Forest Health Management

IMPACTS OF DOUGLAS-FIR BEETLE ON OVERSTORY AND UNDERSTORY CONDITIONS OF DOUGLAS-FIR STANDS

SHOSHONE NATIONAL FOREST, WYOMING

TECHNICAL REPORT R2-64
January 2000

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Forest Service
Rocky Mountain Region
Denver, Colorado

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by

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ABSTRACT

Douglas-fir beetle (*Dendroctonus pseudotsugae*) infestations frequently result from disturbance events that create large volumes of weakened Douglas-fir (*Pseudotsuga menziesii*) trees. Although research has focused on measuring and predicting the amount of tree mortality caused by Douglas-fir beetle infestations following disturbance events, there has been an inadequate amount of work on the consequent changes in both the overstory and understory. In 1988, extensive wildfires occurred in Yellowstone National Park and the Shoshone National Forest. Populations of Douglas-fir beetle increased in fire-scorched trees caused by the wildfires. Subsequent generations of the beetles moved from these injured trees to undamaged trees in neighboring stands on the Shoshone National Forest, Wyoming.

In 1999, Forest Health Management personnel quantified changes in forest stand conditions and subsequent responses in the understory caused by the Douglas-fir beetle infestation using transect sampling (20 miles) and 25 pairs of previously infested and uninfested plots. Significant effects of the Douglas-fir beetle infestation included: 1) Basal area was reduced by 40 - 70 percent, tree diameter decreased by 8 - 40 percent, and the Douglas-fir component of the overstory decreased by more than 15 percent. 2) Conifer seedling regeneration increased nearly four-fold in the infested plots and 90 percent of the regeneration was Douglas-fir. 3) The understory vegetation (forbs, grass, and shrubs) had a three-fold increase in the infested plots compared with uninfested plots. In addition, basal area of Douglas-fir killed by the Douglas-fir beetle was significantly correlated with initial Douglas-fir basal area and percent of Douglas-fir, but not tree diameter or trees per hectare. Significant inverse relationships were also found between post-infestation basal area and the abundance of forbs, grass, shrubs, and understory height.

Based on these results, Douglas-fir beetle infestations, although causing significant short-term impacts in both the overstory and understory, probably are not changing the long-term successional patterns. Management alternatives are presented to control Douglas-fir beetle impacts for areas where the beetle is jeopardizing forest objectives. Information gathered from this study will be useful to the Shoshone National Forest, and other national forests both inside and outside the region, and the Yellowstone National Park.

INTRODUCTION

The Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) infests and kills Douglas-fir (*Pseudotsuga menziesii*) throughout its range in North America. Typically, the beetle reproduces in scattered trees that are highly stressed, such as windfall, defoliated or fire-scorched trees (Furniss, 1962; Furniss, 1965; Lessard and Schmid, 1990). If enough suitable host material is present, beetles can increase in the stressed trees and infest nearby healthy trees (Furniss et al., 1981). Previous research on Douglas-fir beetle infestations have examined forest stand and site characteristics associated with infestations (Furniss et al., 1979; Furniss et al., 1981; Weatherby and Thier, 1993; Negron, 1998), and developed models to predict the extent of tree mortality (Negron et al., 1999). For example, Douglas-fir beetle attacks are most successful on trees that are mature or overmature, largest in diameter, and found in high density stands that contain a high percentage of Douglas-fir in the overstory (Schmitz and Gibson, 1996). However, there is a paucity of research concerning what are the subsequent changes to the forest overstory and understory and forest successional trends (Hadley and Veblen, 1993; Schmid and Mata, 1996).

Fires that started in Yellowstone National Park in 1988 burned onto the Clarks Fork Ranger District of the Shoshone National Forest, Wyoming, killing and scorching a large number of trees. Populations of the Douglas-fir beetle increased in scorched trees and began attacking neighboring green trees in this area (Pasek, 1990). Similar events took place within Yellowstone National Park (Rasmussen et al., 1996). This Douglas-fir beetle infestation has obviously impacted forest stand conditions over the last decade. During the Douglas-fir beetle infestation in this area, an estimated 23,000 trees have been killed over a 7-year period (USDA Forest Service, Forest Health Monitoring aerial surveys). Although changes in beetle populations were estimated (Pasek, 1990, 1991; Pasek, 1996; Pasek and Schaupp, 1995; Schaupp and Pasek, 1993, 1995; Allen and Pasek, 1996) and a predictive model has been developed based on the mortality that occurred in the early to mid 1990's (Negron et al., 1999), additional mortality has occurred since the last measurement of mortality in 1995. Moreover, changes in the level of tree cover, tree species, size classes of residual trees, and changes in the understory have not been quantified.

The overall objective of this technical report was to determine the impact of Douglas-fir beetle on both the over- and understory of Douglas-fir stands in the Shoshone National Forest. Specific questions included: 1. What were the impacts of the Douglas-fir beetle infestation on tree species composition, basal area, and diameter on the Shoshone National Forest? 2. What were the forest conditions present in areas that have experienced high levels of mortality over the past 10 years? 3. What changes have occurred in the understory of infested stands of Douglas-fir? 4. Has the Douglas-fir beetle infestation radically changed long-term successional patterns in the forest? Answers to these questions are not only of value to managers on the Shoshone National Forest, but also should be applicable to other areas of the northern Rockies where there are extensive stands of Douglas-fir. In addition to addressing these questions, we provide some

background information on the biology of Douglas-fir beetle and management strategies for the control of Douglas-fir beetle.

