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A BIOLOGICAL EVALUATION OF FOREST HEALTH IN THE THUNDER RIDGE PROJECT AREA

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By

Elizabeth G. Hebertson, Forest Health Protection Specialist

S&PF Forest Health Protection, Ogden Field Office

Abstract

During the month of September, 2009, the USDA Forest Service, Forest Health Protection, Ogden Field Office (FHP-OFO) surveyed mixed conifer and aspen stands in the Thunder Ridge project area to assess general forest health conditions. Bark beetles have caused significant conifer mortality on the Markagunt Plateau since the mid 1900's. In the mid 2000's, populations of Douglas-fir beetles and fir engravers reached peak levels. The results of this survey indicate that Douglas-fir beetle-caused tree mortality in the Thunder Ridge project area was significant. In stands where large Douglas-fir was a major component, beetles killed 56% to 100% of trees. Significant losses of white fir were not observed. Several stands experienced large amounts (>50%) of subalpine fir mortality although the primary cause of death was undetermined. Water stress induced by drought and competition may have contributed to tree death and/or predisposed trees to other damaging agents. Few current bark beetle attacks were observed indicating that bark beetle populations have returned to endemic levels. Stands generally had low to moderate susceptibility to bark beetle infestation. Light infections of dwarf mistletoe were common in ponderosa, limber, and bristlecone pine components. Little tree mortality or damage was associated with other insects or diseases suggesting that populations of these agents exist at endemic levels. The aspen component in many stands was in poor health. Tree mortality, branch dieback, sparse foliage, the presence of canker diseases, and lack of regeneration were all indicative of aspen decline. The significant amount of tree mortality can contribute to fuel loads. Immediate measures should be taken to reduce the potential for hazardous fuels accumulations near high value recreation sites. Dead trees that pose a hazard should also be removed. The potential for further aspen loss, particularly in the vicinity of Camp Thunder, warrants implementing treatments to rejuvenate stands within the next two to five years. Other general recommendations for the Thunder Ridge project area include monitoring stands annually for increases in insect and disease activity and updating the vegetation management plan to incorporate revised strategies for maintaining short and long-term forest health.

Background

Since the mid 1990's, bark beetles in the genera *Dendroctonus*, *Ips*, and *Scolytus* (Coleoptera: Curculionidae, Scolytinae) have caused significant tree mortality on the Markagunt Plateau. A major spruce beetle (*D. rufipennis* Kirby) outbreak contributed to the majority of annual tree mortality until about 2005 when suitable host resources were finally exhausted. This outbreak resulted in the loss of over 90% percent of mature Engelmann spruce. In the early 2000's, drought triggered outbreaks of both pinyon engravers (*I. confusus* LeConte) and fir engravers (*S. ventralis* LeConte) with these species killing approximately 70,000 and 50,000 trees, respectively, during 2003 and 2004. Tree mortality caused by Douglas-fir beetles (*D. pseudotsugae* Hopkins) also began to rise during this time and reached peak levels in 2004 when 8,700 trees were killed. A large percentage of Douglas-fir beetle and fir engraver-caused tree mortality was detected in the vicinity of Parowan Canyon on lands administered by the Bureau of Land Management (BLM), Cedar City Field Office (CCFO).

In response to these outbreaks and other forest health issues, Doug Page, Silviculturist, CCFO, requested assistance from the Forest Health Protection, Ogden Field Office (FHP-OFO) to complete a forest health evaluation for the Thunder Ridge project area. This project area is located on the Markagunt Plateau approximately eight miles up Parowan Canyon (Highway 143)

in southwestern Utah. The Boy Scouts of America (BSA) presently own the land, however, the Bureau of Land Management (BLM) still retains all timber rights. Camp Thunder is located on the property and provides recreational opportunities for a number of users including the Boy Scouts, church groups, and family groups. Both the BLM and BSA have the common goal of managing forest health to satisfy multiple resource values including recreation, wildlife, and timber. High levels of tree mortality associated with insects and diseases, animal and human damage, and abiotic agents would potentially conflict with these important resource values.

The FHP-OFO conducted ground surveys within the project area in September, 2009, to document forest insect and diseases and to assess stand level susceptibility to these agents. This report first provides a general overview of the project area and discusses the important damaging agents of forest types on the Markagunt Plateau (*see also Appendices 3 and 4). The methods used to survey forest vegetation within the project area are described next followed by a discussion of survey results. Finally, recommendations and management alternatives for reducing potential damage due to insects and diseases and improving forest health are discussed.

General Description of the Project Area

The Thunder Ridge project area covers approximately 1,343 acres and is comprised of 25 stands that range from one to 156 acres in size (Appendix 1). Elevations range from about 8,300 in Parowan Canyon up to 9,435 feet. The topography is variable with relatively rolling terrain on top of the plateau and broad ridgebacks bounded by steep canyons. The climate is typically arid with annual precipitation ranging from eight to eighteen inches.

Most of the land is densely forested and cover types are highly diverse. Douglas-fir, (*Pseudotsuga menziesii* var. *glauca*) often mixed with white fir (*Abies concolor*), occurs on northerly aspects at mid elevations. Stands of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) that are variously mixed with aspen (*Populus tremuloides*) occur at upper elevations. In more mesic locations, stands of trees are often interspersed with small meadows. Less productive sites such as those on south through west-facing slopes and ridgebacks are typically dry with rocky, shallow soils and are sparsely vegetated by ponderosa pine (*Pinus ponderosa*), limber pine (*Pinus flexilis*), Great Basin bristlecone pine (*Pinus longaeva*) and greenleaf manzanita (*Arctostaphylos patua*) (Figure1).

Figure 1. A sparsely vegetated ridgeback.

Bark Beetles

Bark beetle species complete their life cycles within the inner bark of host trees. Both adult and larval stages feed within phloem and to a lesser extent xylem tissues. Feeding damage, in addition to the growth of blue stain fungi introduced during colonization, disrupts the transport of water and nutrients throughout the tree causing death.

Ponderosa Pine

In southern Utah, a complex of *Dendroctonus* bark beetles including the mountain pine beetle (*D. ponderosae* Hopkins), the roundheaded pine beetle (*D. adjunctus* Blandford), and the western pine beetle (*D. brevicomis* LeConte) typically cause ponderosa pine mortality. Ponderosa pine stands most susceptible to mountain pine and western pine beetle infestation are dense (>120 ft^2/ac), even-aged and comprised of more than 50% pines with average diameters exceeding 10 inches diameter at breast height (dbh) (Steele et al. 1996). Roundheaded pine beetle infestations have been associated with slow tree growth resulting from high stocking conditions and drought (Negrón et al. 2000).

When *Dendroctonus* beetle populations are low, they infest weakened and injured trees. During outbreaks, however, tree mortality can occur over extensive areas. Endemic populations often develop into epidemics in unmanaged forests (McGregor and Cole 1985). During outbreaks, beetles infest the older, large diameter trees first, and eventually kill smaller trees as populations build (McGregor and Cole 1985). Epidemics usually collapse with the loss of all or most large trees.

