The Survival of Mountain Pine Beetle in Unpeeled Logs

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ABSTRACT

The mountain pine beetle (*Dendroctonus ponderosae*) is the most serious pest of ponderosa pine (*Pinus ponderosa*). Management of this insect involves indirect controls, reducing stand susceptibility, or direct controls, reducing the beetle population. One tactic for reducing bark beetle populations is to fell and treat infested trees in place. Treatments usually involve cutting the tree trunk into sections and covering the infested logs with plastic or coating in diesel oil and rotating them to kill the beetles. These treatments are not always practical due to labor intensity or environmental impact. A study was conducted to determine whether cutting infested trunks into short, 60- to 75-cm lengths, during autumn without further treatment would be sufficient to serve as a population reduction tactic. Groups of infested trees were felled in October 2006 and 2007 with the trunks cut into 60- to 75-cm lengths and left in place. Brood densities were determined in these sections and standing infested trees during the following March and June and emergence in September. Felling infested trees during autumn and cutting into short sections without rotating resulted in 21–24% beetle emergence compared to standing infested trees and may be a practical means of reducing the potential spread of localized beetle populations.

Keywords: mountain pine beetle, *Dendroctonus ponderosae*, epidemic, sanitation, solar treatments

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is a scolytine bark beetle native to western North America from British Columbia, Canada to Sonora, Mexico and this range includes the Black Hills of South Dakota and Wyoming (Wood 1982). It has recently been discovered in western Nebraska (Costello and Schaupp 2011). Mountain pine beetle is considered the most serious pest of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws). The Black Hills of western South Dakota have almost 480,000 ha of ponderosa pine (Riva et al. 2009) and mountain pine beetle epidemics have been recorded there since the 1890s, each lasting 10 years or longer (Lessard 1986). Ponderosa pine stand morality from mountain pine beetle can be 50% or greater during these epidemics (McCambridge et al. 1982). The current mountain pine beetle epidemic in the Black Hills began in 1997 (Allen and Long 2001).

Management of the mountain pine beetle centers on indirect controls, primarily thinning, to reduce the forest stand density and its susceptibility to mountain pine beetle (Fettig et al. 2007). The insect generally colonizes ponderosa pines that are 20–30 cm in diameter or larger measured at 1.4 m above the ground (dbh) (Schmid and Mata 2005), though even trees as small as 7.5 cm dbh may be attacked during epidemics. Ponderosa pine stands in the Black Hills with a basal area greater than 27.5 m^2/ha are considered highly susceptible to attack (Schmid and Mata 1992) although the threshold may be even lower (Schmid and Mata 2005).

Direct controls are focused on increasing insect mortality (Carroll et al. 2006). These tactics include felling infested trees and processing them at a mill or destroying the tree on site. These population reduction tactics must be completed before the mountain pine beetles emerge. Emergence may begin at the end of June in the Black Hills, though most adults do not emerge until mid July with the typical peak occurring in early August (Schmid 1972). While harvesting and processing the infested trees for wood products may be the most cost-effective approach, it is not always an option. Blue-stain fungi, ophiostomatoid ascomycetes, are closely associated with mountain pine beetles and colonize infested trees (Khadempour et al. 2012). This "blued" wood has little market value in the Black Hills. The forest products industry has set limits on the amount of blue-stain wood it will purchase so there are few opportunities to harvest and process this wood. There are also infested stands in the Black Hills where the trees are too inaccessible for harvest to be economically feasible. Burning infested trees is an option, but cutting and piling logs is time consuming and burning can be restricted due to hazardous conditions (McMullen et al. 1986). Fire bans are common in the Black Hills and piling infested logs with the plan of burning them during the winter or spring is risky as there is the possibility that a ban may prevent the work from being done.

When removal or destruction of infested trees is not practical, felling and treating in place becomes an option (Carroll et al. 2006). Few treatment tactics can achieve the control obtained by removal or complete destruction, however, 100% beetle mortality within a tree is not necessary. Hopkins (1905) pointed out in the first documented effort of direct control of mountain pine beetle that it was only necessary to obtain about 75% beetle mortality to prevent infestations from spreading.

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; kilometers (km): 1 km = 0.6 mi; hectares (ha): 1 ha = 2.47 ac.