METHODS AND MATERIALS

Douglas-fir beetle life history

The Douglas-fir beetle has one generation per year (Schmitz and Gibson, 1996). Although adult flight times vary by year, most new attacks occur in late spring to early summer on the Shoshone National Forest. Broods develop under the bark throughout the summer and early fall. The overwintering lifestage can be either as adults or as larvae. Larvae that overwinter emerge as adults in the summer. A small percentage of adults that overwintered will re-emerge from the spring-attacked trees and attack additional trees in the middle of the summer.

Study area

The studies were conducted in the drainages of Sunlight Creek and Clarks Fork River (44° 50' N, 109° 30' W) adjacent to the eastern border of Yellowstone National Park, Wyoming (Figure 1). The areas of study were characterized by predominantly pure stands of Douglas-fir and to a lesser extent mixed stands consisting of Douglas-fir, Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and/or lodgepole (*Pinus contorta*), whitebark (*P. albicaulis*) or limber pine (*P. flexilis*). Elevation in the study area ranged from 6,500 to 8,500 ft. Negron et al. (1999) provide additional descriptions of the area, site indices, and forest types.

Impact of Douglas-fir beetle on stand conditions

Overall, the methods followed the design of McCambridge et al. (1982a) that examined the impact of mountain pine beetle on ponderosa pine stands, but also included additional measurements as described below. Measurement of forest conditions and Douglas-fir beetle impact were conducted using systematic sampling through stands that were predominantly Douglas-fir and that had experienced older mortality (e.g., mortality that had primarily occurred more than 5 years prior to the study). A 20 basal area factor (BAF) variable radius plot was installed every 10 chains (667 ft.) throughout these areas. A total of 161 plots were installed for measurements of forest conditions and beetle impacts. In general, transects were not placed in areas that had trees removed within the past 10 years; however, transect 16 near Badger Spring was observed to contain limited areas of salvage harvesting.

Within each plot, Forest Health Monitoring-type mensuration measurements were taken on all "in" trees, including: tree species, diameter at breast height (DBH), and crown class and condition/damages. Information on percent slope, aspect, and other general site characteristics were gleaned from an earlier report on plot establishment (Negron et al. 1999). If an "in" tree was found to have been attacked by Douglas-fir beetle, the year of attack was recorded. The year of attack was classified using the following categories:

Current year attack: green tree under attack, resin flow and fresh boring dust evident. **1-year old attack:** fader, foliage orange but some green may still be present, bark still hard and tight, galleries evident, exit holes present. **2-year old attack:** most foliage missing, remaining foliage (if any) is orange, galleries still identifiable, small twigs present, secondary wood borers may be present but not abundant, exit holes present. **3-year old attack:** all foliage gone but small twigs still present, bark loose and galleries hard to find, lots of secondary wood borers burrowing, exit holes present. **4-year old and older attack:** smaller twigs gone, exit holes present (Negron, 1998).

Impact of Douglas-fir beetle on understory conditions and successional patterns

In addition to the transect survey method of evaluating beetle impact, measurements were recorded in permanent plots established in the early-1990's. These plots were originally constructed to develop hazard rating systems and a prediction model for Douglas-fir beetle-caused mortality using pairs of infested and uninfested plots (Negron et al., 1999; W.C. Schuapp, unpublished data). The methods for plot inspection follow those reported by Negron (1998), which resulted in infested and uninfested points being intermingled. Infested plots were installed at random in areas of mortality in the stand. Uninfested plots were installed a random direction from the infested plots in unaffected areas of the stand. Plots were separated by at least 130 ft. and less than 330 ft. Twenty-five paired plots were examined in the Clarks Fork and Sunlight Creek drainages. The primary objective of using these paired plots in the present study was to quantify changes in the understory as a result of the Douglas-fir beetle infestation and, in turn, what changes in forest succession may be taking place.

Upon locating a plot, a 20 BAF prism was used to determine "in" trees and mensuration measurements were recorded. In addition, understory growth and abundance was measured by counting the number of total cm that grass, forb and shrub species cover along 3 m lines running North - South and East - West of plot center. Understory height also was measured by recording the height of the understory 10 feet from plot center in each Cardinal direction and at the plot center. In addition, the species, number, and type of regeneration (saplings [1.0" $\leq$ dbh <5.0"], seedlings [dbh <1.0"]) were measured along an 11.78-foot radius (0.01 acre plot) from plot center.

Data analysis

Data collected from the transect portion of the study were used to calculate transect means and standard error of the means (SEM) for all variables. These means were in turn used to compute linear regressions between stand characteristics and the amount of basal area killed by Douglas-fir beetle and to provide a description of stand conditions. Measurements collected from the infested and uninfested plots were evaluated by calculating means of all variables and then compared using a paired-sample t-test analysis. Data were also used to calculate coefficients of determination using simple linear regression analysis between the post-infestation basal area (or conversely, basal area killed) and understory variables. All statistical analysis was conducted using Systat® software (Wilkinson, 1991).