Species of engraver beetles including *Ips pini* (Say), *Ips lecontei* (Swaine), *Ips knausi* (Swaine) can also cause significant ponderosa pine mortality (Steed 2005). Pine engraver populations may erupt during periods of drought or following stand disturbances such as blowdown, fire, or management activities. These insects are particularly attracted to host volatiles and green slash created during tree removal. Outbreaks of *Ips* bark beetles in standing, healthy trees, however, are typically sporadic and of short duration. Engraver bark beetles are usually secondary species found in weakened or damaged trees, or associated with tree-killing insect species. Most *Ips* species focus their attacks on smaller diameter pine or the tops of large diameter trees (Furniss and Carolin 1980, Kolb et al. 2006).

The adults of *Dendroctonus* bark beetle species generally disperse in July-August. Female beetles initiate attacks followed by males and other females. Evidence of successfully attacked trees include pitch tubes mixed with boring dust, and reddish, dry boring dust (similar to fine sawdust) found in bark crevices and at the base of attacked trees. Mountain pine beetles and roundheaded bark beetles construct characteristic “J-shaped” egg galleries within the phloem (inner bark tissue) of the host tree. The egg galleries of western pine beetles are typically more serpentine. Galleries can be over 30” in length and are packed with boring dust. Females deposit eggs in niches along the sides of each gallery. Brood development generally takes one year to complete. After eggs hatch (August-September), larvae mine horizontally away from the main egg gallery. Older larvae overwinter within the inner bark and resume maturation feeding through the late spring. Pupation occurs in chambers constructed at the end of larval mines. Brood adults feed briefly before tunneling to the bark surface to emerge. The spring following

attack, trees will fade to a yellowish color then turn reddish-orange, and eventually reddish-brown. Trees will begin to lose needles the second year following attack. Most trees lose all needles three years after attack (Coulson and Witter 1984).

Like *Dendroctonus* beetles, *Ips* beetles inhabit the inner bark tissues of host trees and cause damage by disrupting the transport of water and nutrients. The life cycles of *Ips* beetles, however, generally last from six to eight weeks and thus five generations of beetles may be produced in one season depending on the climate, elevation, and species. With more than one population in a given area, the generations may overlap. Consequently, beetles may attack host trees throughout the season. Normally, in Utah, *Ips* beetles will generally begin attacking host trees in mid-April.

Ips beetles are attracted to trees that are under stress. They prefer to attack trunks or branches that are one to four inches in diameter, but might also attack larger diameter material. *Ips* populations often build in fresh green material including pruned branches and wind snapped or downed trees. Populations may also build in groups of small diameter stressed trees. Once populations are sufficiently large, they can attack and kill healthy trees. Beetles will usually initiate attacks at the tops of larger trees or individual branches.

When a beetle chews through the bark it produces red or orange boring dust. Successfully attacked trees will generally have this boring dust in bark crevices and/or around the base of the tree. Needles on branches or trees killed by the beetle will generally turn yellow or light green, in spruce; and yellow to red in pines, within a year of attack.

Douglas-Fir

The Douglas-fir beetle is a native insect that infests and kills Douglas-fir. Endemic populations of beetles typically infest downed host material including wind thrown trees, logging slash and avalanche debris (Stark 1993, Jenkins 1990, Fredricks and Jenkins 1988, Coulson and Witter 1984). Beetles will infest host material down to 8 inches in diameter provided the material is not too dry. Douglas-fir beetles will produce three times more brood in downed host material as in standing live trees. Populations have been known to reach outbreak levels following disturbances that produce an abundance of fresh host material (Hadley and Veblen 1993, Lejeune et al. 1961).

Beetles sometimes attack trees injured by fire, defoliation, and root disease (Jenkins 1990, Fredricks and Jenkins 1988, Furniss 1965). Outbreaks also appear to coincide with drought. Stressed trees lack the ability to exude sufficient pitch to push attacking beetles out. Mortality centers may be confined to small groups of trees, but during intense outbreaks, beetles may kill groups exceeding 100 trees (Schmitz and Gibson 1996). In the early stages of infestation, beetles attack trees over 12 inches diameter at breast height (Amman and Ryan 1991). Larger diameter trees have thicker phloem necessary for greater reproductive success (Amman and Ryan 1991). Only during epidemics do beetles attack smaller diameter trees.

The Douglas-fir beetle typically completes one generation per year. Adult beetles fly and attack trees from mid-April to June depending on climatic conditions. Upon successful attack, female beetles construct egg galleries approximately 5-12 inches long that run parallel to the wood.

Eggs are laid in masses alternately along opposite sides of the gallery. The eggs hatch 1-3 weeks later, and the larvae feed on inner bark tissues creating mines that run perpendicular to the egg gallery. Larval development occurs in four stages. At the end of the final stage, larvae construct chambers for pupation and emerge as adults the following season. Some early attacking adults can re-emerge in the summer and attack a second time. All broods mature and emerge approximately one year later (Furniss and Carolin 1980). Damage and mortality occurs as a result of larval mining that girdles the tree.

Engelmann Spruce

The spruce beetle is the most important biotic disturbance agent affecting post-fire, spruce-fir forests in the intermountain region (Jenkins et al. 1998, Veblen et al. 1994). Engelmann spruce serves as the principle host for spruce beetles, although they also attack Colorado blue spruce (*Picea pungens*). During epidemics spruce beetles may also attack lodgepole pine (*Pinus contorta*) and subalpine fir (Schmid and Frye 1977, Miller 1970).

Spruce beetles typically infest downed host material, which lacks the ability to pitch out attacking beetles. Snow cover over host material also acts as an insulator that protects beetles from lethally cold winter temperatures and from predation by woodpeckers (Schmid 1981). Endemic populations may attack large, overmature spruce, killing trees individually or in small groups creating canopy gaps (Veblen et al. 1991). Local populations can build to epidemic levels following logging activities, blowdown, and avalanche disturbances that create an abundance of suitable host material (Jenkins et al. 1998, Schmid and Frye 1977). As competition for food intensifies, beetles may then attack standing live trees.

Depending on climate and elevation, spruce beetle flight begins in the late spring. Pioneering female beetles locate suitable host trees and bore into the inner bark. These females emit aggregation pheromones that attract other females and males to the host tree. Once mated, females begin to construct relatively short, vertical egg galleries and deposit eggs in niches along alternate sides of the gallery. Eggs are generally oblong, pearly white and up to 1 mm long. Incubation lasts 3-4 weeks before an egg hatches into a stout, white legless larva with a prominent rust-colored head capsule. Larvae feed in the phloem creating mines perpendicular to the egg gallery. Larval feeding effectively girdles the tree eventually causing death (Schmid and Frye 1977).

In intermountain forests the spruce beetle life cycle typically lasts two years (Furniss and Carolin 1980). The larvae of two-year beetles develop up to the fourth instar before overwintering. Larvae generally resume development the following spring with pupation occurring in the early summer. Callow adults (sexually immature) overwinter in their pupal chambers, or at the base of the host tree. Spruce beetles reach maturity prior to flight the following spring and emerge to attack fresh host material. New adults are dark brown to black with reddish brown wing covers and will turn uniformily black with age.

Seasonal temperatures appear to have an important role in the timing and length of spruce beetle development. Spruce beetle larvae may mature in one year during exceptionally long, warm periods following peak flight (Hansen et al. 2001, Schmid and Frye 1977, Dyer 1969). A high

proportion of one-year beetles can greatly influence local population trends becoming an important factor in determining spruce beetle risk (Hansen et al. 2001).