Felling and peeling the bark from the infested logs was a tactic used by Hopkins (1905) during the 1890s mountain pine beetle epidemic. Peeling the bark from the logs exposes the larvae to environmental stress, loss of food, and predation; however, this procedure is very labor intensive or requires specialized mechanical peelers so peeling is not being used in the Black Hills at this time. Felling and cutting the trunks into sections and treating the logs with insecticides was a procedure used until the 1970s (Stevens and McCambridge 1978) but has limited application under current pesticide regulation. Applying diesel fuel oil on the infested logs is an effective means of reducing larval survival (Mata et al. 2001) but the cost of diesel fuel and environmental concerns limits its application. The wood can also be chipped and either left on site or removed but this procedure is limited to accessible sites and can be expensive. The simplest procedure to managing infested trees is felling and cutting the trunk into logs and exposing them to sunlight (Patterson 1930, Negron et al. 2001). Patterson (1930) found limited success with this method. His efforts involved leaving the entire trunk in one piece with the limbs removed, but the severed trunks had to be rolled frequently to achieve significant mortality. The solar treatments used today usually entails cutting the logs into 1.2–2.4-m sections and either rotating the logs periodically or covering them with plastic sheeting (Leatherman 2001). While these treatments can reduce the mountain pine beetle survival in infested logs, they may not be practical in all situations. It may not be easy to return to remote stands to rotate the logs. Plastic sheeting may also be impractical due to the difficulty of having someone return to the logs for removal and disposal of the plastic as well as the cost of the material if large numbers of infested logs need to be covered. Felling the trees and cutting into logs without further treatment may be the limits of practicality in many circumstances.

The optimum period to implement mechanical control tactics is considered to be autumn after the cessation of the flight. Leatherman (2001) noted that infested trees should be felled, regardless of treatment, at the end of the flight period, approximately the beginning of October. Negron et al. (2001) felled infested trees in the spring and then either covered the logs with plastic or rotated them periodically. They suggested that there may be greater efficacy of such treatments if trees are felled in autumn.

Custer State Park is located in the southern Black Hills of South Dakota approximately 55 km South of Rapid City, South Dakota. The 960 ha northwestern corner of Custer State Park, known as the Needles, experienced an incipient-epidemic mountain pine beetle population transitioning to an epidemic population by the early 2000s. The Needles is bordered on the north and east by the Black Elk Wildness Area, an area that had experienced nearly 100% mortality of the ponderosa pine from mountain pine beetle during the same time period (Allen and Long 2008). Most of the Needles area of Custer State Park is not readily accessible due to the steep south- and west-facing slopes and rocky terrain. Since many of the infested trees could not be removed from the site and the cost of stacking and covering with plastic was considered too expensive, the decision was made to fell the infested trees during autumn, cut the trunks into logs, and leave in place as a direct control measure to reduce the emerging beetle population the following summer. The logs were cut into short sections, approximately 60–75 cm, and separated by simply pushing each piece away from the adjacent sections. This kept all the sections lying on their side and in contact with the ground. While the desire to scatter the logs for ease of passage through these cut stands was a key reason for cutting into 60–75-cm lengths rather than the 1.2 m done in other studies, these shorter lengths may also increase mortality. Patterson (1930) indicated he observed greater mortality with solar treatments if the trunks were in contact with the ground rather than having them lay across one another. Steed and Wagner (2004) in a study of bark beetles reproductive success in logs commented that if phloem drying occurs near the ends of the logs, brood production could be decreased by cutting logs into short pieces.

The objective of this study was to determine whether felling mountain pine beetle infested trees in autumn and cutting the trunks into 60–75-cm lengths, without further treatment, would significantly reduce the number of adult beetles emerging from the logs the following summer compared to emergence from standing infested trees.

Methods

Almost all the mountain pine beetle infested trees within the Needles area of Custer State Park were marked and felled during October of 2006 and 2007. Approximately 3,800 infested trees were marked in 2006 and 11,900 in 2007. The infested trees were in groups ranging from 2 trees to more than 250, though groups between 20 and 50 trees were the most common. The trunks of the felled trees were cut into approximately 60–75-cm lengths to a minimum log diameter of 15 cm, the smallest diameter wood generally infested by the beetle (Schmid 1972). The logs were rolled to separate them from adjacent sections and received no further treatments, either peeling or rolling.

Five randomly selected groups of infested trees in the Needles area were used for the study in 2006–2007 and another five randomly selected for 2007–2008. The groups were selected each year by assigning a number to each group containing 20–50 infested trees and drawing five numbers. The five study sites for each year were on south to southwestern aspects with a slope between 20 and 40% and between 1,850 and 1,950 m elevation above sea level. The study sites were even-age stands with an average basal area of 25 m^2/ha and an average tree diameter of 27 cm dbh. Once the infested trees were felled the stands had less than 20% canopy closure as measured by a sighting tube (Ganey and Block 1994). All the study sites for both years included infested trees that were left standing and infested trees that were felled during October and the trunks cut into 60–75-cm lengths. Samples were collected from the logs of the felled and cut trees and the nearby standing, infested trees during the second week of March, June, and September the year following felling.