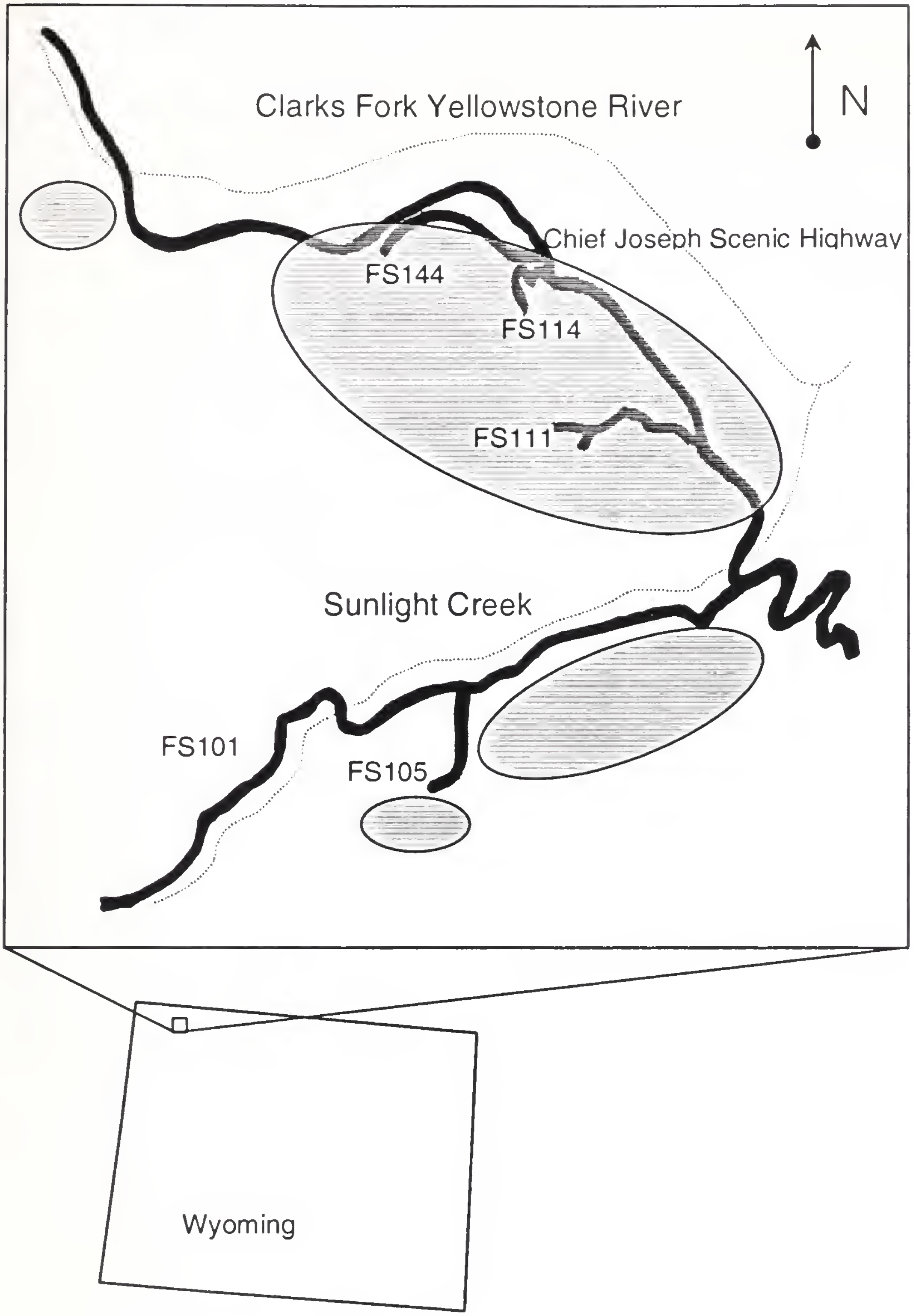

***Figure 1**. Location of sites used to study the impact of Douglas-fir beetle on Douglas-fir in the Greater Yellowstone Area of the Shoshone National Forest.*

RESULTS AND DISCUSSION

Impact of Douglas-fir beetle on forest stand conditions

Overall, Douglas-fir beetle had a significant impact on the forest overstory conditions of the areas studied (Tables 1 - 3). Approximately two-thirds of the mortality occurred more than 3 years previous to the start of the study (Tables 1 and 2) and the greatest proportion of that mortality probably occurred 5 to 8 years ago (Negron et al., 1999). USDA Forest Service Forest Health Management aerial surveys have detected a resurgence in Douglas-fir beetle-caused tree mortality beginning in 1998; however, the amount of mortality was less than occurred in the early to mid 1990's. The uninfested plots had sustained basal area losses less than 13 ft.^{2}/ac by 1999 with most of this occurring in the last 2 years (Table 3). This suggests that Douglas-fir beetle may be moving out of stands of higher susceptibility to stands of lower susceptibility over time.

Table 1. *Tree mortality caused by Douglas-fir beetle on the Clarks Fork Ranger District, Shoshone National Forest, based on Forest Health Monitoring aerial detection surveys.*

Year	Acres Infested	Trees Killed	Timber Volume Killed (ft.^{3})
1992	2,324	5,585	309,130
1993	1,559	4,113	227,656
1994	2,481	5,115	283,115
1995	1,723	4,542	251,400
1996	1,271	1,075	59,501
1997	1,203	989	54,741
1998[a]	2,383	1,680	92,988
1999[b]	5,791	14,449	799,754
Total	18,735	37,548	2,078,285

[a] Prior to 1998, most mortality occurred in the Sunlight Basin and near the Clarks Fork Yellowstone River. Starting in 1998, the infestation moved and most of the mortality occurred along the North Fork of the Shoshone River.

[b] The 1999 aerial survey found increased tree mortality along both the North Fork of the Shoshone River, and its tributaries, and in the Sunlight Basin and near the Clarks Fork Yellowstone River.

Based on the transect studies, Douglas-fir beetle caused reductions in Douglas-fir basal area by more than 70 ft.^{2}/ac (46 percent), total basal area by 43 percent, and the average stand diameter to be decreased by more than 1 inch (8 percent) (Table 2). The percent reduction in basal area found in transect portion of this study was slightly lower than reported by Negron et al. (1999) for the same general area. The difference in basal area reduction between the two studies may have been caused by different methods being used

to measure the impact on basal area. Negron et al. (1999) selected points a random distance and direction from infested spots to develop mortality models. Whereas in our transect study, whole stands were surveyed and, therefore, areas of high and low infestations were included. Using a subsample of the plots reported in Negron et al. (1999), we found basal area was reduced more than 70 percent in infested plots compared with the uninfested plots (Table 3). Similarly, the reduction in tree diameter was greater using the paired plots than in the transect portion of the study. Tree diameters in the infested plots averaged 6 inches less than trees in the uninfested plots. The mortality observed in the infested plots were probably representative of stands that experienced heavy mortality, and the mortality levels found along each transect was likely more reflective of the type of mortality that occurs across a watershed.