Subalpine Fir

Extensive subalpine fir mortality in the intermountain region has been attributed to a complex of associated agents including, primarily, root diseases and the western balsam bark beetle (*Dryocoetes confusus* Swaine). The western balsam bark beetle is found throughout the range of subalpine fir and may act as a primary tree killer. Low populations of western balsam bark beetle typically infest trees weakened by old age, diseased trees and downed host material (Furniss and Carolin 1980). In western states, Tomentosus (*Inonotus tomentosus*), Armillaria (*Armillaria ostoyae*), and Annosum (*Heterobasidion annosum*) root diseases often contribute to windthrow that allows populations of western balsam bark beetle to build (Gibson et al. 1997). Western balsam bark beetles may emerge from infested material and attack nearby standing trees or trees stressed by root disease. Infested stands may experience rapid and extensive subalpine fir mortality during periods of drought. Introduction of the blue-staining fungus, *Ceratocystis dryocoetidis* may also contribute to tree mortality. Bole lesions caused by this fungus may coalesce and kill the host tree even when beetles have infested a limited portion of the tree (Doidge 1981).

Western balsam bark beetles begin to initiate attacks as soon as the weather warms in the spring and continue to attack trees from late June through October. Within the inner bark tissues male beetles excavate a nuptial chamber and mate with several females. Female beetles excavate egg galleries that radiate outward from the nuptial chamber creating a star-shaped gallery pattern. Eggs are laid throughout the summer, and young larvae and adults over winter in egg galleries. In the spring, female beetles continue to expand the egg galleries and deposit eggs until mid-summer. The parent beetles then re-emerge and attack new trees producing eggs until mid-August (Doige 1981).

White Fir

The fir engraver beetle is commonly found in endemic numbers in true firs, especially in areas with green slash and diseased trees. In these situations, attacks will usually result in top kill, branch kill, or strip attacks; types of damages that white fir can usually survive. However, this beetle will occur in epidemic numbers during periods of drought in association with tree diseases. In recent years, outbreaks of this insect have caused significant white fir mortality throughout the Intermountain region.

Adult beetles fly and infest trees in mid-summer (July-August). After mating, female beetles construct a horizontal egg gallery and lay eggs in niches along each side. The eggs hatch in two weeks and larvae begin to feed within phloem tissues creating mines that run perpendicular to the egg gallery. The larvae continue to feed throughout the fall and overwinter in their fourth instar. The following year, they resume feeding for a short period before constructing pupal chambers. After two weeks of pupation new adults emerge. Adult beetles are shiny black and approximately 1/8th of an inch long. Fir engravers have an abrupt rear end that distinguishes them from other bark beetle species.

Diseases

Dwarf Mistletoes

Dwarf mistletoes, *Arceuthobium spp*., are small, leafless parasitic plants that infect coniferous trees to obtain nourishment. Stress induced by dwarf mistletoes may weaken heavily infected trees causing branch dieback, top kill and even death. Dwarf mistletoes may predispose infected trees to attack by insects, root disease and decay causing fungi (Hawksworth and Shaw 1984, Byler 1978, Johnson et al. 1976). With associated insect pests and fungal pathogens, dwarf mistletoes may reduce the longevity of infected trees.

Where stands are comprised of commercially important species, dwarf mistletoes may cause unacceptable losses of timber products annually (Geils et al. 2002, Wicker 1984). Heavily infested stands have reduced rates of height and diameter growth and increased rates of mortality producing less volume than comparable mistletoe-free stands (Hawksworth and Wiens 1972). Heavy dwarf mistletoe infections also compromise wood quality (Hawksworth and Johnson 1989).

Mortality resulting from heavy dwarf mistletoe infestations alters the fuel complex of infected stands. Dwarf mistletoe infested stands have more dead woody ground fuels than comparable uninfested stands (Hawksworth and Hinds 1964). The presence of witches' brooms also enhances vertical fuel continuity increasing the likelihood of a fire to crown (Brown 1975). In recreation areas, excessive tree mortality may diminish scenic quality. Dead trees, large brooms, and dead tops present a hazard to visitors (Hawksworth and Johnson 1989).

Openings resulting from tree mortality in dwarf mistletoe infested stands, however, may enhance understory plant growth and vegetative diversity that is more favorable for some wildlife species. Witches' brooms provide nesting sites and cover for many birds and mammals (Nicholls et al. 1984). A few bird, rodent, and insect species, utilize mistletoe plants for food (Hawksworth 1975). Mistletoe-killed trees also create habitat for cavity nesting birds (Hawksworth and Johnson 1989).

Dwarf mistletoes require a living host to survive and are generally host specific. Southwestern dwarf mistletoe, *A.vaginatum* subsp. *cryptopodum*, typically infests ponderosa pine in southern Utah. Other important dwarf mistletoe species include *A. cyanocarpum* that infects limber and bristlecone pines, and *A. divaricatum*, and *A. douglasii* that infect pinyon pines and Douglas-fir, respectively.

Root Diseases

Root diseases also contribute to some conifer mortality throughout the intermountain region. Root disease fungi infect the cambial tissues of roots and root collar eventually girdling and killing the host tree. Fungi spread from the roots of diseased trees to those of healthy ones via root contact and root disease centers are characterized by circular openings in the main canopy approximately one-tenth acre in size. These 'mortality centers' are associated with dying and dead conifers. The root systems of downed trees within mortality centers are completely decayed leaving them with a 'ball and socket' appearance that is typical of root disease. Root

tissues will have evidence of staining and decay. Trees sometimes respond to infection by producing copious amounts of resin near the base of the stem. The foliage of root diseased trees typically appears chlorotic and thin. Trees will lose needles from the lower crown upward and from the inside (near the stem) outward. Trees may also produce a stress cone crop in response to infection. Heavy root disease infections can predispose trees to attack by bark beetles contributing to additional tree mortality.

Tomentosus, Armillaria, and annosum root diseases have all been reported in southern Utah. Both Armillaria and tomentosus root diseases infect Engelmann spruce, although Armillaria is most commonly found on lodgepole pine. Tomentosus root disease will occasionally infect lodgepole pine and blue spruce. Annosum root disease, either alone, or acting in association with western balsam bark beetles, drought and other agents, has caused the majority of subalpine fir mortality throughout the watershed. Although these agents are broadly distributed, more mesic locations such as drainage bottoms, lower slope positions, and northerly aspects tend to have greater incidence of infection. Higher incidence of these root diseases may also occur where stumps serve as a source of inoculum. In these locations, root diseases can rapidly kill small trees and regeneration.

Other Diseases of Conifers

Dense witch's brooms resulting from broom rust infections commonly occur in the crowns of both subalpine fir and Engelmann spruce. The brooms have stunted yellow needles that fall in the winter giving brooms a dead appearance. The fungal agents sporulate in the spring on new foliage producing orange pustules that erupt through the needle surface. Severe infections can result in growth loss and deformities.

Damaging Agents of Aspen

A number of insect and disease agents contribute to aspen damage. The most serious insect affecting aspen is the aspen borer (*Saperda calcarata* Say, Coleoptera: Cerambycidae) a roundheaded, longhorn beetle. This beetle typically attacks trees stressed by disease, drought and other damaging agents. Females lay eggs in bark crevices during the early summer. Once the eggs hatch, developing larvae feed first in the inner bark then move into the sapwood. Numerous larval tunnels can weaken tree trunks making them susceptible to snow and wind breakage. Woodpecker excavations and decay fungi further weaken trees (Solomon 1995, Karen 1986).

