FOREST HEALTH PROTECTION
USDA Forest Service
State and Private Forestry

OFO-BE-09-02
December 2008

A BIOLOGICAL EVALUATION OF BARK BEETLE ACTIVITY IN THE IRON SPRINGS/GRIFFIN TOP RESOURCE MANAGEMENT PROJECT AREA

DIXIE NATIONAL FOREST
ESCALANTE RANGER DISTRICT

By

Kjerstin R. Skov, Entomologist

State and Private Forestry, Forest Health Protection
Ogden Field Office

A Biological Evaluation of Bark Beetle Activity in the Iron Springs/Griffin Top Resource Management Project Area

Abstract

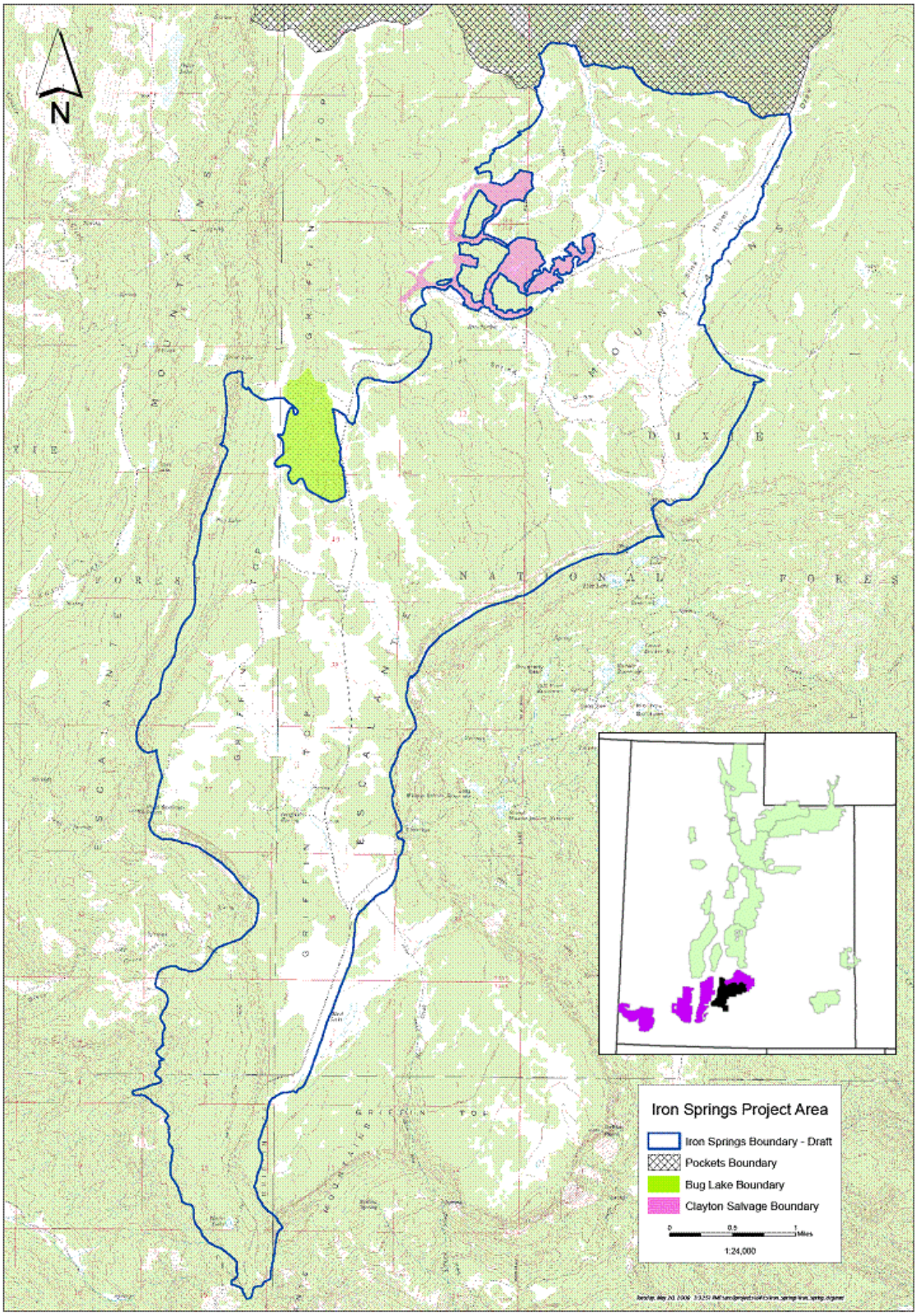
Engelmann spruce mortality due to spruce beetle has been increasing on the Escalante Ranger District and spreading into the Iron Springs/Griffin Top Project Area. This area has also experienced mortality of subalpine fir attributed to the subalpine fir mortality complex. Forest Health Protection personnel from the Ogden Field Office conducted ground surveys of this project area in the summer of 2008 to assess spruce beetle infestation levels and stand susceptibility to spruce beetle-caused mortality. All of the twelve stands in this project area were found to be moderately susceptible to mortality by spruce beetle. Current spruce beetle infestation levels in these stands ranged from no infestation in most stands to outbreak levels in one stand. Silvicultural strategies to reduce stand susceptibility to spruce beetle and to reduce infestation levels are discussed.

Introduction

The Iron Springs/Griffin Top Project Area is located north of Escalante, UT on the Escalante Ranger District (RD) of the Dixie National Forest (NF). The management unit is located on the Aquarius Plateau (approximately 10,000 feet elevation) and is delineated in Figure 1. It includes meadows and forests composed primarily of Engelmann spruce (*Picea engelmanni*), subalpine fir (*Abies lasiocarpa*), and aspen (*Populus tremuloides*).

Recent spruce beetle (*Dendroctonus rufipennis* Kirby, Coleoptera: Curculionidae) outbreaks on the Aquarius Plateau began in the mid 1990's. Acres affected by spruce beetle increased in size and spread from the northwest side of the plateau and the Escalante Mountains south into the project area. Spruce beetle populations have been elevated in the Escalante RD for the last five years according to Aerial Detection Surveys (Figure 2). Aerial Detection Surveys (ADS) are conducted every year by Forest Health Protection specialists. They include estimates of the amount (numbers of trees and acres) and locations of mortality or damage for each tree species. Only tree damage visible from the air is mapped. Bark beetle-caused mortality is mapped using fading foliage as a signature for dead trees which usually occurs in the summer after the year of attack. Engelmann spruce mortality attributed to spruce beetle has been increasing in the Iron Springs/Griffin Top Project Area (Figure 3). ADS results indicate that more than 100,000 Engelmann spruce trees have been killed by spruce beetle on the Escalante RD since 2003 (Figure 4). Additional mortality was mapped in the 2008 survey and also recorded in sites visited during this ground survey. In addition, mortality of subalpine fir attributed to the subalpine fir mortality complex has affected nearly as many acres as the

Figure 1. Project boundary on the Escalante Ranger District of the Dixie National Forest.



spruce beetle (Figure 2). Subalpine fir mortality complex includes mortality attributed to several agents, primarily root diseases and western balsam bark beetle (*Dryocoetes confuses* Swaine, Coleoptera: Scolytidae). Subalpine fir is a significant component of the spruce-fir forest in the Iron Springs/Griffin Top Project Area.