The percentage of Douglas-fir in the stand and basal area were important in determining the level of Douglas-fir beetle impact. Regression analyses found a significant linear relationship between the percentage of Douglas-fir ($y = -135 + 2.2DF\%$, $r^2 = 0.469$, $P = 0.003$), total basal area ($y = -148 + 1.4BA$, $r^2 = 0.439$, $P = 0.005$) and Douglas-fir basal area ($y = -99.3 + 1.12BA$, $r^2 = 0.68$, $P = 0.001$), but not Douglas-fir diameter ($P = 0.86$) or trees per acre diameter ($P = 0.77$), with the basal area of Douglas-fir killed by Douglas-fir beetle (Figure 2). For example, the only transect that had less than 80 percent of a Douglas-fir component in the overstory had no recorded mortality caused by Douglas-fir beetle. Moreover, the three transects having the highest average basal areas had the three highest total mortality values. Transect 16 (Badger Spring 3) also had a high total mortality value, but a comparatively low basal area. Upon reinspection of this transect area, past salvage harvesting activities were discovered and therefore resulted in a lower basal area. The coefficient of determination in this study was higher to that reported earlier for the area (e.g., $r^2 = 0.46$, Negron et al., 1999) perhaps because the beetles have more fully utilized their food resources. However, care must be taken when using linear regression equations of this kind because, although actual mortality can be derived, relatively low precision estimates may be generated (Negron et al., 1999).

The relationships between the amount of tree mortality and basal area and percentage of Douglas-fir are, in general, consistent with previous studies on Douglas-fir beetle in other geographical locations (Furniss et al., 1979; Furniss et al., 1981; Weatherby and Thier, 1993; Negron, 1998). Hypotheses as to why Douglas-fir beetle prefers stands of higher basal area or stand density include that trees are subjected to greater moisture stress and the beetle's preference for trees with shaded stems (Furniss et al., 1981). One possible reason dbh was not as important in this study as it was in Idaho and Montana (Furniss et al., 1979; Furniss et al., 1981), is that we measured impact at or near the conclusion of the infestation. Therefore, most of the largest trees may have already been attacked and the beetles moved on to smaller trees. Pasek (1990) reported that Douglas-fir beetle preferentially attacked the largest diameter trees first in this area following the 1988 fires. Our study was not designed to necessarily find stand and site characteristics that are critical to the initial population build up, but what was the beetle's overall impact on the forest. Nonetheless, tree diameter prior to the infestation was significantly higher in the infested plots and significantly lower after the infestation than in the uninfested plots (Table

2). This reinforces the argument that Douglas-fir beetle initially attacks larger diameter trees.

In addition, Douglas-fir beetle caused a marginal reduction in the percentage (15 percent) of Douglas-fir in the overstory relative to other tree species. Although the percentage of Douglas-fir did not differ between the infested and uninfested plots when measured post-infestation because of the large variance in the infested plots (Table 3), there was a significant decrease in the percentage of Douglas-fir when compared with pre-infestation levels ($t = 2.343$, $P = 0.028$). Consequently, the percentage of Engelmann spruce, white pines and lodgepole pine increased relative to Douglas-fir in the overstory of infested plots. The percent reduction of Douglas-fir in the overstory probably depends on the initial overstory composition of tree species. Reductions in the percentage of Douglas-fir in the overstory were greater (e.g., 20 percent) in Idaho where stands were initially only 60 percent or higher Douglas-fir (Furniss et al., 1979).

Table 2. *Summary of stand conditions and Douglas-fir beetle impact on stand conditions in the Sunlight Creek and Clarks Fork River drainages based on variable radius plot sampling.*

								Basal Area (ft²/ac) Killed by Year[a]				
Transect	**BA**	**DFBA**	**TPA**	**DBH**	**Live DBH**	**% DF[b]**	**CY**	**1 yr**	**2 yr**	**3 yr**	**4 yr+**	**Total**
FS144	155	90	111.2	16.9	17.4	58.1	0.0	0.0	0.0	0.0	0.0	0.0
E. Reef Cr.1	180	175	112.1	17.1	13.3	97.2	20.0	2.6	12.6	17.6	47.6	100.4
E. Reef Cr.2	154	137	117.3	15.5	13.8	87.0	12.0	0.0	0.0	2.8	40.0	54.8
Reef Cr.3	170	155	155.5	14.4	14.0	92.4	10.0	17.6	7.6	10.0	27.6	72.8
Reef Cr.4	185	175	103.1	16.0	14.6	94.3	5.0	10.0	20.0	35.0	45.0	115.0
E. Reef Cr.5	173	170	107.6	17.6	16.1	98.1	8.4	5.0	11.6	23.4	26.6	75.0
Badger Spr.1	135	130	116.3	14.4	12.3	92.3	5.0	0.0	10.0	10.0	35.0	60.0
Sunlight Basin1	163	163	217.8	11.9	11.1	100	5.0	7.6	7.6	6.2	36.2	62.6
Sunlight Basin2	180	180	178.2	14.0	14.6	100	20.0	17.6	2.6	10.0	87.6	137.8
D.O.T. West	159	159	181.5	12.6	11.5	100	17.5	2.6	6.6	16.4	32.6	75.7
D.O.T. East	158	150	203.4	11.0	9.7	96.2	10.0	6.0	14.0	18.0	24.0	72.0
Badger Spr.2	144	144	123.7	13.9	13.3	100	20.0	2.0	12.0	10.0	16.0	60.0
Sunlight Basin3	173	170	267.1	10.9	10.6	98.1	11.6	1.6	5.0	0.0	28.4	46.6
Hunter Peak	129	109	145.9	13.0	12.7	84.2	2.2	0.0	1.2	7.8	7.8	19.0
FS105	158	149	135.6	14.7	13.3	94.4	5.0	10.0	12.6	10.0	32.6	70.2
Badger Spr.3	155	150	155.0	14.7	12.2	96.8	15.0	10.0	5.0	25.0	45.0	100.0
Mean	**161**	**150.7**	**152.0**	**14.3**	**13.2**	**93.1**	**10.4**	**5.7**	**8.0**	**12.6**	**33.3**	**70.1**
SEM	**4.1**	**6.3**	**11.7**	**0.5**	**0.4**	**2.6**	**1.6**	**1.5**	**1.4**	**2.4**	**4.9**	**8.4**