The bronze poplar borer (*Agrilus granulatus liragus* Barter and Brown, Coleoptera: Buprestidae), a flatheaded, metallic beetle can also infest aspen. Damaged trees, and those attacked by aspen borers are most susceptible to attack. The larvae of this beetle initially feed in the cambium creating shallow, long-winding tunnels that can girdle the branches and trunks of infested trees. Up to 75% of aspen with only a few attacks can experience mortality as a result of this larval feeding. The larvae then bore into the sapwood and heartwood to complete their development. This activity weakens the tree structurally and allows for the introduction of decay fungi. In recreation sites, affected trees can present a hazard.

Several important diseases commonly infect aspen. Aspen leaf spot (*Marssonina populi*) is the most common foliar disease infecting aspen. This disease causes dry, brownish lesions with yellowish borders. The most serious infections generally occur during exceptionally wet springs and result in extensive defoliation. Wood boring insects and wounding often predispose trees to a number of serious canker diseases. Sooty-bark canker (*Encoelia pruinosa*), Cryptosphaeria canker (*Cryptosphaeria populina*), black canker (*Ceratocystis fimbriata*), and Cytospora canker (*Cytospora chrysosperma*) commonly infect aspen in intermountain forests. Some canker diseases are lethal to healthy trees, while others kill stressed trees. Cankers can also create infection sites for decay fungi.

The fruiting bodies on the boles of trees are indicative of infection by aspen trunk rot (*Phellinus tremulae*). This fungus infects trees through branch scars and wounds and decays the heartwood. In advanced stages, the central decay column is characterized by soft, yellow-white wood ringed by black zone lines. The fruiting bodies are perennial, woody, hoof-shaped conks often associated with old branch scars. The presence of a single conk usually indicates considerable decay, and aspen with up to two conks have the potential for stem breakage.

Armillaria and Ganoderma (*Ganoderma applanatum*) root diseases also infect aspen, particularly in more mesic sites. Windthrow often occurs with extensive root decay. The root wads of windthrown trees often exhibit a “ball and socket” appearance. Wood tissue at the root collar appears yellowish and stringy, and in some cases, pocketed. Fruiting bodies may occur at the base of diseased trees. Insects also usually attack infected trees.

Other Damage

Many trees in recreation sites have injuries typical of those caused by human activity (e.g. ax and vehicle damage). Trees also suffer physical injuries due to animal chewing, rubbing, and scratching. Physical injuries are often associated with heavy resin flow, particularly if trees are wounded in the spring. A ridge of callus tissue typically develops around wound margins to seal off the injury. Fire-damaged trees have elliptical scars extending upward from the base of trees. Fires scars are often associated with bole char. Frost cracks and lightning cause long, narrow scars that run either vertically, or spiral up tree boles.

Depending on their severity, wounds can seriously stress trees predisposing them to attack by insects and decay fungi. The activity of these agents also structurally weakens wood tissues increasing the likelihood of wind damage. Extensive colonization by wood boring insects can ultimately result in tree mortality. Structurally weakened, declining and dead trees also create hazards that pose a threat to recreators.

Survey Methods

Data Collection

Ortho-photo quads and topographic maps were used to design a strategy for surveying stands located in the Thunder Ridge project area. Insect and disease data was collected from points systematically distributed throughout stands. These points were spaced at 10 chain (1 chain = 66 feet) intervals along parallel transects located 10 chains apart to ensure sufficient coverage

within each stand. From each sample point, a variable radius plot (basal area factor of 20) was established to determine sample trees. All trees greater than five inches diameter at breast height (dbh) were tallied and measured. Tree mensuration data collected included tree species and condition (live, declining, or dead), and dbh. All symptomatic trees in each plot were examined for evidence of insects and diseases. Indicators of damage and poor tree health included discolored foliage, sparse foliage, chewed foliage, webbing, brooms, branch dieback, pitch streaming, wood staining, and basal resinosus. Once identified the causal agent and type, extent, and severity of damage was recorded. Symptomatic trees observed between points were also mapped.

All tree regeneration less than five inches dbh, and greater than six inches in height was tallied in a 1/300th acre subplot (radius = 6.8') at plot center. Species of shrubs, herbaceous plants, grasses, and other vegetation found within a 1/10th acre subplot established at plot center were recorded.

Data Analyses

Upon completion of the survey, data was entered into a spreadsheet and summarized using the Forest Insect and Disease Tally (FINDIT) program. These statistics were then used to determine the susceptibility of stands to important insect and disease agents.

Insect and Disease Hazard Ratings

Hazard rating systems are often used by forest health specialists to evaluate stand conditions conducive to the growth and spread of damaging agents. "Hazard" or "susceptibility" is the inherent characteristics or qualities of a stand of trees that affect its likelihood of attack and damage by an insect or disease agent. "Risk" is defined as the short-term expectancy of tree mortality in a stand as a result of a damaging agent. Risk is a function of tree/stand susceptibility and 'pressure' imposed by the damaging agent. Pressure is the magnitude of the damaging agent population affecting a stand as determined by the number of currently infested/infected trees and their proximity to the stand being assessed. Pressure relates to the likelihood of damaging agents entering a given stand. A "high-hazard" stand can exist with little risk when populations of damaging agents remain low. Conversely, a "low-hazard" stand can have moderate risk when populations of damaging agents are high.

Numerous insects and diseases damage trees in southwestern and intermountain forests. Hazard rating systems do not exist for most of these agents because they cause only minor damage or the factors contributing to stand susceptibility are not well understood. Consequently, stand susceptibility was only determined for bark beetle species in which reliable systems have been developed. In these systems, outbreak populations of bark beetles will likely infest stands with high susceptibility and moderately susceptible stands as outbreaks intensify. Beetles may infest stands with low susceptibility when populations have reached high levels (high risk), or when they have depleted all suitable host type elsewhere.

Bark beetle hazard rating systems

PONDEROSA PINE: There has been little research conducted in the southwest to determine how the condition of ponderosa pine stands relates to the potential for bark beetle infestation. However, research conducted in western states shows that trees in overstocked stands are more susceptible to bark beetle attack. No stand hazard rating models for Southwestern ponderosa pine have been validated for pine engraver beetle species (*Ips* spp.), primarily because beetle populations are often driven by drought and factors leading to large amounts of slash. Stand hazard ratings for *Dendroctonus* bark beetles that infest ponderosa pine typically incorporate measures of tree size, density (mean BA or SDI), and the percent of host trees within the stand.

In general, even-aged ponderosa pine stands that have an average dbh greater than 12 inches and a stand basal area greater than120ft^2/acre have a high risk to bark beetle attack. Stand basal areas of 80 to120 ft^2/acre have a moderate risk, and stand basal area less than 80ft^2/acre are considered low risk.

In this survey, hazard rating systems developed by Munson and Anhold (1995) and Steele and others (1996) were used to evaluate stand susceptibility to *Dendroctonus* beetle species in ponderosa pine. The Munson and Anhold system is given in Table 1 (modified from Chojnacky et al., 2000). This system was validated across several sites including the North Kaibab in Arizona.