Silvicultural treatments including thinning, sanitation, and salvage have been used since the late 1990's to treat approximately 15,000 forested acres near the Iron Springs/Griffin Top Project Area. Treatments include spruce beetle population monitoring, thinning to reduce long-term stand susceptibility, sanitation treatments to remove infested trees and reduce spruce beetle populations, and salvage. Similar treatments are planned for the Iron Springs/Griffin Top Project Area.

At the request of the Escalante RD of the Dixie NF, Forest Health Protection personnel from the Ogden Field Office surveyed forest stands within the Iron Springs/Griffin Top Resource Management Project Area in July and August 2008. The purpose of these surveys was to assess current levels of spruce beetle activity, current stand conditions, and the susceptibility of stands to further spruce beetle infestation. This biological evaluation includes descriptions of survey methods, results, and discussion of survey results, management alternatives and recommendations to improve forest health.

Figure 2. 2003-2007 Aerial Detection Survey results summarizing acres with tree mortality caused by three agents on the Escalante Ranger District.

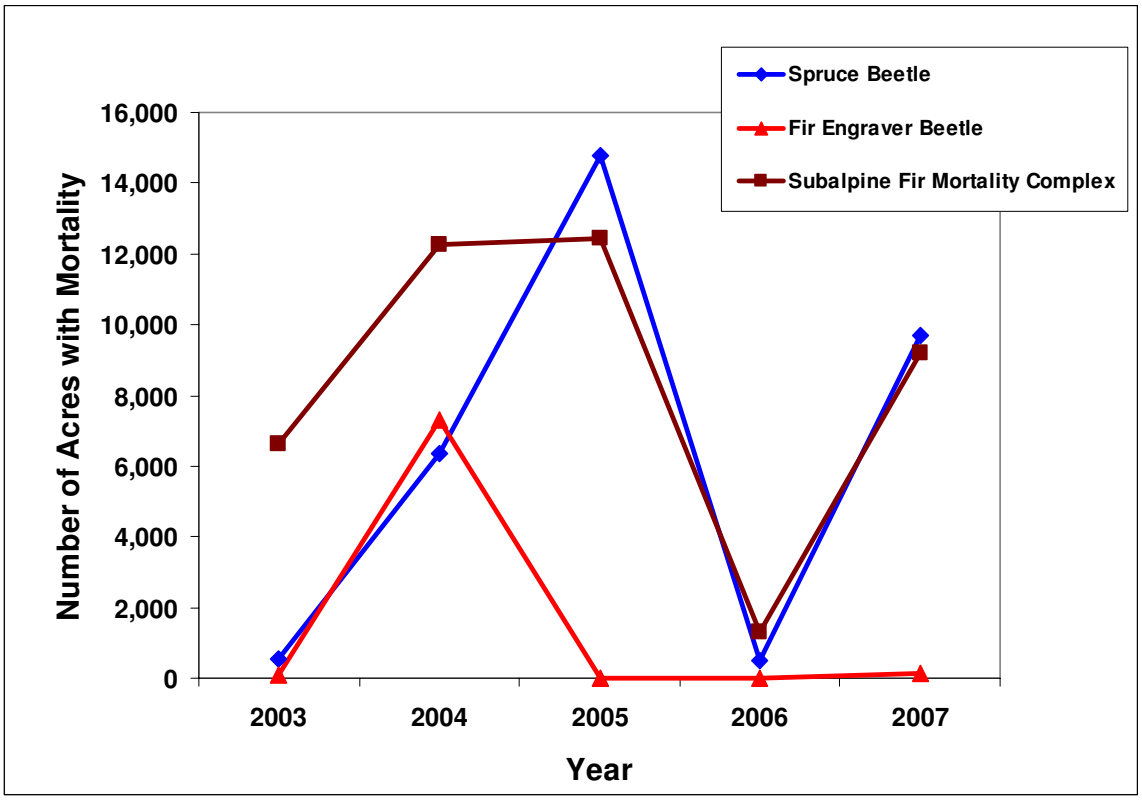
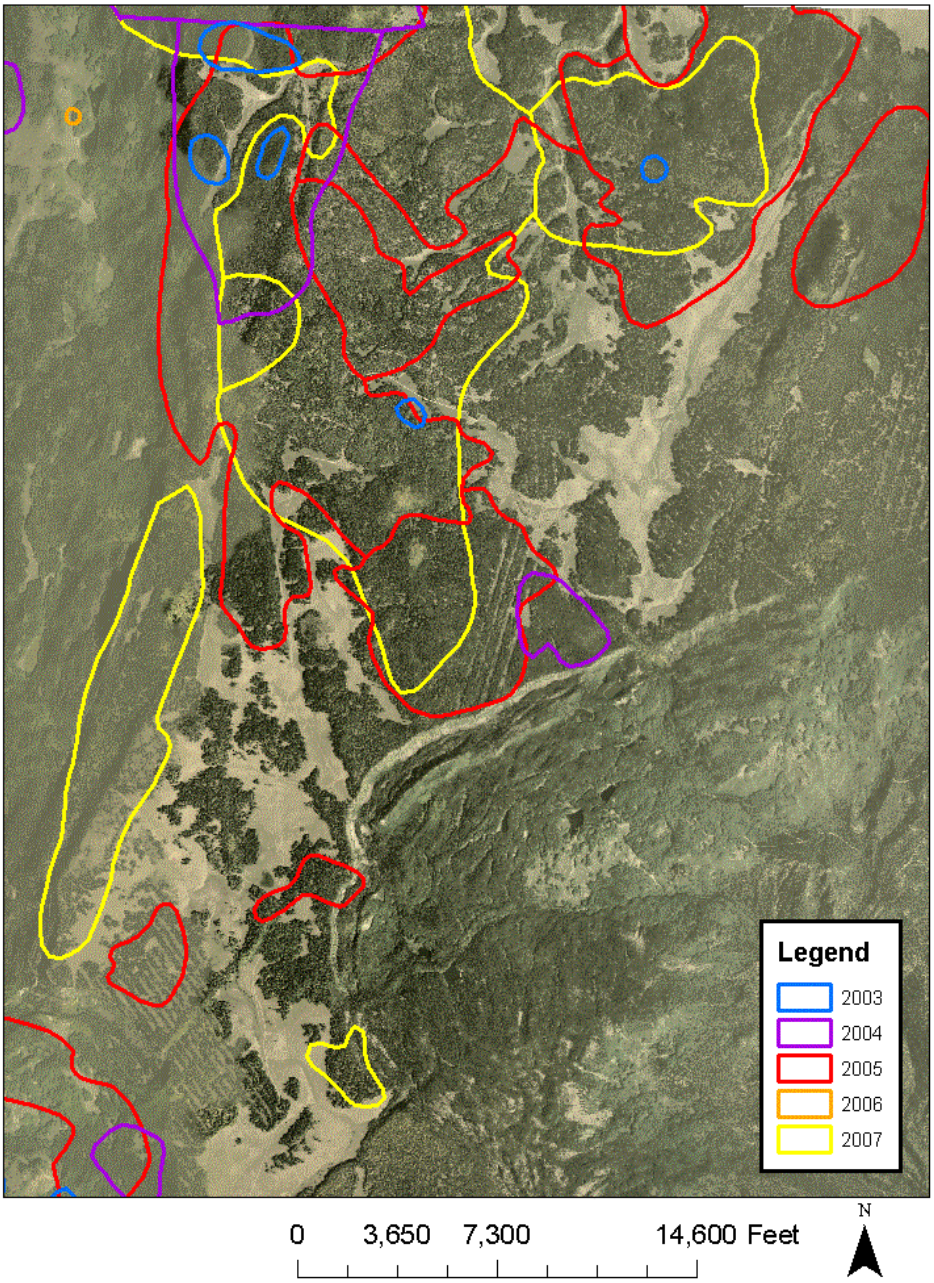


Figure 3. Areas with Engelmann spruce mortality attributed to the spruce beetle, Aerial Detection Survey from 2003 to 2007.