[a] Basal area killed by year refers to the basal area killed by Douglas-fir beetle according to the year of attack (e.g., CY = basal area currently infested by Douglas-fir beetle, 1 yr = basal area killed 1 year prior to the study, 2 yr = basal area killed 2 years prior to the study, 3 yr = basal area killed 3 years prior to the study, 4 yr+ = basal area killed 4 or more years prior to the study, Total = sum of basal area killed).

[b] BA equals average basal area (ft²/ac) found for all points in the transect. [c] DFBA equals average Douglas-fir basal area (ft²/ac).

[d] TPA equals trees per acre.

[e] DBH equals diameter at breast height (inches). [f] Live DBH equals diameter at breast height (inches) for all living Douglas-fir trees.

[g] % DF equals the percentage of trees in the variable radius plot that were Douglas-fir.

Impact of Douglas-fir beetle on understory conditions

Douglas-fir beetle also had a significant impact on the understory. Although the abundance of forbs, shrubs, and grass did not change relative to each other, there was an approximate three-fold increase in their total abundance in the infested plots compared with the uninfested plots (Figure 3). Grass species had the greatest percentage increase in abundance among the three groups of understory plants. In addition, the average height of the understory more than tripled in the infested plots (Table 3). Significant inverse relationships were found between the post-infestation basal area and the abundance of forbs ($y = 48.1 - 0.16BA$, $r^2 = 0.256$, $P < 0.001$), grass ($y = 18.4 - 0.10BA$, $r^2 = 0.168$, $P = 0.003$), shrubs ($y = 29.1 - 0.10BA$, $r^2 = 0.113$, $P = 0.017$) and understory height ($y = 21.6 - 0.10BA$, $r^2 = 0.468$, $P = 0.005$), but not the amount of seedling regeneration ($P = 0.174$). The relative abundances of understory plants will probably change over time as the amount and height of conifer regeneration increases and, therefore, should not be considered as a permanent change. However, in the short-term, previously infested spots may serve as areas of increased forage suitable for large ungulates (Schmid and Amman, 1992). Although impacts of Douglas-fir beetle to the understory have not been reported other than the present study, mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreaks have resulted in increased herbage production in Colorado (McCambridge et al., 1982b). For example, forb, sedge, and grass production increased following the beetle-caused mortality of ponderosa pine in the overstory. Similarly, spruce beetle (*D. rufipennis* Kirby) outbreaks have been shown to increase herbage production in Colorado (Yeager and Riordan, 1953). However, in contrast to the impacts caused by Douglas-fir beetle, forbs increased more than browse plants following the spruce beetle epidemic.

In addition to the increase in the understory herbaceous layer, there was a significant increase in the amount of conifer regeneration (Table 3). Although there was more than three times the regeneration in the infested plots compared with the uninfested plots, approximately 90 percent of the regeneration in both plots was Douglas-fir. Therefore, it seems that areas experiencing heavy Douglas-fir mortality will remain predominantly Douglas-fir. These findings are not really surprising considering that the stands were initially almost pure Douglas-fir. Similar studies in more mixed stands would probably find a greater increase in the regeneration of other species. These results are similar to the Colorado Front Range where Douglas-fir remained the dominant tree species after repeated and overlapping outbreaks of western spruce budworm and Douglas-fir beetle (Hadley and Veblen, 1993). Thus, the combined effects of western spruce budworm and Douglas-fir beetle caused a slowing of the successional trend toward a steady-state Douglas-fir forest along the Colorado Front Range. A similar successional pattern may be happening on the Shoshone National Forest.

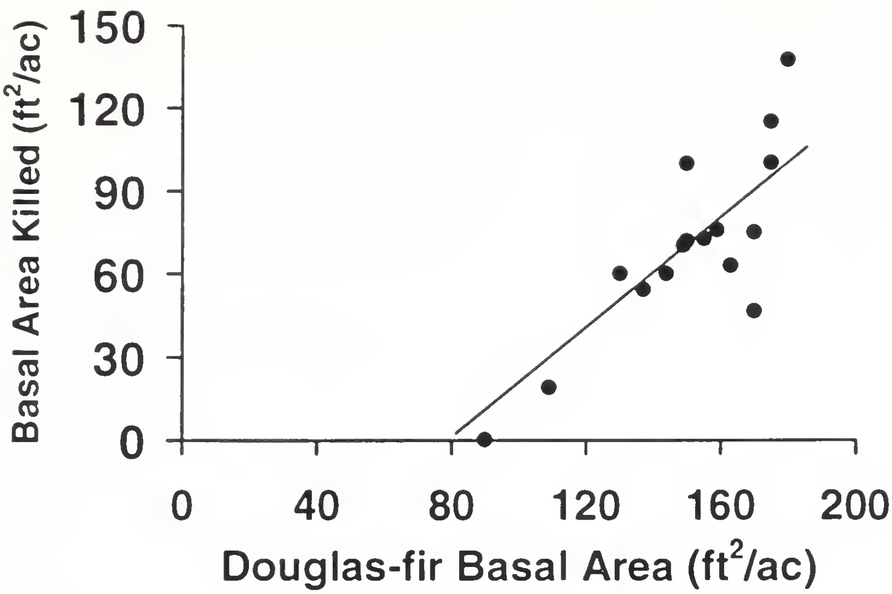

Figure 2. *Relationship between basal area of Douglas-fir killed by Douglas-fir beetle and initial Douglas-fir basal area on the Shoshone National Forest.*