Table 1. Hazard rating system developed by Munson and Anhold for mountain pine beetle in ponderosa pine.

% PP	Value	Ave. dbh	Value	B A	Value	Total	HR
>85	3	12	3	>120	3	8-9	High
50-85	2	8-12	2	80-120	2	5-7	Moderate
<50	1	<8	1	<80	1	3-4	Low

PP = ponderosa pine; dbh = diameter at breast height; BA = Mean basal area (ft^2/acre); HR = hazard rating.

Because of the more xeric conditions in the southwest compared to other western states, the low risk category may be less than 80ft^2/acre. Also, because pine engraver beetles typically cause the majority of ponderosa pine mortality in the southwest, average stand diameter may not be as important as other areas in the west where *Dendroctonus* beetles cause most of the tree mortality.

DOUGLAS-FIR: Epidemics are more damaging in Douglas-fir stands that are mature to over-mature, densely stocked, and of a high percentage of Douglas-fir. Also, the persisting drought continues to weaken trees, increasing their susceptibility to DFB attack. Stands most susceptible to Douglas-fir beetle infestation typically have average ages greater than 120 years, basal areas exceeding 150ft^2/acre, average Douglas-fir diameters greater than 14 inches, and are comprised of more than 50% of a live Douglas-fir component.

ENGELMANN SPRUCE: Stand susceptibility for each unit surveyed was previously determined using the hazard rating system developed by Schmid and Frye (1976). This system is based on the average diameter of live spruce > 10 inches dbh, the basal area of the live stand and the percentage of live spruce in the stand. This system also considers the physiographic location of the stand and site index. Stands considered most susceptible to spruce beetle attack include those located in drainage bottoms with basal areas exceeding 150 ft^2, a live spruce component > 60%

and average spruce diameters > 16 inches dbh. In mixed conifer stands, Engelmann spruce often occurs in dense clumps. Active beetle populations present a risk of spruce beetles spreading into dense spruce patches. These patches could experience a substantial loss (> 80%) of both large diameter Engelmann and blue spruce should they become infested.

Mistletoes

With the detection of dwarf mistletoe (*Arceuthobium* spp.), the Hawksworth's 6-class dwarf mistletoe rating system (DMR) was used to rate individual ponderosa pines and derive an average susceptibility of trees in each stand to dwarf mistletoe infection. In this system, the live tree crown is visually divided into thirds (top, middle, and bottom). Each third is rated according to the proportion of crown infected (0 = no infection; 1 = ½ of branches in third infected; 2 = greater than ½ of branches in third infected). The ratings of each third are summed to give a total tree DMR from 0 to 6. A tree with a DMR of three is considered moderately infected. Because the distribution of dwarf mistletoes is patchy, a stand with an average DMR of three is considered heavily infected.

No systems have been developed to assess stand susceptibility to dwarf mistletoes in southwestern and intermountain forests. Generally, host composition and stand structure is considered most important for the incidence and spread of dwarf mistletoes. Multi-storied stands provide the greatest opportunity for dwarf mistletoe spread as dispersing seeds can infect various size classes. Most growth loss occurs in stands older than 60 years as trees begin to experience age-induced stress. Host tree resistance, ecological, and climatic factors may also limit dwarf mistletoe spread.

Site conditions have been associated with the distribution of juniper mistletoe infections (*Phoradendron juniperinum* Engel. ex A. Gray). Greg (1991) found that the most heavily infected sites are those with a dependable moisture supply to maintain the high demand of infected trees. Others have observed that juniper mistletoes more seriously impact female plants than male plants.

Results

The following section summarizes the survey results and hazard ratings for stands surveyed in Thunder Ridge project area. These results provide useful descriptions of stand conditions. However, standard errors of means were generally high due to the low number of plots sampled in each stand. Therefore, our interpretation of the results, particularly hazard ratings, and recommendations considered this limitation.

Eighteen out of 25 stands were inventoried in the Thunder Ridge project area. These stands included 1, 2, 3, 6, 7, 8, 9, 11, 12, 13, 14, 15, 17, 18, 19, 20, and 21. Stands 4, 5, 10, 22, 23, 24, and 25 were not surveyed due to logistical and time constraints. A summary of overall forest conditions for stands inventoried is provided in Table 2. Tables 3 through 20 (Appendix 2) provide individual stand summaries from which the following discussion is based.

The composition of overstory vegetation within the Thunder Ridge project area was highly variable. On average, white fir comprised the highest percentage (37%) of trees per acre

followed by Douglas-fir (23%) and aspen (23%). Most stands were dominated by mixtures of white fir and Douglas-fir. The exceptions were Stands 6, 15, 18, and 19 where Douglas-fir and/or white fir, other conifer species and aspen were equally abundant. The majority of aspen occurred in Stands 8, 9, 11, 13 and 21 where there was evidence of an old burn and the sites were more shallow, and mesic.

The distribution of other conifer species and aspen was dependent upon site characteristics. Ponderosa pine was a major component (>15%) in Stands 2, and 8 that were located on more exposed aspects and ridgelines. Minor amounts of limber pine also occurred in these same stands except in Stand 6 where it was a major component (56%). Although bristlecone pine was not inventoried in any of the sample plots it was observed in these same locations. Subalpine fir occurred in stands near the southern end of the project area including 9, 14, 15, 19, 20, and 21. Subalpine fir was a major component in Stand 15. Engelmann spruce was only found in Stands 19 and 20 at upper elevation and on more northerly aspects.

Mean basal areas of inventoried stands ranged from 59ft^2 to 200ft^2 per acre. Stands with the highest mean basal areas (Stands 9, 11, 14, and 21) typically had high percentages (>55%) of small diameter (<10 inches dbh) aspen and subalpine fir, or were comprised of moderate percentages (20-54%) of medium sized (11 to 14 inches dbh) trees. Stands with the least amount of basal area (Stands 3, 6, 8, 19, and 20) occurred on more exposed/open aspects and ridgelines but were comprised of moderate to high percentages of large diameter (>15 inches dbh) ponderosa pine, Douglas-fir, Englemann spruce or white fir.

Overall, natural regeneration throughout the project area was good with approximately 628 trees less than five inches dbh inventoried per acre. However, most of these were seedlings (< 3 inches dbh) of late successional conifer species (73% white fir and subalpine fir). Aspen regeneration was poor with only 60 seedlings per acre. Ponderosa pine and juniper had the least amount of regeneration (1%).

Summary of Damaging Agents

As Table 2 indicates, there has been considerable subalpine fir, aspen and Douglas-fir mortality in the Thunder Ridge project area. Over half of the subalpine fir, and over one third of the Douglas-fir and aspen inventoried were dead. Subalpine fir and Douglas-fir had experienced the greatest loss of mean basal area. Douglas-fir and aspen, however, accounted for the greatest general loss of trees since these species were major components of forest stands.

Table 2. Summary of forest conditions in the Thunder Ridge Project Area.