Methods

Plot data for the twelve stands in this project area (Figure 5) was collected by Forest Health Protection personnel in July and August 2008. Forest stands were delimited using aerial photographs. In each stand, variable radius (20 basal area factor) plots were located in a grid pattern with a random start point and ten chains (660 feet) between plots

(with the exception of stand six, which had twenty chains between plots). All plots were at least two chains from the stand boundary. Total numbers of plots varied with stand size (Table 1). Only trees greater than five inches diameter at breast height (4.5 feet above ground, hereafter dbh) were included in the variable radius plots. Plot data included tree species, tree diameter at breast height, tree regeneration (number and species), current mass attacked trees or strip-attacks, previous year mass attacked or strip-attacks, older mortality or strip-attacks, and other damage. Plot regeneration was determined on 1/300th acre fixed radius plots and included tallies of each tree less than five inches dbh by tree species.

Plot data was analyzed using the Forest Insect and Disease Tally (FINDIT) system (Bentz, 2000). FINDIT summarizes stand data and the incidence of insects, pathogens, and other biotic and abiotic influences and provides a stand hazard rating for spruce beetle. The spruce beetle hazard rating in FINDIT is based on the system developed by Schmid and Frye (1976) and is based on the average diameter of live spruce trees, live stand basal area, proportion of live spruce, and the physiographic location of the stand.

Figure 4. Cumulative number of Engelmann spruce trees killed by spruce beetle on the Escalante Ranger District recorded by Aerial Detection survey (2003-2007).

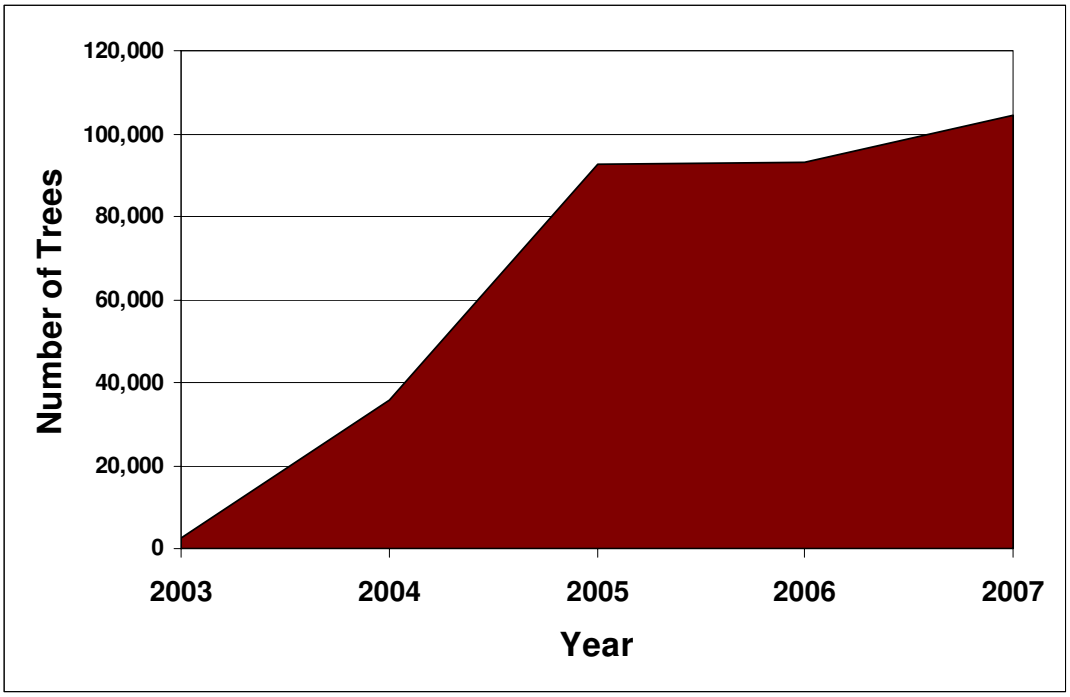


Figure 5. Project boundary and individual stand boundaries used for this biological evaluation.