Table 3. *Summary of Douglas-fir beetle impact on stand conditions in the Sunlight Creek and Clarks Fork River drainages based on paired plot sampling. Mean (+/- standard deviation) for each variable is presented.*

Variable	Uninfested Plots	Infested Plots	|t|-value	$p > t$
Total basal area (ft^2/ac)	187.2 (10.1)	193.6 (8.5)	0.489	0.630
Douglas-fir basal area (ft^2/ac)	177.7 (12.6)	192.1 (8.7)	0.931	0.361
Live basal area (ft^2/ac)	177.6 (10.7)	36.0 (8.5)	11.862	<0.001
Live Douglas-fir basal area (ft^2/ac)	168.1 (2.8)	34.4 (5.2)	10.006	<0.001
Total tree DBH (inches)	13.1 (0.5)	14.9 (0.5)	4.111	<0.001
Living tree DBH (inches)	12.9 (0.5)	8.6 (1.1)	3.188	0.004
Basal area killed (ft^2/ac)	9.5 (3.5)	157.7 (8.7)	14.513	<0.001
Percent Douglas-fir				
Pre-infestation	93.8 (3.0)	99.6 (0.4)	2.004	0.056
Post-infestation	93.6 (3.0)	78.0 (7.6)	1.441	0.162
Regeneration[b]	8.3 (2.5)	30.6 (8.5)	3.020	0.006
Understory height (inches)	5.8 (0.8)	19.4 (2.0)	7.810	<0.001

[b] Regeneration refers to the number of seedling and saplings recorded per 0.01 acre plot.

