 6

Occurrence of resin flow, *D. confusus* life stages and associated bark beetles in felled baited and naturally mass attacked trees.

Observation ^a	% Mass attacked trees affected		Remarks
	Baited (n=10)	Natural (n=13)	
Resin flow	30	69	
<i>D. confusus</i> adults	100	100	
eggs	90	92	
small larvae	60	69	
medium larvae	30	46	
large larvae	0	30	
Secondary scolytid, probably <i>Pityokteines</i> <i>minutus</i>	10	23	Only a few adults in newly established galleries above zone of <i>D. confusus</i> colonization.
<i>Crypturgus borealis</i>	40	69	Found in 100% of trees with medium or large larvae and 50% of other trees, with galleries constructed adjacent to <i>D. confusus</i> galleries, often in large numbers.
<i>Rhizophagus dimidiatus</i>	40	76	Predaceous, found in association with <i>D. confusus</i>

^aSmall, medium and large larvae may correspond to the first three of four larval instars (Stock 1991), however head capsule measurements were not made.

should be removed at harvest. Lightly attacked trees should also be considered for removal because they could still be high risk. Heavily attacked trees turn colour quickly, whereas lightly attacked trees may require more than one year to show colour change.

Less than half of the 23 mass attacked trees felled and assessed in the single-bait and non baited areas at Sicamous Creek, had obvious signs of external resin flow originating in the year of attack (1995). Nine trees had resin flow above and overlapping the area occupied by *D. confusus*, and two trees had resin flow contained within that area. There was a greater number of gallery systems attempted in resin flow areas, but with fewer, shorter egg galleries. There were significantly greater proportions of failed gallery systems in resin flow zones compared to those in non-resinous areas (Chi square, $P<0.001$). In other words, resin flow appears to inhibit the success of egg gallery production. The invading beetles are pitched out from the tree and if the pathogenic fungus *O. dryocoetidis* is not successfully introduced, then the attacked tree will most likely survive. The presence of resin on the bole, therefore, indicates unsuccessful attack. Typically, successfully mass attacked trees do not have copious amounts of resin on the bole but instead may present a large amount of frass.

Depending on the beetle pressure in a stand and individual susceptibility of baited trees (Bleiker *et al.* 2003), attacks may range from unsuccessful or no attack, to successfully mass attacked. It appears that often in the initial year of attack, *D. confusus* will initiate nuptial chambers but very few egg galleries in the attacked tree. During the late summer flight, made up primarily of females (Stock 1991), additional females can enter existing nuptial chambers and begin excavating new egg galleries. This extended period of attack on a baited tree would, in part, explain the variability in colour change observed.

CONCLUSIONS

Harvesting removes beetle-infested trees. While eliminating all *D. confusus* infested trees in the cut areas, the 1.0 ha and 10 ha clearcuts left populations relatively untouched in the buffer strips. In harvesting the 0.1 ha and single tree selection areas, most of the snags, grey and red trees were removed in spite of the fact that logging occurred without conscious effort to remove beetle-attacked trees. In B.C., harvesting of this type requires that all dead trees be removed for safety reasons. Even without baiting, most infested trees were removed from the area, leaving a portion of new 1994 mass attacked trees as sources of new infestation. Pre-harvest baiting of these stands would have allowed removal of most new 1994 mass attacked trees as well.

While the short-term benefits of reducing *D. confusus* populations in single tree selection and patch cut systems are evident, in the long term, the possibility of windthrow exists in single tree selection and patch cut areas (Novak *et al.* 1997). Stands harvested by single tree selection may be too open (Coates 1997), while patch cut stands are fragmented and have a large ratio of edge relative to patch size (Novak *et al.* 1997). Build up of *D. confusus* populations in windthrow could possibly jeopardize the remaining standing trees resulting in populations too large for pheromone-based management. Moreover, mortality due to root and butt rot pathogens tends to increase to very high levels in stands that are partially cut (Morrison *et al.* 1991).

Pheromone baiting to manage *D. confusus* populations when conducting single tree selection or patch cut systems is recommended. By varying the number and placement of bait trees, it is possible to reduce the resident population of *D. confusus*. The attractive power of baits seems to be sufficient to draw the majority of adult *D. confusus* from buffer strips into very small areas designated for cutting. Operational tests should be done over time to develop protocols for pheromone baiting that are consistent with a wide variety of possible harvesting regimes and infestation levels.