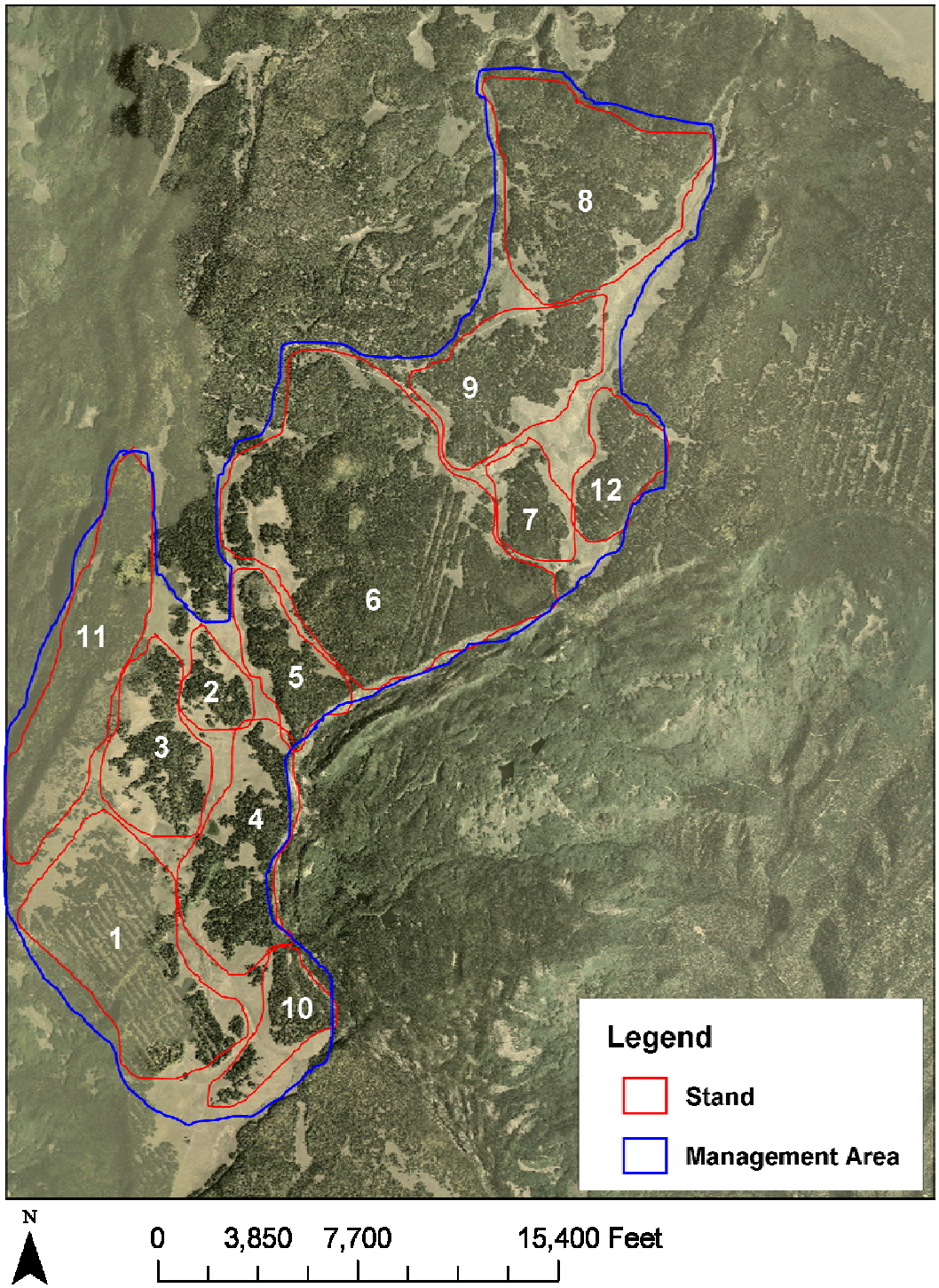


Table 1. Stand conditions of the Iron Springs/Griffin Top Project Area. TPA = trees per acre; BA = total basal area; SE = standard error; QMD = quadratic mean diameter all species; SDI = stand density index; ALSD = average live spruce diameter at breast height (≥10 in.). Calculations for TPA, BA, and QMD include live and dead trees. SDI and ALSD include live trees only.

Stand	Number of Plots	TPA (SE)	% Spruce TPA	BA (SE)	% Spruce BA	Live QMD	Live SDI	ALSD	Hazard Rating
1	50	114.09 (18.9)	79.7	81.6 (11.0)	86.4	9.99	116.64	17.0	Moderate
2	9	70.52 (23.4)	91.4	53.33 (13.3)	89.5	13.85	66.8	18.3	Moderate
3	18	101.89 (24.4)	98.4	82.22 (16.0)	98.4	11.69	98.87	18.6	Moderate
4	15	161.38 (33.7)	51.5	106.67 (17.85)	65.6	10.94	140.92	18.6	Moderate
5	18	155.50 (27.9)	80.7	87.78 (12.9)	80.3	11.56	144.87	17.3	Moderate
6	48	270.04 (28.3)	44.8	144.58 (12.6)	56.7	10.07	193.61	15.9	Moderate
7	11	132.86 (39.4)	43.6	103.64 (24.4)	71.1	9.36	134.37	17.3	Moderate
8	20	271.19 (52.3)	51.8	139.00 (21.5)	55.7	9.38	233.14	14.3	Moderate
9	16	290.13 (37.1)	63.8	171.25 (21.8)	74.6	10.75	248.37	15.5	Moderate
10	8	225.19 (43.0)	72.9	151.43 (24.6)	87.5	11.74	230.90	15.2	Moderate
11	24	69.66 (19.5)	96.5	56.67 (15.1)	95.5	11.71	70.99	18.8	Moderate
12	8	149.74 (34.5)	57.1	97.50 (27.9)	71.9	9.23	137.20	16.8	Moderate

Results

All the stands in the Iron Springs/Griffin Top Project Area were rated as moderately susceptible to spruce beetle (Table 1), primarily due to the large percentage of Engelmann spruce within the surveyed stands (Figure 6) and the large average spruce diameters (Table 1). Most of the spruce beetle-caused tree mortality recorded in these stands was older mortality; however trees infested in 2008 were recorded in four stands in the central part of the project area (Figure 7). Engelmann spruce regeneration was 130-1050 trees per acre (tpa) and averaged 473 tpa. In many stands, regeneration was dominated by subalpine fir and aspen, with the highest levels of regeneration in stands four, six, eight, and nine (Figure 8).

Stand one is composed of 100-200 foot wide strips of trees (Figure 5), which contributed to low stand basal area. Thirty percent of the plots in this stand were located in openings between tree strips and had either no trees or smaller diameter advance regeneration. Nevertheless, this stand received a moderate hazard rating (Table 1). Within the tree strips, 79% of the trees are Engelmann spruce (Figure 6) with an average spruce diameter of 17 inches (Table 1). No current spruce beetle activity was recorded but current spruce beetle infestations were observed in surrounding stands (Figure 7). Englemann spruce, subalpine fir, and aspen regeneration were equally represented (Figure 8). Less than 6% subalpine fir and aspen mortality was recorded in Stand 1 (Figure 9).

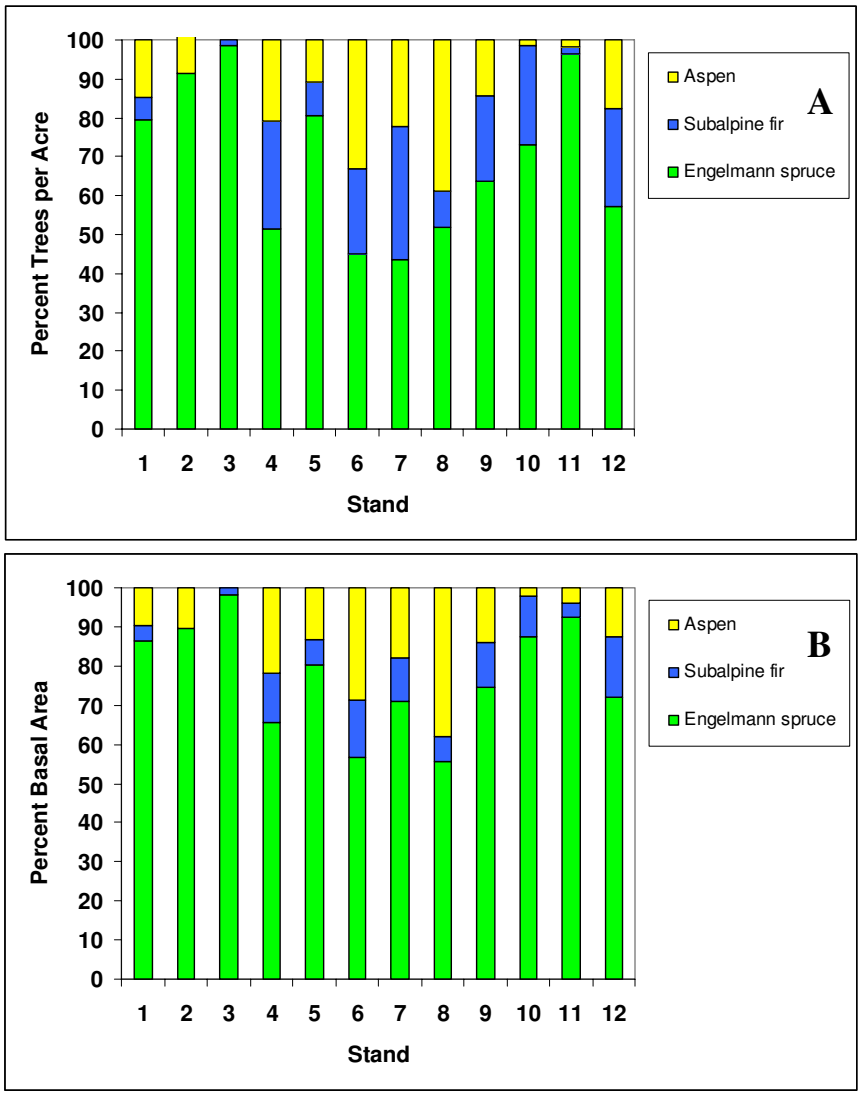
Stand two is one of the smallest stands with the lowest stand density, but has a high proportion of large spruce trees (>91% tpa). Aspen was the only other tree species observed (Figure 6) and most of the regeneration recorded was aspen (Figure 8). No recent or older spruce beetle attacks were recorded in this stand (Figure 7). Stand two had more aspen mortality (23%) than any other stand surveyed (Figure 9).