During each sample date, 20 logs from felled and cut trees and 20 standing infested trees were selected, four from each of the five treated stands. A 15.2 × 30.5 cm section of bark was removed from the top of each log (the sunlit side) and the bottom (the side in contact with the ground). The bark was removed from the middle of each log, about 25–30 cm from the end. A log was sampled only once. The logs that were used for sampling were from a portion of the tree that would have been 1.8 m from the ground, the same height that samples were taken from the standing infested trees. An identical size section of bark was removed from the north and south sides of the standing infested trees during the same time periods. The pieces were removed at a height of approximately 1.8 m. Each standing infested tree was sampled only once. The March and June samples had all live life stages counted while the September samples had only adult emergence recorded. Emergence from the standing trees and logs was not determined from the number of beetles collected from caged logs or trunks but by counting the number of exit holes from a 15.2 × 30.5 cm piece of bark following procedures outlined by Safranyik and Linton (1985). Ventilation holes were excluded and we accounted for more than one beetle possibly emerging from the same exit hole, which frequently occurs (Reid 1963).

Data were analyzed using generalized linear model (GLM) and analysis of variance (ANOVA) (SAS/STAT^R version 9.3 software) comparing means of brood and emergence density between logs and standing trees for all sampling dates (March, June, and September) and both years (2007 and 2008) were separated with Duncan's multiple range test (SAS Institute, Inc. 2011). In addition, the number of live mountain pine beetles recorded from the March and June sampling dates between treated logs and standing trees was compared as well as the aspect of the sample, either the top or bottom of the log or the north or south side of the standing infested tree. An identical comparison was made of adult emergence for the September sampling. A one-way ANOVA was conducted for each sampling date with the four treatment/aspect groups; the north and south samples from standing infested trees and the top and bottom samples from logs. If the F ratio was found to be significant ($P < 0.05$) then Tukey's honestly significant difference (HSD) test was applied to determine where the differences occurred among means at a sample date.

Results and Discussion

The mean diameter of the standing infested trees used in this study was 27.1 ± 3.4 cm while the diameter of the logs at midsection was 26.7 ± 4.2 cm. There was no significant difference in mean diameter of the logs and the standing infested trees ($t = 0.41$, $t_{.05} = 1.96$). The mean length of the logs was 68.1 ± 11.2 cm.

The mountain pine beetles collected in the March 2007 and 2008 from standing trees and logs were third and fourth instar larvae. During the June 2007 and 2008 the collection was composed of fourth instar larvae, pupae, and adults. The June 2007 sampling contained 22% larvae, 31% pupae, and 47% callow adults. The June 2008 sampling contained a higher percentage of larvae, 41%, and lower percentage of pupae (30%) and callow adults (29%). There was no difference in the percentage composition of life stages between standing infested trees and logs during the June sampling from either year.

There was a significant difference between the live brood and emergence densities between the logs and standing trees (Table 1). The infested trees and logs had similar brood densities in the March sampling for both years but the densities of live mountain pine beetles between logs and trees differed in the June sampling (Tables 2 and 3). However, at the June sampling, only the tops of the logs had significantly lower densities of live beetles, while the bottoms of the logs had densities similar to that obtained from the standing infested trees.

The results of the March and June sampling were similar to that obtained in an evaluation of similarly treated mountain pine beetle infested trees in the Black Hills. In a comparison of infested trees felled between February and April and cut into logs (length not specified) and scored longitudinally with a chainsaw, there was a decrease in live brood density in the treated trees relative to that of standing infested trees. However, the difference was not significant in June (Schaupp 2003). A study conducted in Colorado by Negron et al. (2001) on solar treatments of infested ponderosa pine logs cut into 1.2-m lengths concluded that placing logs in one or two layers and covering with plastic resulted in the highest mortality of mountain pine beetle, but the authors suggested if covering with plastic sheeting was impractical, then the logs should be left exposed. Negron et al. (2001) did not find a significant difference in overall survival between rotated logs and logs not rotated, though significantly increased survival was found on the underside of logs not rotated. Negron et al. (2001) contend that little change in brood

Table 1. Results of generalized liner model analysis on mountain pine beetle brood or emergence density per 0.05 m^2 area of bark from logs or standing trees. Data for all sample dates (March, June, and September) for 2 years (2007 and 2008) were combined in the analysis.