Subalpine fir should be considered in conjunction with the many other species present in high elevation ecosystems. The relationship between *D. confusus* and root diseases should be further explored. At present, root disease induced mortality appears limited to suppressed subalpine fir and spruce (Merler 1997), in spite of long-term disturbance due to *D. confusus*. Wildlife species such as mountain caribou may depend on old growth stand characteristics (Armeler and Waterhouse 1994) in high elevation ecosystems. There are concerns that birds, such as the three-toed woodpecker depend on snags for habitat and/or food (Klenner and Huggard 1997). Backhouse and Louiser (1991) list over 90 species of vertebrates that utilize snags for a variety of purposes. A large number of invertebrates, bryophytes, and lichens are also likely to depend on large dead trees. Thus, there are many reasons to be cautious about removing *D. confusus* from *A. lasiocarpa* stands. The possible conservation importance of stands characterized by large *A. lasiocarpa* and the *D. confusus* dynamics contained within them may limit harvesting and managing options.

ACKNOWLEDGEMENTS

We gratefully acknowledge Connie Harder for her support and assistance and Lynn Kristmanson for her artwork. This study was funded in part by Forest Renewal B.C. and the B.C. Forest Service.

REFERENCES

- Armeler, H. and M. Waterhouse. 1994. Wildlife diversity in managed high elevation stands. B.C. Ministry of Forests. Extension Note No. 14.
- Backhouse, F. and J.D. Louiser. 1991. Silviculture systems research: wildlife tree problem analysis. B.C. Ministry of Forests and B.C. Ministry of the Environment, Lands and Parks, Wildlife Tree Committee, Victoria, B.C.
- Berryman, A.A. and M. Ashraf. 1970. Effects of *Abies grandis* resin on the attack behavior and brood survival of *Scolytus ventralis* (Coleoptera: Scolytidae). Canadian Entomologist 102: 1229-1236.
- Bleiker, K.P., Lindgren, B.S. and L.E. Maclauchlan. 2003. Characteristics of subalpine fir susceptible to attack by western balsam bark beetle (Coleoptera: Scolytidae). Canadian Journal of Forest Research 33: 1538-1543.
- Borden, J.H. 1990. Use of semiochemicals to manage coniferous tree pests in western Canada, pp. 281-315. In R.L. Ridgeway, R.M. Silverstein and M.N. Inscoe (eds.), Behavior-Modifying Chemicals for Insect Management. Marcel Dekker, New York, NY.
- B.C. Ministry of Forests. 1992. Annual Report 1990-1991. Victoria, B.C.
- B.C. Ministry of Forests. 1993. Annual Report 1991-1992. Victoria, B.C.
- B.C. Ministry of Forests. 2001. Annual Report 2000-2001. Victoria, B.C.
- Coates, K.D. 1997. Windthrow damage 2 years after partial cutting at the Date Creek silvicultural systems study in the interior cedar-hemlock forests of northwestern British Columbia. Canadian Journal of Forest Research 27: 1695-1701.
- Farnden, C. 1994. Forest regeneration in the ESSF zone of north-central British Columbia. Pacific Forestry Centre Information Report BC-X-351, Canadian Forest Service, Victoria, B.C.
- Garbutt R. 1992. Western balsam bark beetle. Pacific Forestry Centre Forest Pest Leaflet No. 64, Canadian Forest Service, Victoria, B.C.
- Garbutt, R. and A. Stewart. 1991. Forest insect and disease conditions, Prince Rupert Forest Region. 1990. Pacific Forestry Centre FIDS Report No. 91-5, Canadian Forest Service, Victoria, B.C..
- Gray, D.R. and J.H. Borden. 1989. Containment and concentration of mountain pine beetle (Coleoptera: Scolytidae) infestations with semiochemicals: validation by sampling of baited and surrounding zones. Journal of Economic Entomology 82: 1399-1405.