Stand three is adjacent to stand two and also has stand density more than 82 ft^2/acre composed primarily of large-diameter spruce (Table 1). The only other tree species noted was a small component of subalpine fir (Figure 6) and a small amount of aspen regeneration (Figure 8). More spruce beetle activity was recorded in stand three, but most of this activity was older mass attacks or current and last year strip-attacks (Figure 7). No aspen or subalpine fir mortality was detected in stand three (Figure 9).

Stand four has a basal area greater than 106 ft^2/acre, more than 65% of which is spruce trees. These spruce trees also have a large average diameter, all of which contributes to a moderate hazard rating (Table 1). This stand has a higher percentage (>48%) of subalpine fir and aspen trees per acre in the overstory (Figure 6) and the most subalpine fir and aspen per acre in the understory (Figure 8). Stand four has the highest amount of regeneration. All of the spruce beetle activity recorded in stand four was older mass attacks and strip-attacks (Figure 7).

Stand five is similar to stands one through three in basal area, percent of spruce trees and average live spruce diameter and has a moderate hazard rating (Table 1). It is more than

Figure 6. Tree species composition of twelve stands by percent trees per acre (A) and percent basal area (B).

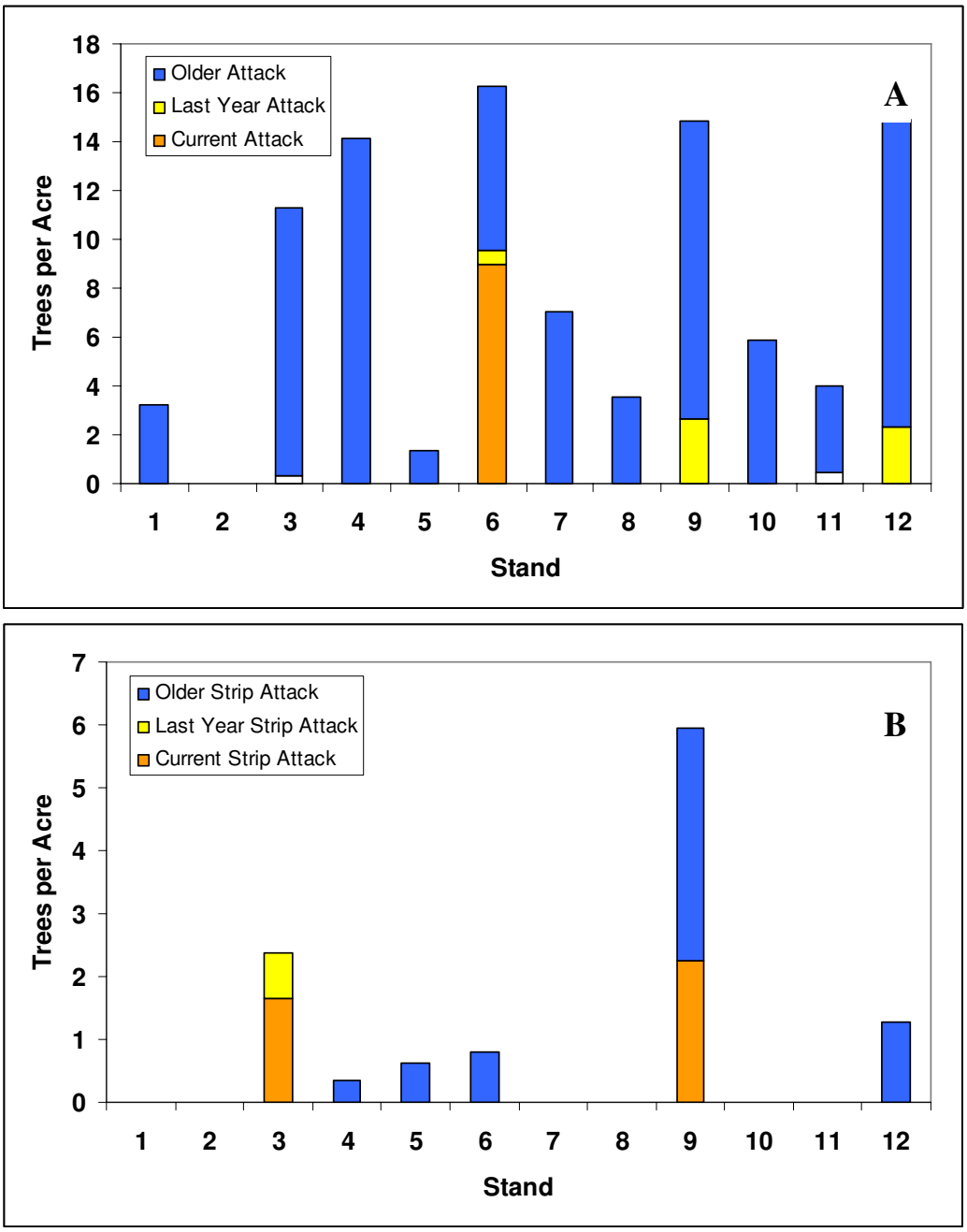


80% Englemann spruce trees with some subalpine fir and aspen in both the overstory (Figure 6) and understory (Figure 8). Less than two trees per acre of spruce beetle activity was observed and all of this activity was older mass attacks and strip attacks (Figure 7).

Stand six has a less than 45% tpa of Engelmann spruce and among the lowest average live spruce diameters (15.9 in dbh). However, stand basal area is more than 144 ft^2/acre and this stand has a moderate hazard rating (Table 1). Stand six has the highest number of infested spruce trees, including more than eight trees per acre with mass attacks in 2008 (Figure 7). Most of the regeneration in stand six is subalpine fir (Figure 8). Stand six had more subalpine fir mortality (>32 tpa) than any other stand (Figure 9).