SP*	TPA	TPA % Dead	MBA (ft^2)	MBA % Dead	LQMD (in)	LSDI	Reg < 5 in dbh	Age
SAF	31(12)	56	7	57	7.9	7	180	72
ES	1(<1)	0	1	0	17.4	2	47	86
DF	57(23)	38	36	53	12.2	30	80	104
LM	7(3)	0	3	0	12.4	6	27	191
PP	6(2)	<1	6	<1	20.6	8	7	145
WF	92(37)	14	38	11	10.4	62	280	121
AS	57(23)	39	21	33	8.6	26	60	105
J	-	-	-	-	-	-	7	-
Total	251	-	112	-	12.8	141	628	117

*Tree species; SAF=subalpine fir; ES=Engelmann spruce; DF=Douglas-fir; LM=limber pine; PP=ponderosa pine; WF=white fir; AS=aspen; J=juniper; TPA=trees per acre; MBA=mean basal area; LQMD=quadratic mean diameter of live trees; LSDI=stand density index of live trees; Reg=regeneration.

Douglas-fir beetle was the primary causal agent of all Douglas-fir mortality recorded (Figure 2). Beetles had killed all trees greater than 17 inches dbh and the majority of trees between 13 and 16.9 inches dbh. Approximately one third of trees between 7 and 10.9 inches had also been killed. Over 99% of the attacks were older than three years indicating that beetle population levels are presently low. With the loss of most large diameter trees, the susceptibility of stands to further infestation ranged from low to moderate. Were population levels to increase, Stands 7, 11, and 17 would have the greatest likelihood of infestation.

Douglas-fir dwarf mistletoe had infected approximately five percent of trees (~ four trees per acre) inventoried (Figure 2). Most of the infected trees had diameters between 7 and 10.9 inches with infections either being light (DMRs 1, 2) or heavy (DMRs 5, 6). One tree had been defoliated by an undetermined agent and another had some minor physical damage.

The primary causal agent(s) of subalpine fir mortality was undetermined (Figure 3). Only one tree examined had evidence (exit holes and galleries) of western balsam bark beetle attack. The foliage had fallen off of most trees making any diagnoses using crown symptoms difficult. Wood tissues examined at the root collars were often dry, but resinosus, staining, and decay typical of root disease were not apparent. The root wads of some wind-thrown trees that were observed off plot did have a ‘ball and socket’ appearance typical of root disease. However, no signs of disease were found making the diagnoses inconclusive.

No single agent was responsible for the aspen mortality observed. Rather, a complex of diseases including sooty bark canker, Cytospora canker, and aspen heart rot were observed throughout the type (Figure 4). The entrance holes of poplar borers were occasionally observed on some trees. The galleries of bronze poplar borers were also found beneath the inner bark of dead trees. However, attack rates were not lethal suggesting that these insects were acting as secondary agents.

Most of the aspen examined in stands surrounding Camp Thunder had wounds and other damage inflicted by humans. Many of these trees also had branch dieback, sparse foliage, and other symptoms indicative of decay fungi that were probably introduced as a result of wounding.

Approximately eleven percent of white fir had evidence of older or current fir engraver attack (Figure 5). The current attacks were only observed on relatively small diameter trees while older attacks were generally distributed among most diameter classes. The small amount of top-kill reported was also attributed to fir engraver attack. Two to three percent of mortality was caused by undetermined agents and trees experienced a minor amount of physical damage.

Less than 1% of the ponderosa pine inventoried throughout the project area had damage (Table 2). One tree currently attacked by mountain pine beetle was found in Stand 6. All of the susceptible pines near this tree were healthy. The susceptibility of stands where ponderosa pine was a major component rated generally low. The exceptions were Stands 2 and 7 that rated moderate.

Although ponderosa, limber and bristlecone pine dwarf mistletoes were not reported on any of the plots inventoried, dwarf mistletoe-infected trees were commonly observed. Most infections were light to moderate (DMRs 1 to 4) with few trees exhibiting symptoms of stress.

The Engelmann spruce component was generally healthy and the susceptibility of stands to spruce beetle infestation rated low.

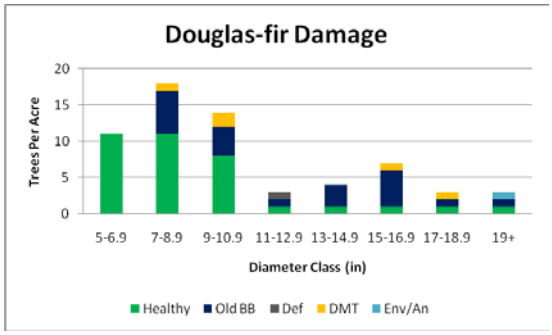

Figure 2. The number of Douglas-fir per acre damaged by various agents by two inch diameter class.

*Old BB = bark beetle attack > two years; Def = defoliation; DMT = dwarf mistletoe; Env/An = environmental or animal damage.

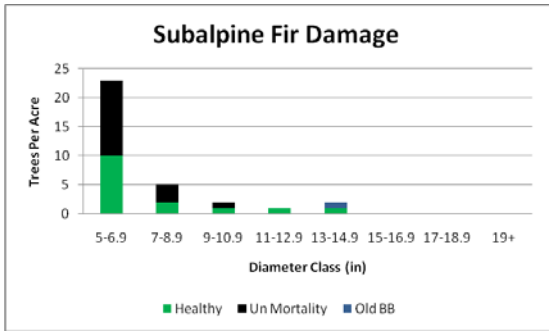

Figure 3. The number of subalpine fir per acre damaged by various agents by two inch diameter class.

*Old BB = bark beetle attack > two years; Un Mortality = unknown mortality.

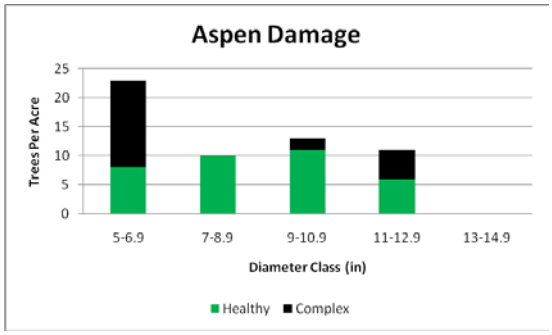

Figure 4. The number of aspen per acre damaged by various agents by two inch diameter class.

*Complex = complex of aspen agents including canker and stem diseases and insects.

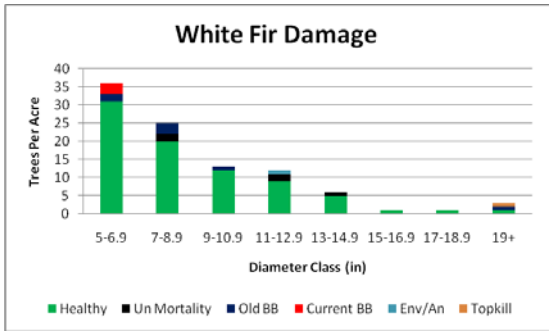

Figure 5. The number of white fir per acre damaged by various agents by two inch diameter class.

*Old BB = bark beetle attack > two years; Un Mortality = unknown mortality;Current BB = current bark beetle attack; Env/An = environmental or animal damage; Topkill = top killed trees.

Discussion

Native insects and diseases naturally occur throughout intermountain woodland and forest cover types. The level of insect and disease activity fluctuates with the availability of host material, stand conditions, environmental factors, and the abundance of parasites and predators. These agents typically occur at endemic levels within forest ecosystems affecting overmature and weakened trees. Insects, fungi, and other microorganisms colonize inner bark of dead trees utilizing nutritious tissues as food. The relatively high moisture content of these tissues also makes them more easily digested.