- Harder, L. 1998. Historical mortality of subalpine fir (*Abies lasiocarpa*) by the western balsam bark beetle (*Dryocoetes confusus* Swaine) at the Sicamous Creek Silviculture Project Research Site and semiochemical based management in partial and patch cut silviculture systems. M.P.M. Thesis, Simon Fraser University, Burnaby, B.C.
- Klenner, W. and D. Huggard. 1997. Three-toed woodpecker nesting and foraging at Sicamous Creek, pp. 224-233. In C. Hollstedt and A. Vyse (eds.), Sicamous Creek Silvicultural Systems Project, Workshop Proceedings, April 24-25, 1996, Kamloops, B.C, Working Paper 24/1997. Research Branch, B.C. Ministry of Forests, Victoria, B.C.
- Kneeshaw, D.D. and P.J. Burton. 1997. Canopy and age structures of some old sub-boreal *Picea* stands in British Columbia. Journal of Vegetation Science 8: 615-626.
- Lloyd, D., K. Angove, G. Hope and C. Thompson. 1990. A guide to site identification and interpretation for the Kamloops Forest Region, B.C. Ministry of Forests Land Management Handbook in 2 parts. BC Ministry of Forests, Victoria, B.C.
- Maclauchlan, L.E. and J. Brooks. 1999. Strategies and tactics for managing the mountain pine beetle, *Dendroctonus ponderosae*. B.C. Ministry of Forests, Kamloops Region, Kamloops, B.C.
- McMillin, J.D., K.K. Allen, D.F. Long, J.L. Harris and F. Cross. 2001. Impact of subalpine fir decline on the spruce-fir forest type of the Bighorn National Forest, Wyoming. U.S. Department of Agriculture Forest Service, Rocky Mountain Region, Technical Report R2-65.
- Merler, H. 1997. Forest Pathology at Sicamous Creek, pp. 41-44. In C. Hollstedt and A. Vyse (eds.), Sicamous Creek Silvicultural Systems Project, Workshop Proceedings, April 24-25, 1996, Kamloops, B.C, Working Paper 24/1997. Research Branch, B.C. Ministry of Forests, Victoria, B.C.
- Morrison, D., H. Merler and D. Norris. 1991. Detection, recognition, and management of *Armillaria* and *Phellinus* root diseases in the southern interior of British Columbia. FRDA Report No. 179, B.C. Ministry of Forests, Victoria, B.C.
- Novak, M., A. Orchansky, R. Adams, W. Chen and R. Ketler. 1997. Wind and temperature regimes in the B-5 clearing at the Sicamous Creek Silviculture Systems Research Area: Preliminary results from 1995, pp. 45-56. In C. Hollstedt and A. Vyse (eds.), Sicamous Creek Silvicultural Systems Project, Workshop Proceedings, April 24-25, 1996, Kamloops, B.C, Working Paper 24/1997. Research Branch, B.C. Ministry of Forests, Victoria, B.C.

- Parrish, R. 1997. Age and size structure of the forest at Sicamous Creek, pp. 16-31. In C. Hollstedt and A. Vyse (eds.), Sicamous Creek Silvicultural Systems Project, Workshop Proceedings, April 24-25, 1996, Kamloops, B.C., Working Paper 24/1997. Research Branch, B.C. Ministry of Forests, Victoria, B.C.
- Shore, T.L., P.M. Hall and T.F. Maher. 1990. Grid baiting of spruce stands with frontalalin for pre-harvest containment of the spruce beetle, *Dendroctonus rufipennis* (Kirby) (Coleoptera: Scolytidae). Journal of Applied Entomology 109: 315-319.
- Stock, A.J. 1991. The western balsam bark beetle, *Dryocoetes confusus* Swaine: impact and semiochemical-based management. PhD thesis. Simon Fraser University, Burnaby, B.C.
- Stock, A.J., J.H. Borden and T.L. Pratt. 1994. Containment and concentration of infestations of *Dryocoetes confusus* (Coleoptera: Scolytidae), using the aggregation pheromone *exo*-brevicomin. Canadian Journal of Forest Research 24: 483-492.
- Unger, L. and A. Stewart. 1993. Forest insects and disease conditions: Nelson Forest Region-1992. FIDS Report No. 93-3, Canadian Forest Service, Pacific Forestry Centre, Victoria, B.C.