Stand seven has a high average live spruce diameter, basal area greater than 103 ft^2/acre, and a high proportion of spruce trees (Table 1). Like stands four, six and eight, stand seven has a higher percentage of subalpine fir (>34%) and aspen (>22%) in both the overstory (Figure 6) and understory (Figure 8). All the spruce beetle activity observed in stand seven was older mass attacks (Figure 7). Stand seven had subalpine fir mortality but no observed aspen mortality (Figure 9).

Figure 7. Spruce beetle mass attacks (A) and strip attacks (B) during three time periods: current (2008), last year (2007), and older.



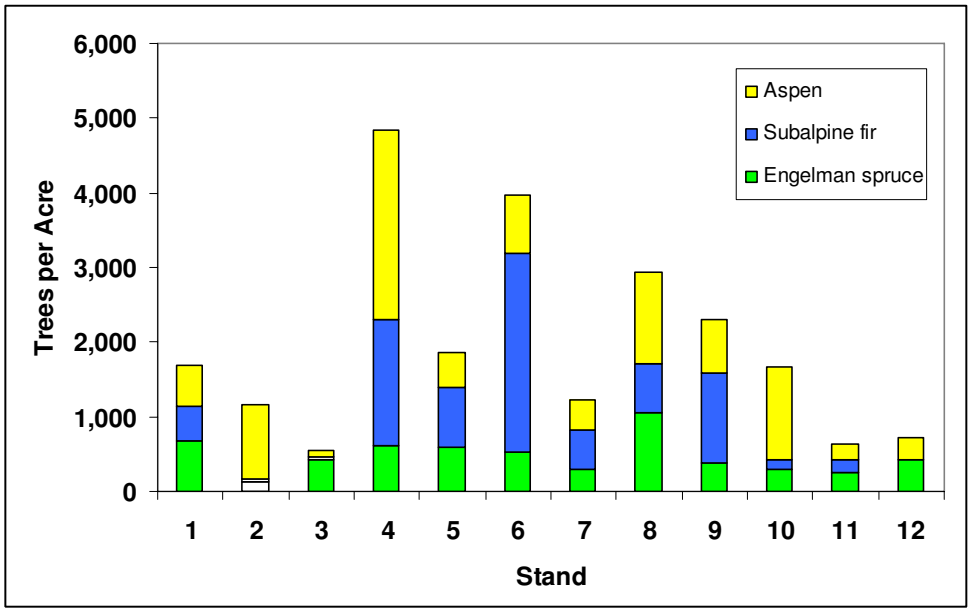
Stand basal area, percentage of spruce, and average spruce diameter were all moderate in stand eight resulting in a moderate hazard rating (Table 1). Stand eight has some subalpine fir and more aspen (Figures 6 and 8) and no current spruce beetle activity (Figure 7). In addition, western spruce budworm (*Choristoneura occidentalis* Freeman) was observed by field crews throughout stand eight. Aerial detection surveys have recorded increasing acres with defoliation by the western spruce budworm on the Escalante RD since 2002, mostly east of the Iron Springs/Griffin Top Project Area.

Stand nine has the highest basal area of all the stands, almost 75% of which is spruce trees (Table 1). However stand nine has among the lowest average live spruce diameters (15.5 inches). Most of the regeneration is subalpine fir (Figure 8), though both subalpine fire and aspen are present (Figure 6). Stand nine had among the highest amount of recorded spruce beetle activity although most of it was older mass attacks and strip-attacks (Figure 7). Almost 15 tpa of subalpine fir mortality but no aspen mortality was observed in stand nine (Figure 9).

Stand ten is similar to stand nine but with a higher proportion of spruce (Table 1). It has the lowest amount of aspen in the overstory (<2%) but most of the regeneration is aspen (Figure 8). The only recorded spruce beetle activity was older mass attacks (Figure 7). More than 10 tpa of subalpine fir mortality was observed in stand ten but no aspen mortality (Figure 9).

Stand eleven is a more open stand along the rim and therefore has a lower stand basal area (<57 ft^2/acre), though most of these trees are Engelmann spruce of large diameter (Table 1). This stand has the lowest amount of subalpine fir and aspen (Figure 6). Stand eleven did have some spruce beetle-infested trees in 2008, though less than one tree per acre (Figure 7).

Figure 8. Trees per acre of regeneration by tree species in twelve stands.



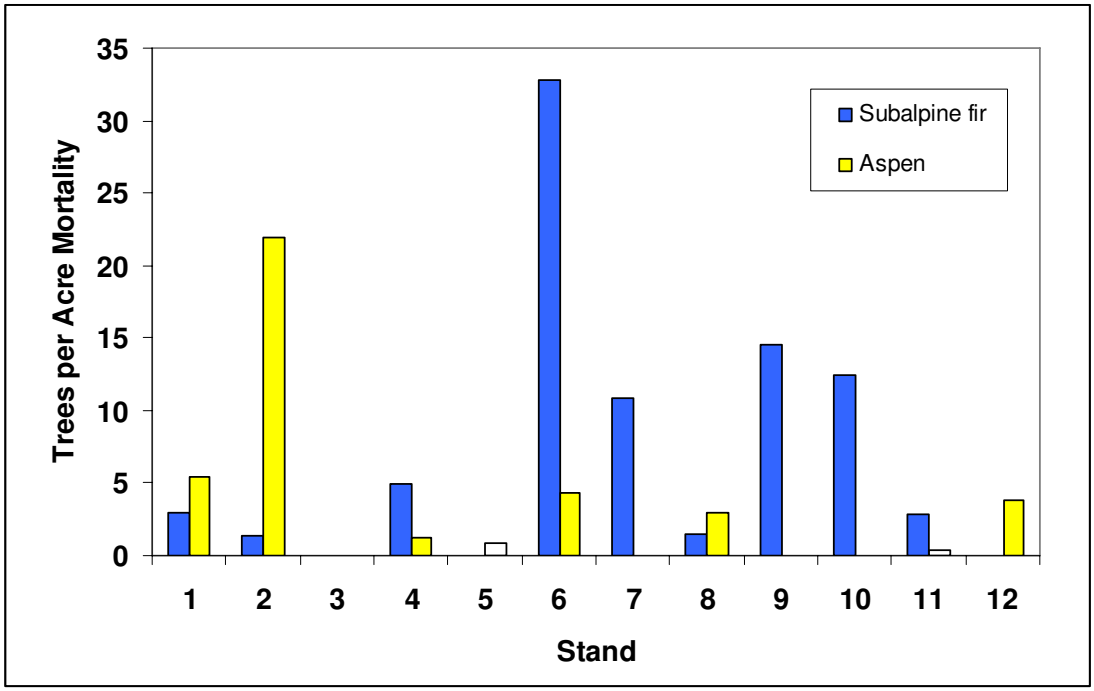
Stand twelve has an average live spruce diameter greater than 16 in dbh, more than 57% tpa are spruce trees, and stand basal area more than 97 ft^2/acre (Table 1). It includes subalpine fir and aspen in the overstory (Figure 6) though no subalpine fir regeneration was detected in the understory (Figure 8). In the past stand twelve had higher spruce beetle mass attacks and strip-attacks, but no spruce beetle activity was recorded in 2008 (Figure 7). Less than five trees per acre of aspen mortality were observed in stand twelve but no subalpine fir mortality (Figure 9).