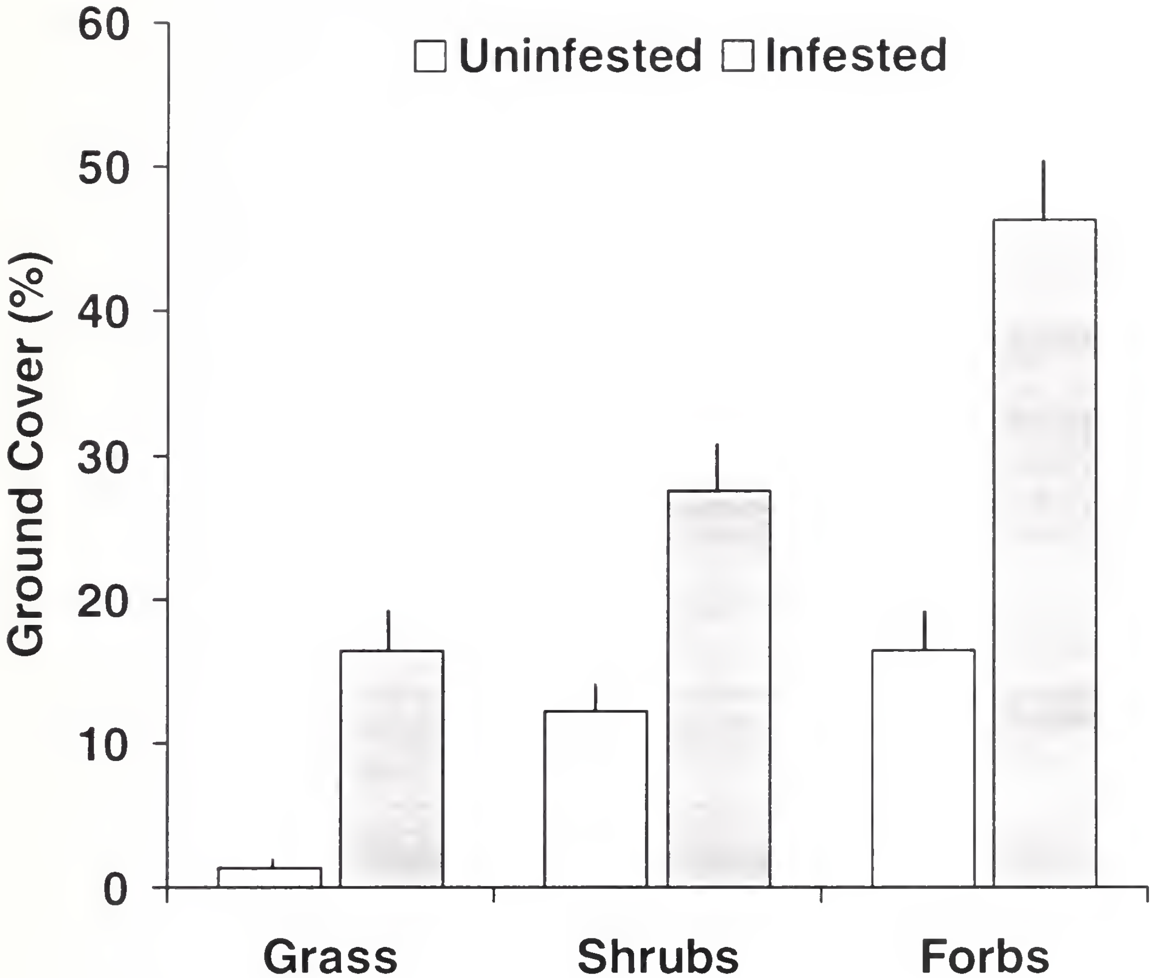

Figure 3. Impact of Douglas-fir beetle on understory (forbs, grass, shrubs) abundance in the Greater Yellowstone area of the Shoshone National Forest. Bars represent mean + SEM.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Douglas-fir beetle impacted both the overstory and understory conditions of the forest. There were significant reductions in the overstory and consequent increases in the understory. Overstory mortality and associated changes in the understory will continue before the Douglas-fir beetle population collapses to endemic levels. However, it is important to remember that these reductions in the overstory are temporary, as tree diameter may be accelerated in the remaining live trees and as the regeneration matures. How long it takes basal area and tree size to return to the pre-infestation levels remains to be determined. Based on the average tree size and tree age of 165 years reported by Negron et al. (1999), it will probably take between 25 to 200 years to return to pre-infestation tree densities and size depending on the severity of tree mortality for a given stand. Moreover, it must be emphasized that the changes are characteristic of a dynamic forest ecosystem. For example, insect-caused disturbances work with other disturbances such as fire to shape the continual changing spatial and temporal patterns of the forest (Schmid and Mata, 1996).

If no management actions are implemented while the Douglas-fir beetle outbreak continues, there will be further reductions in overstory basal area and average tree diameter across the landscape. Based on the levels of mortality that have occurred to date, managers can expect to lose between and 40 and 70 percent of the Douglas-fir basal areas in areas of heavy tree mortality. In addition, the average size of trees will be reduced in the short-term. Regeneration and forage production will increase in beetle-caused openings in the forest. The majority of the regeneration should continue to be Douglas-fir and smaller percentages of spruce, fir, and pine.

For areas of the forest where control of Douglas-fir beetle is warranted, current management strategies include:

Salvage/sanitation harvesting

Sanitation harvesting involves removing currently infested trees from the site. Removal of these infested can decrease a localized beetle population. Sanitation harvesting should be completed before the beetles start to emerge in May of each year. In addition, in stands that have been heavily attacked and mortality has been high, salvaging dead trees to capture some economic value in the near future is appropriate. However, salvage harvesting does not reduce beetle populations. This action will depend on management objectives for each area.

Anti-aggregation pheromones (MCH)

Douglas-fir beetle has a well-studied complex of pheromones (message-bearing chemicals), which it emits to regulate the behavior of other beetles. Anti-aggregation pheromones (3-methylcyclohex-2-en-1-one [MCH]) serve to disrupt aggregation behavior of beetles (Schmitz and Gibson, 1996). MCH has been used experimentally to reduce the

level of attack in high-risk areas (Ross and Daterman, 1994, 1995). In addition, the use of MCH can be combined with aggregation pheromones that are attached to funnel traps located outside areas of high value to reduce beetle population. Another alternative is to concentrate attacks on certain trees by using the aggregation pheromones and the remove those trees (i.e., trap tree method), thereby lowering the beetle population in a localized area.

Silvicultural treatment

Being that Douglas-fir beetle attacks are most successful in unmanaged, overstocked stands that contain a high percentage of large diameter Douglas-fir, silvicultural treatments that alter these stand conditions will reduce a stand's susceptibility to attack and potential wide-spread damage. Silvicultural treatments are used in stands that have not yet been affected by the beetle to reduce susceptibility to attack. It should be part of an ongoing vegetation management program to help increase the health of stands by decreasing their vulnerability to any insects and diseases, not just Douglas-fir beetle. To reduce the susceptibility of stands to Douglas-fir beetle, basal area should be below 80% of normal stocking (Furniss et al. 1981). Harvesting in old, mature stands and thinning younger stands could be used to create healthier stand conditions where it is appropriate.

No action

The no action alternative represents taking no management actions in the Douglas-fir beetle impacted areas outside of normal activities. It accepts present and possible future tree mortality as a natural process. Tree resistance, natural enemies, such as parasitic and predacious insects and other invertebrates, loss of suitable host trees, and weather-related factors will help to collapse the Douglas-fir beetle populations over time.

REFERENCES

Allen, K.K. and Pasek, J.E. 1996. Emergence and overwintering brood of Douglas-fir beetle eight years after the Clover Mist Fire on the Clarks Fork Ranger District, Shoshone National Forest, Wyoming. USDA For. Serv., Rocky Mountain Region, Biol. Eval. R2-97-03, 16 pp.

Furniss, M.M. 1962. Infestation patterns of Douglas-fir beetle in standing and windthrown trees in southern Idaho. J. Econ. Entomol., 55: 486-491.

Furniss, M.M. 1965. Susceptibility of fire-injured Douglas-fir to bark beetle attack in southern Idaho. J. For., 63: 8-11.

Furniss, M.M., McGregor, M.D., Foiles, M.W. and Partridge, A.D. 1979. Chronology and characteristics of a Douglas-fir beetle outbreak in northern Idaho. USDA For. Serv., Gen. Tech. Rep. INT-59, 19 pp.

Furniss, M.M., Livingston, R.L. and McGregor, D.M. 1981. Development of a stand susceptibility classification for Douglas-fir beetle. In: Symposium Proceedings, Hazard Rating Systems in Forest Pest Management (Univ. Georgia, Athens, Ga., July 31 - Aug. 1, 1980). USDA For. Serv., Gen. Tech. Rep. WO-27, Washington, D.C., pp. 115-128.