The activities of insect and disease agents may have ecological and/or economic benefits or costs. Some wildlife species consume insects as food and dead trees benefit snag dependent wildlife species by providing nesting habitat. Over longer temporal scales, mortality produces coarse woody debris and initiates decomposition that contributes to nutrient cycling.

Periodically, populations of insects and diseases reach outbreak levels and impact healthy trees. Of damaging agents, outbreaks of bark beetles have the potential to cause rapid and extensive tree mortality and thus pose the greatest threat to important resource values in western conifer forest types. Bark beetles, particularly Douglas-fir beetle, were the primary cause of tree mortality in the Thunder Ridge project area. More recently, however, aspen dieback has also become a major forest health concern, as well as the loss of high elevation species including subalpine fir. The results of this survey indicate that factors contributing to the general loss of aspen and subalpine fir were operating as well.

Assessment of Bark Beetle Impacts

During the 1990's, a spruce beetle outbreak erupted on the Markagunt Plateau causing extensive tree mortality. In most stands, over 90% of the mature Engelmann spruce component was lost. Engelmann spruce, however, was only a minor component of stands in the Thunder Ridge project area and consequently impacts due to this agent have been minimal. No currently

infested trees were found in any of the stands surveyed. This finding is consistent with aerial detection surveys and indicates that spruce beetle risk is presently low. Although susceptible trees do occur in some stands, stand conditions are generally not conducive to spruce beetle spread.

Some possible explanations for the general lack of Engelmann spruce in the Thunder Ridge project area compared to other locations on the Markagunt Plateau include site differences (lower elevation), past harvesting, and fire. Natural or artificial disturbances resulting in the removal of overstory trees and potential seed sources may also explain the small amount of natural regeneration.

The initiation of Douglas-fir beetle outbreaks appear to be coincident with drought that occurred during the early 2000's. Since that time, Douglas-fir beetle has been the most significant damaging agent in the project area. In stands where Douglas-fir was once a major component beetles have killed 87 to 100% of large diameter trees. The loss of these trees will modify stand structure and species composition by reducing average Douglas-fir diameters, heights, basal area, and age and likely impact timber values.

Although some large diameter Douglas-fir escaped infestation, the number of these trees may not sufficiently satisfy management objectives that require retention of larger, green trees for maintaining structural and compositional diversity. Negative impacts associated with severe bark beetle outbreaks can include loss of hiding cover, thermal cover and older tree habitat for other wildlife species and increased run-off. Additionally, the loss of seed sources in stands with few seedlings or saplings such as Stands 1, 12, 14, and 15 may also deter the natural establishment of seedlings requiring artificial regeneration to achieve long-term management goals.

The loss of trees in recreation settings reduces shade, screening, and aesthetics, and compromises the experiences of visitors to Camp Thunder. Dead trees also pose potential hazards to public safety and warrant implementing routine tree hazard inspections, particularly in areas near facilities and other structures, roads and parking areas, campsites, and highly used trails.

Forest fuels were not inventoried in this survey. Examination of Douglas-fir beetle-killed trees indicated that they had lost their foliage and fine twigs. Dead needles on the forest floor were beginning to compact and decompose. Understory shrubs and other vegetation had also begun to release. Consequently, it is unlikely that tree mortality will significantly influence fire behavior at this time. Over time, however, the dead snags will begin to fall and contribute to coarse woody fuel loads. Reliable fall rates for beetle-killed Douglas-fir remain unknown. However, higher fall rates are more likely on steeper slopes and more mesic sites. Dead fuels may accumulate due to the relatively cool moist conditions at upper elevations within the project area increasing potential fire hazard.

This is particularly a concern where past fire exclusion and suppression practices may have altered mixed-severity fire regimes at lower elevations (8,000'- 9,000'). With greater potential for high-intensity fires initiated at lower elevations to burn upslope into higher elevation stands, hazardous fuels accumulations pose more of a concern for unnatural levels of damage.

Stands with a significant loss of overstory trees may also experience increased solar input resulting in higher temperatures and decreased relative humidity resulting in the desiccation of fuels and lower fuel moisture content (see Jenkins et al. 2008, attached). Under extreme fire weather conditions (i.e. drought), large quantities of dead fuels would contribute to more intense and widespread fire in bark beetle-killed stands than in unaffected forests. Adverse impacts to resource values resulting from wildfire in the Thunder Ridge project area would especially include the potential loss of important recreational sites and amenities, wildlife habitat, timber and water values.

Assessment of Aspen Health

Historically, aspen was a major component of western North American forests. Frequent wildfires served to rejuvenate aspen stands and reduce the incidence and extent of fungal diseases, wood borers, and other damaging agents throughout the type (Bartos et al. 2000). Past management practices including fire exclusion and suppression, livestock grazing, and a reduction in timber harvests, however, have adversely impacted the health of many aspen communities. Forest Inventory and Analysis (FIA) data indicate that approximately 66% of stands once dominated by aspen are now mixed with conifer species (O'Brien 1999). Overmature stands have also begun to deteriorate and much of the unmanaged aspen component has become decadent with insects and diseases now contributing to decline.

Our examination of aspen in the Thunder Ridge project area revealed signs and symptoms of poor health typical of those observed elsewhere throughout the type. These included branch dieback, discolored foliage and bark, bole wounds, and scars. Canker diseases were the most serious agents affecting aspen in the general forest area. Some of these diseases were lethal to healthy trees, while others may have predisposed them to infection by decay fungi and attack by wood boring insects.

A high incidence of insect and disease activity is not necessarily indicative of poor aspen health in stands outside of developed recreation sites. Aspen mortality in stands with sufficient regeneration (> 5000 suckers per acre) for recruitment into the overstory generally signifies the natural 'turn-over' of healthy stands.

Most aspen stands in this project area were overcrowded and contained high percentages of Douglas-fir, white fir, or subalpine fir indicative of conifer encroachment. More disconcerting was the generally low amounts of aspen regeneration recorded. Insufficient regeneration in conjunction with insect and disease mortality, particularly in stands impacted by grazing, will result in the loss of aspen without treatment or adequate protection from livestock and wildlife.

Many aspen in recreation sites had injuries typical of those caused by human activity (e.g. ax and vehicle damage). Trees also suffered physical injuries due to animal chewing, rubbing, and scratching. Depending on their severity, such wounds can seriously stress trees predisposing them to attack by insects and decay fungi. The activity of these agents also structurally weakens wood tissues increasing the likelihood of wind damage. Extensive colonization by wood boring insects can ultimately result in tree mortality. Structurally weakened, declining and dead trees also create hazards that pose a threat to recreators.

Assessment of Subalpine Fir Health

The results of this survey did not provide sufficient information to determine the direct cause of subalpine fir mortality. Because no signs or symptoms of damaging agents were identified it is likely that water stress induced by competition and drought was a major contributor to tree mortality and/or may have predisposed trees to the few other damaging agents detected.

The loss of mature subalpine fir in the Thunder Ridge project area may adversely impact wildlife habitat (hiding and thermal cover) and food resources, aesthetics, and recreation values. Subalpine fir tends to windthrow due to their shallow root systems and predisposition to root decay fungi. Consequently, dead firs pose a significant hazard to public safety. Over time, the fall of subalpine fir snags may also contribute to hazardous fuels accumulations.