Discussion

At endemic levels, spruce beetles infest mostly downed host material or large, overmature spruce trees. These trees offer fewer defenses against the spruce beetle and downed material offers predator-free space and snow insulation from cold winter temperatures (Schmid 1981). Endemic-level spruce beetle populations open canopy gaps and increase stand structural diversity (Veblen et al 1991, Samman and Logan 2000). In addition, they facilitate colonization of dead or downed wood by decomposers including invertebrates and microorganisms (Maser and Trappe 1984, Solheim 1995, Hanula 1996).

Aerial detection survey estimates of spruce beetle-caused tree mortality in and around the Iron Springs/Griffin Top Project Area have shown outbreak population levels of spruce beetle for most of the last five years. Outbreak levels have been defined as two or more clumps of at least five infested trees for every five acres (Bentz and Munson 2000).

Figure 9. Subalpine fir and aspen tree mortality per acre for the twelve stands in the project area.



The heaviest mortality has been concentrated along the northwest side of the project area and to the north of the project area. However, increasing amounts of mortality within the project area have been mapped in the most recent aerial surveys. In addition, the size of the areas with mortality has been increasing from small pockets to very large areas of infestation (Figure 3). The results of this on-the-ground survey indicate that at least portions of stand six have outbreak levels of spruce beetle-infested trees. However spruce beetle were also active in stands three, nine and eleven. All of these stands are along the northwestern edge of the project area where most of the past mortality was mapped by Aerial Detection Survey.

Several factors may contribute to the transition of spruce beetle populations from endemic to epidemic or outbreak levels. An abundance of host material with little or no defenses due to logging activities, avalanche, blowdown, or drought may allow populations to grow quickly to levels that can kill stronger trees (Wygant and Lejeune 1967, McCambridge and Knight 1972, Holsten et al 1999, Hebertson and Jenkins 2008). Hansen et al (2001) predict that periods of elevated temperatures may contribute to spruce beetle population growth by decreasing development time in a greater portion of the spruce beetle population. Finally, the availability of forest stands susceptible to spruce beetle provide host material in which the beetle populations can grow and spread (Holsten et al 1999). Characteristics of susceptible stands include high proportions of large-diameter spruce trees in stands with high basal area (Schmid and Frye 1976).

Periodic outbreaks are a natural part of spruce beetle population dynamics (Schmid and Frye 1977). At outbreak levels, spruce beetle may kill most of the large spruce trees across a landscape and can have many important impacts (Holsten et al 1999). Stand characteristics including tree species composition, size-class distribution, and regeneration will be altered (Veblen et al 1991, Lexer and Hönninger 1998). Fuel loading will transition from a short-term abundance of fine fuels to an eventual increase in downed woody material (Knight 1987, Jenkins et al 2008). Watershed hydrology will be altered and resource uses by wildlife, recreationalists, and timber may be impacted (Potts 1984, Goyer et al 1998, Murphy and Lehnhausen 1998).

The spruce beetle populations in this project area are finding stands that are moderately susceptible to infestation. The large average diameter and relatively high percentages of Engelmann spruce trees in these stands contribute the most toward the moderate hazard rating. However higher stand basal areas, particularly in stands nine and ten, also serve to increase stand susceptibility. Because these stands still contain many large, live Engelmann spruce trees, locally high spruce beetle populations may continue to spread into the project area and cause further mortality of Engelmann spruce trees.

The principal emphasis of this survey was to evaluate these stands for activity by and susceptibility to the spruce beetle. However, subalpine fir and aspen make up a significant component of many of these stands. We observed mortality of these trees at levels similar to those observed in Engelmann spruce trees. Almost all of this mortality was coded to be of unknown origin, but much of that in the subalpine fir is mapped as Subalpine Fir Mortality Complex by Aerial Detection Survey. These tree species

dominate the regeneration observed in most of these stands though, so these dying trees are being replaced naturally.

Western spruce budworm was observed within the project area during this survey and outside the project area by Aerial Detection Survey. Western spruce budworm may be moving into the project area from adjacent forested areas. Host trees include Douglas-fir, all true firs, spruce, western larch and sometimes pines. This defoliator can cause significant defoliation, reduction of seeds and cones, loss of growth, and even tree mortality (Alfaro 1982, Fellin and Dewey 1982, Swetnam 1986). It may also predispose some trees to subsequent attack by bark beetles (Lessard and Schmid 1990, Schmid and Mata 1996). The Iron Springs/Griffin Top project area primarily contains host trees (spruce and fir) of the western spruce budworm. Forest treatments that enhance tree vigor, increase spacing between trees, and encourage growth of non-host tree species can reduce the spread of and damage caused by western spruce budworm.

Recommendations

Spruce beetle management strategies include prevention, suppression, and techniques. Prevention strategies alter stand conditions to lower stand susceptibility to bark beetles. Suppression strategies target the building bark beetle population to reduce its numbers and spread. Restoration techniques help to re-establish desired stand conditions after bark beetle-caused mortality.

Prevention treatments alter the factors that contribute to stand susceptibility including basal area, proportion of spruce trees, and average live diameter of spruce and may slow or prevent the spread of bark beetles (Holsten et al 1999). All of the stands in the Iron Springs/Griffin Top Resource Management Project Area were rated as moderately susceptible. Almost all (except stand six) had high proportions of spruce, most had high average live spruce diameters, and half had high stand basal areas (Table 1). We recommend thinning stands to less than 100 ft^2/acre (preferably 80 ft^2 per acre). Stands four, six, seven, eight, nine, and ten have basal areas >100 ft^2/acre. We also recommend reducing the proportion of live spruce in each stand to less than 65%. Every stand except stands six and eight have >65% spruce. Finally, every stand has average live spruce diameter greater than twelve inches dbh and trees should be removed such that the average live spruce diameter is twelve inches dbh (Schmid and Frye 1976).

Several factors may compromise thinning treatment efficacy include mitigation measures such as leaving dense clumps of trees for wildlife, road buffers, or riparian corridors. Additionally, avoid thinning activities during spruce beetle flight (May-June) to reduce the likelihood of infestation in green slash or cull material. Post-thinning activities should include treating any host material that can be infested by spruce beetle including slash greater than ten inches in diameter, stumps more than twelve inches tall, or trees scorched by slash burning.

Sanitation/salvage treatments may be a useful short-term suppression tool in those stands with current spruce beetle infestations such as stands three, six, nine, and eleven. These treatments remove currently infested and potential host trees (sanitation) as well as dead trees (salvage). Removal of live insects in infested trees reduces local populations of the spruce beetle. Sanitation treatments alone however, will not necessarily impact long-term stand susceptibility if they do not significantly impact stocking levels or the percentage of large, live spruce trees to desired levels. Therefore, sanitation treatments may require several years of repeated treatments or associated prevention treatments. Many of the stands in the Iron Springs/Griffin Top Project Area (particularly stands three, four, six, nine, and twelve) have older dead material and salvage treatments would enable the Forest to recoup economic value from these stands.