Hadley, K.S. and Veblen, T.T. 1993. Stand response to western spruce budworm and Douglas-fir bark beetle outbreaks, Colorado Front Range. Can. J. For. Res., 23: 479-491.

Lessard, E.D. and Schmid, J.M. 1990. Emergence, attack densities, and host relationships for the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) in northern Colorado. Great Basin Nat., 50: 333-338.

McCambridge, W.F., Hawksworth, F.G., Edminister, C.B. and Laut, J.G. 1982a. Ponderosa pine mortality resulting from a mountain pine beetle outbreak. USDA For. Serv., Research Paper, RM-235, 7 pp.

McCambridge, W.F., Morris, M.J. and Edminister, C.B. 1982b. Herbage production under ponderosa pine killed by the mountain pine beetle in Colorado. USDA For. Serv., Research Note, RM-416, 3 pp.

Negron, J.F. 1998. Probability of infestation and extent of mortality associated with the Douglas-fir beetle in the Colorado Front Range. For. Ecol. Manage., 107: 71-85.

Negron, J.F., Schaupp, Jr., W.C., Gibson, K.E., Anhold, J., Hansen, D., Thier, R. and Mocettini, P. 1999. Estimating extent of mortality associated with the Douglas-fir beetle in the central and northern Rockies. West. J. Appl. For., 14: 121-127.

Pasek, J.E. 1990. Douglas-fir beetle infestations following the Clover Mist Fire on the Clarks Fork Ranger District, Shoshone National Forest, Wyoming. USDA For. Serv., Rocky Mountain Region, Biol. Eval. R2-90-01, 10 pp.

Pasek, J.E. 1991. Populations of Douglas-fir beetle in scorched and green trees 2 years following the Clover Mist Fire on the Clarks Fork Ranger District, Shoshone National Forest, Wyoming. USDA For. Serv., Biol. Eval. R2-91-01, 20 pp.

Pasek, J.E. 1996. Emergence and overwintering brood of Douglas-fir beetle seven years after the Clover Mist Fire on the Clarks Fork Ranger District, Shoshone National Forest, Wyoming. USDA For. Serv., Rocky Mountain Region, Biol. Eval. R2-96-01, 16 pp.

Pasek, J.E. and Schaupp, Jr., W.C. 1992. Populations of Douglas-fir beetle in green trees three years after the Clover Mist Fire on the Clarks Fork Ranger District, Shoshone

National Forest, Wyoming. USDA For. Serv., Rocky Mountain Region, Biol. Eval. R2-92-02, 13 pp.

Pasek, J.E. and Schaupp, Jr., W.C. 1995. Emergence and overwintering brood of Douglas-fir beetle six years after the Clover Mist Fire on the Clarks Fork Ranger District, Shoshone National Forest, Wyoming. USDA For. Serv., Rocky Mountain Region, Biol. Eval. R2-95-02, 17 pp.

Rasmussen, L.A., Amman, G.D., Vandygriff, J.C., Oakes, R.D., Munsen, A.S. and Gibson, K.E. 1996. Bark beetle and wood borer infestation in the Greater Yellowstone Area during four postfire years. USDA For. Serv. Gen. Tech. Rep. INT-RP-487, 10 pp.

Ross, D. W., and Daterman, G. E. 1994. Reduction of Douglas-fir beetle infestation of high-risk stands by antiaggregation and aggregation pheromones. Can. J. For. Res., 24: 2184-2190.

Ross, D. W., and Daterman, G. E. 1995. Efficacy of an antiaggregation pheromone for reducing Douglas-fir beetle, Dendroctonus pseudotsugae Hopkins (Coleoptera: Scolytidae), infestation of high risk stands. Can. Entomol., 127: 805-811.

Schaupp, W.C., Jr. and Pasek, J.E. 1993. Emergence and overwintering brood of Douglas-fir beetle four years after the Clover Mist Fire on the Clarks Fork Ranger District, Shoshone National Forest, Wyoming. USDA For. Serv., Rocky Mountain Region, Biol. Eval. R2-94-01, 14 pp.

Schaupp, W.C., Jr. and Pasek, J.E. 1995. Emergence and overwintering brood of Douglas-fir beetle five years after the Clover Mist Fire on the Clarks Fork Ranger District, Shoshone National Forest, Wyoming. USDA For. Serv., Rocky Mountain Region, Biol. Eval. R2-54-01, 19 pp.

Schmid, J.M. and Amman, G.D. 1992. *Dendroctonus* beetles and old-growth forests in the Rockies. In: Workshop Proceedings, Old-growth forests in the Southwest and Rocky Mountain regions (Portal, AZ., 9 – 13 March 1992). USDA For. Serv., Gen. Tech. Rpt. RM-213, Fort Collins, CO., pp. 51-59.

Schmid, J.M. and Mata, S.A. 1996. Natural variability of specific forest insect populations and their associated effects in Colorado. USDA For. Serv., Rocky Mountain Forest and Range Experiment Station, Gen. Tech. Rep. RM-GTR-275, 14 pp.

Schmitz, R.F. and Gibson, K.E. 1996. Douglas-fir beetle. USDA For. Serv. Forest Insect and Disease Leaflet 5. 8 p.

Weatherby, J.C. and Thier, R.W. 1993. A preliminary validation of a Douglas-fir beetle hazard rating system, Mountain Home Ranger District, Boise National Forest, 1992. USDA For. Serv., Intermountain Region, For. Pest Manage., Rep. No. R4-93-05. 7 pp.

Wilkinson, L. 1991. SYSTAT: The System for Statistics. Evanston, IL, U.S.A.

Yeager, L.E. and Riordan, L.E. 1953. Effects of beetle-killed timber on range and wildlife in Colorado. In: Conference Proceedings, Trans. 18th North American Wildlife Conference, pp. 596-616.