Treatment/aspect	n	Mean	Duncan grouping
Tree/south side	120	42.5	A
			A
Tree/north side	120	39.5	A
Log/bottom	120	30.1	B
			B
Log/top	120	21.8	B

Treatments/aspect means with the same letter are not significantly different at the $P < 0.05$ level.
Mean separation tests were conducted using Duncan multiple range test (SAS version 9.3, SAS Institute Inc., Cary NC).

Table 2. Mean (SE) of brood densities (March, June) or adult emergence densities (September) of mountain pine beetles per 0.05 m^2 area of bark in 20 infested trees and 20 logs by treatment and aspect for 2007.

Date	Treatment	Aspect	Mean
March	Trees	North	62.5 (13.2)a
		South	60.2 (9.7)a
	Logs	Top	57.0 (16.8)a
		Bottom	55.2 (21.2)a
June	Trees	North	33.8 (16.6)a
		South	28.6 (9.3)a
	Logs	Top	4.6 (4.8)b
		Bottom	22.4 (11.4)a
September	Trees	North	31.1 (11.7)a
		South	27.6 (7.7)a
	Logs	Top	1.4 (2.5)b
		Bottom	13.5 (7.1)b

Means of treatments and aspect or log location for each date followed by the same letter are not significantly different at the $P = 0.05$ level.

Table 3. Mean (SE) in brood densities (March, June) or adult emergence densities (September) of mountain pine beetles per 0.05 m^2 area of bark in 20 infested trees and 20 logs by treatment and aspect for 2008.

Date	Treatment	Aspect	Mean
March	Trees	North	59.9 (10.1)a
		South	58.5 (16.9)a
	Logs	Top	64.8 (18.3)a
		Bottom	51.8 (17.8)a
June	Trees	North	33.4 (18.3)a
		South	31.4 (21.3)a
	Logs	Top	1.6 (2.8)b
		Bottom	25.1 (9.7)a
September	Trees	North	33.9 (11.7)a
		South	30.5 (11.7)a
	Logs	Top	0.7 (2.0)b
		Bottom	12.8 (4.7)b

Means of treatments and aspects or log location for each date followed by the same letter are not significantly different at the $P = 0.05$ level.

density occurs after late May. However, Schmid (1972) noted brood densities continued to decline beyond the first of June in standing infested trees. Survivorship curves developed by Knight (1959) indicated that substantial mortality of brood may still occur between April and July. Knight (1967) stated that reasonably good estimates of adult emergence could be made from sampling in April. However, because more accurate predictions could be made from samples taken in July, he used these later samples to develop his sequential sampling procedures for trend predictions.

Studies by Schaupp (2003) and Negron et al. (2001) terminated sampling in late June and early July, respectively, before emergence, in an effort to simplify posttreatment brood counts. These investigators suggested that a further reduction in survival may have been observed if treatments had been left in place longer (Negron et al. 2001). In this study we found a significant difference in adult emergence in logs compared to emergence from standing infested trees. The brood density was significantly lower only in the tops of the logs, compared to standing infested trees and the bottoms of logs, in the earlier June sampling. The July to August time period resulted in significantly decreased survival on the underside of the logs.

In previous studies using mechanical treatments, varied effects on mountain pine beetle brood were found. For example, Schmid et al. (2001) found 8.3% survival after treating single layer logs with diesel oil. Negron et al. (2001) observed no survival in tops and 75% survival in bottoms of single layer logs that were not rotated. Overall survival in these logs was approximately 25%. However, in their study, the logs were placed so the north aspect of the tree, where brood densities are highest, was oriented to the top and the south aspect oriented to the bottom of the log. The logs were also placed in meadows. In the current study, the logs were not oriented with regard to the aspect of the tree and left in the forest stand from which they were cut, a more practical situation for field operation. The survival in logs was 24% (2007) to 21% (2008) in logs compared to standing infested trees. This strong reduction in survival of mountain pine beetle relative to that in standing trees indicates this treatment can be effective in reducing spread.

Conclusion

Rotating logs, covering them with plastic, or coating with diesel oil are labor intensive and can have a negative effect on the environment. This study found that simply felling trees and cutting them into logs is a practical and effective way to reduce emergence and lower the potential for spread of localized infestations of mountain pine beetle.

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