Other short-term suppression techniques include trap trees (felled or baited). Trap trees are large spruce trees (more than sixteen inches dbh) that attract spruce beetle infestation because they have been either felled or baited with the aggregation pheromone of the spruce beetle. Trap trees should be treated at the beginning of the spruce beetle flight period and used for more isolated spruce beetle populations such as stands three and eleven. In these stands, fell one trap tree for every two to three infested trees, depending on the relative diameters of the infested and the trap trees. Larger diameter trap trees can absorb more beetles (Nagel et al 1957). Felled trees should be in a cool, moist location, preferably away from susceptible host trees or stands. Baited trees should be in clusters near active spruce beetle populations. Trap trees, especially those that are baited, may result in spillover attacks to adjacent spruce trees. These trees and the baited trees must be removed or debarked such that the infesting spruce beetles are killed in the *same year* as the beetle attack. We recommend complete removal of infested trees, perhaps in conjunction with other thinning activities.

Thinning treatments may impact the subalpine fir and aspen in these stands as well as regeneration. Subalpine fir mortality complex has been mapped and unidentified subalpine fir mortality has been recorded in these stands, particularly stands six, seven, nine, and ten. Root diseases commonly contribute to subalpine fir mortality in spruce-fir stands and increase fir vulnerability to blowdown. Any thinning treatments in these stands, but particularly in those stands with higher subalpine fir mortality, may increase the likelihood of blowdown. Prevention treatments in these stands may require repeated entry to mitigate this threat. Thinning treatments may also decrease the amount of regeneration present in these stands and may necessitate supplemental planting.

We recommend prioritizing treatment in those stands with current spruce beetle infestations using a combination of sanitation/salvage treatments to reduce current infestation levels and prevention treatments to reduce stand susceptibility to future infestations. Stands without current infestations may then be treated to reduce stand susceptibility as outline above. Post-treatment monitoring should be conducted annually in all stands to identify and remove newly infested and windthrown spruce trees.

Conclusions

Mortality of Engelmann spruce trees due to spruce beetle has been increasing in and around this project area for the last several years and thousands of trees have already been killed on the Escalante RD. Spruce beetle in most of the Iron Springs/Griffin Top Project Area is still below outbreak levels at this time. All of the stands in the project area are moderately susceptible to spruce beetle-caused mortality and may loose additional large diameter spruce in the future. Silvicultural treatments to reduce stand susceptibility and to remove beetles currently infesting these stands may minimize these future losses. These treatments will facilitate and may benefit from similar, on-going treatment efforts in adjacent forested areas.

Literature Cited

Alfaro, R. I. 1982. Tree mortality and radial growth losses caused by the western spruce budworm in a Douglas-fir stand in British Columbia. Canadian Journal of Forest Research 12 (4): 780-787.

Bentz BJ. 2000. FINDIT, Forest Insect and Disease Tally system. USDA Forest Service, Rocky Mountain Research Station. Logan, UT pp. 17.

Bentz, B. J. and Munson,A. S. 2000. Spruce beetle population suppression in Northern Utah. Western Journal of Applied Forestry 15:122–128.

Fellin, D. G. and Dewey, J. F. 1982. Western spruce budworm. USDA Forest Service Forest Insect and Disease Leaflet No. 53

Goyer RA, Wagner MR, Schowalter TD. 1998. Current and Proposed Technologies for bark beetle management. *Journal of Forestry* 96(12): 29-33

Hanula, J.L. 1996. Relationship of wood-feeding insects and coarse woody debris. pp. 55-8 1. In: J. W. McMinn and D.A. Crossley Jr. (Eds.), Biodiversity and coarse woody debris in southern forests. USDA For. Serv., Gen. Tech. Report. SE-94.

Holsten EH, Their RW, Munson AS, Gibson KE. 1999. The spruce beetle. USDA Forest Service Forest Insect and Disease Leaflet No. 127

Jenkins, M. J., Hebertson, E., Page, W. and Jorgensen, C. A. 2008. Bark beetles, fuels, fires and implications for forest management in the Intermountain West. Forest Ecology and Management 254 (1): 16-34.

Knight, D. H. 1987. Parasites, lightning, and the vegetation mosaic in wilderness landscapes. Pages 59-83 in M. G. Turner, editor. Landscape heterogeneity and disturbance. Springer-Verlag, New York, New York, USA.

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

Lexer, M. J. and Hönninger, K. 1998. Simulated effects of bark beetle infestations on stand dynamics in *Picea abies* stands; coupling a patch model and a stand risk model. *In* The Impacts of Climate Variability on Forests, M. Beniston and J. L. Innes Eds. Lecture Notes in Earth Sciences 74: 289-308.

Maser C. and Trappe J.M. 1984. The seen and unseen world of the fallen tree. USDA Forest Service Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-164

McCambridge, W. F. and Knight, F. B. 1972. Factors affecting spruce beetles during a small outbreak. Ecology 53: 830-839.

Murphy, E.C. and Lehnhausen, W. A. 1998. Density and foraging ecology of woodpeckers following a stand-replacement fire. Journal of Wildlife Management 62 (4): 1359-1372.

Nagel, R. H., McComb, D., and Knight, F. B. 1957. Trap tree method for controlling the Engelmann spruce beetle in Colorado. Journal of Forestry 55: 894-898.

Potts, D. F. 1984. Hydrologic impacts of a large-scale mountain pine beetle (Dendroctonus ponderosae Hopkins) epidemic. Journal of the American Water Resources Association 20 (3): 373-377.

Samman S, Logan J. 2000. Assessment and response to bark beetle outbreaks in the Rocky Mountain area. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-62.

Schmid JM. 1981. Spruce beetles in blowdown. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Resource Note RM-411.

Schmid JM and Frye RH. 1976. Stand ratings for spruce beetles. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Research Note RM-309

Schmid JM and Frye RH. 1977. Spruce beetle in the Rockies. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-49

Schmid, J. M. and Mata, S. A. 1996. Natural variability of specific insect populations and their associated effects in Colorado. USDA Forest Service General Technical Report

RM-275. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 14 pp.

Solheim, H. 1995. A comparison of bluestain fungi associated with the North America spruce beetle *Dendroctonus rufipennis* and the Eurasian spruce bark beetle *Ips typographus*. Aktuelt fra Skogforsk 4: 61-67.

Swetnam, T. W. 1986. Radial growth losses in Douglas-fir and white fir caused by western spruce budworm in northern New Mexico: 1700-1983. USDA Forest Service Southwest Regional Forest Pest Management Report 86-2.

Veblen TT, KS Hadley, MS Reid, AJ Rebertus. 1991. The response of subalpine forests to spruce beetle outbreak in Colorado *Ecology* 72:213-231.

Wygant, N. D.; Lejeune, R. R. 1967. Englemann spruce beetle *Dendroctonus obesus* (Mann)(=*D. engelmanni* Hopk.). *In* Important forest insects and diseases of mutual concern to Canada, the United States and Mexico. Canadian Department of Forest and Rural Development, Publ. No. 1180. Ottawa. 248 p.