Unlike aspen and Douglas-fir, however, there were relatively high amounts of subalpine fir regeneration throughout the project area. With seedlings and saplings available to replace overstory trees, the loss of this species from the project area is less of a concern. Any adverse impacts associated with tree loss would be only short-term.

Other Forest Types

Although ponderosa, limber, and bristlecone pines were relatively minor components of stands in the Thunder Ridge project area, these species greatly contribute to plant community diversity and overall character of the landscape. Large ponderosa and limber pines occur in the vicinities of important recreation sites such as Camp Thunder and Little Thunder Lake. Mortality associated with insects and diseases affecting these species would have significant impacts due to their high value.

Populations of bark beetles that typically infest these species of pines, however, were at endemic levels suggesting that the risk of attack is presently low. The susceptibility of ponderosa pine stands to mountain pine beetle outbreak ranged from low to moderate. In the event of a bark beetle outbreak, Stand 2 would have the greatest likelihood of experiencing unacceptable losses ponderosa pine. Stands 6 and 8, however, were comprised of large pines (average diameters 16 and 21 inches dbh, respectively) that would be susceptible to infestation with increasing population levels.

Recommendations for Insect and Disease Management

Generally, insect and disease treatment strategies include prevention, suppression and restoration activities. Prevention strategies often utilize silvicultural practices to modify stand conditions favorable to insect and disease agents and should occur before populations reach unmanageable levels. By enhancing stand diversity and resiliency, prevention strategies can help avoid unacceptable losses of valuable resources, maintain or enhance resource objectives, and maximize revenue in the long term. Suppression strategies are usually implemented with building insect populations. When implemented during the initial stages of an outbreak, suppression activities can reduce population levels and the rate of insect spread. Treatment alternatives associated with suppression are usually limited, however, because they often occur at small scales being environmentally prohibitive and/or costly. Because treatments may not

sufficiently modify stand conditions, the benefits are also often short term. Restoration activities attempt to reestablish vegetation and promote the long-term resiliency of forests to insects and diseases.

In 2000, the Thunder Ridge Forest Stewardship Plan (Reese, 2000) was developed to provide guidance for meeting both long and short-term vegetation management goals within the Thunder Ridge project area and included insect and disease treatment strategies to minimize adverse impacts to resources. The plan reported that stands were largely overstocked and would benefit from silvicultural treatments (thinning, sanitation) designed to reduce densities, promote the abundance and diversity of desirable tree species, remove unhealthy trees, and create greater structural and age class diversity.

If and when the landowner(s) implemented any of the recommended treatments is unknown. A considerable amount of Douglas-fir, aspen, and subalpine fir mortality has occurred in the Thunder Ridge project area since that time, however, altering the composition and structure of many stands. As a consequence, achieving many of the former resource objectives specified for stands in each compartment may no longer be possible and recommended treatments may no longer apply. The landowners, working cooperatively with the Utah Division of Forestry Fire and State Lands, and the USDI Bureau of Land Management should consider updating the plan with new management objectives and treatment strategies based on the present stand conditions.

When revising the plan it is important to note that a single treatment strategy generally does not address all resource values within a susceptible, infested, and/or damaged landscape. Therefore, the selection of ecologically appropriate and economically feasible treatments should consider resource management priorities. The high recreation and property values in the Thunder Ridge project area warrant first addressing the extensive Douglas-fir, aspen, and subalpine fir mortality. In stands where tree mortality occurs in conjunction with locally high stand densities, treatments should be implemented to reduce hazardous fuels and potential fire behavior (Stands 11, 13, 14, and 15). Specific recommendations for such treatments are beyond the scope of this report, but should be designed in consultation with fire management professionals and silviculturists. The number of dead trees also warrants conducting regular hazard tree inspections and tree removal around facilities and in developed and dispersed recreation sites. These treatments can be designed and implemented in conjunction with the maintenance of defensible spaces. Preventing further tree mortality in these same sites is best accomplished by maintaining vigor. Measures should be taken to minimize tree injury from insects, dwarf mistletoes, wind, fungi, animals, and humans. Cultural practices including removing infested, dead or severely damaged portions of trees can reduce insect populations and potential hazards. Both natural and artificial regeneration should favor a mixture of indigenous tree species to enhance diversity that will reduce long-term insect and disease impacts.

Specific Insect and Disease Management Strategies

<u>Bark Beetles</u>

Although bark beetle populations are presently at endemic levels in the Thunder Ridge project area several stands are moderately susceptible to infestation. Stands that still have a susceptible Douglas-fir component include 7, 11, and 17; ponderosa pines in Stands 2, 7, and 8 were most

susceptible to mountain pine beetle attack; while the Engelmann spruce type was not susceptible to spruce beetle infestation. Fir engravers would be most likely to infest stands comprised with high amounts white fir (> 50% of trees) such as 1, 2, 12, 17, 18, 19, and 20, and those that have large average white fir diameters (Stand 6).

PREVENTION: In the above stands, prevention strategies would offer the greatest likelihood of reducing the long-term susceptibility by creating a mosaic of structures, age classes, and species mixtures. Thinning strategies could be used to selectively remove trees to benefit the quality of the stand, reduce competition for water and nutrients. Such treatments would also effectively reduce host resources that support bark beetle populations and disrupt pheromone communication altering the attack behavior of the insect. The higher temperatures in thinned stands could reduce bark beetle brood survival.

The majority of Douglas-fir stands in the project area occur on steep slopes and the difficult terrain may limit the feasibility of implementing thinning treatments. Where possible, however, susceptible Douglas-fir stands should receive the highest priority for treatment, especially where tree mortality could increase hazardous fuels, or further impact recreation or other critical resource values. Negron and others (2000*b*) observed that residual Douglas-fir basal areas following an outbreak averaged 59ft^2/acre providing a target for density management. The desired stocking levels in the project area may prohibit achieving this target, however, thinning should result in Douglas-fir diameters that average 7 inches dbh, average ages of 80 years, stocking densities less than 100ft^2/acre, and less than a 50% Douglas-fir component.

Where ponderosa pine is a major tree component, thinning treatments should reduce stand densities to less than 80ft^2/acre while maintaining inner-tree spacing and reducing average stand diameters to eight inches dbh. As density increases above 100ft^2/acre, bark beetle susceptibility generally increases. In portions of the project area not surveyed, stands with an excess of 120ft^2/acre mean basal area and average tree diameters of eight inches or larger are susceptible to bark beetle population increases. Susceptibility also will increase as ponderosa pine dbh reaches eight inches or larger. Smaller diameter trees will be attacked when mixed with larger trees. In areas where resource objectives rely on the clumpiness of ponderosa pine, inter-tree spacing guidelines should be implemented between clumps with age-class diversity emphasized to reduce losses if an outbreak does occur. In mixed conifer stands, the susceptibility to mountain pine beetle will increase when the ponderosa pine component exceeds 50 percent, ponderosa pine dbh averages greater than eight inches, and mean basal areas exceed100ft^2/acre.

Benefits and Limitations of Thinning Treatments. To maximize their effectiveness, thinning strategies should be implemented while bark beetle populations remain low. After the initiation of an outbreak, management options become increasingly limited and delays in treatment greatly reduce opportunities for success. Other factors may also compromise the effectiveness of thinning treatments including mitigation measures that require leaving buffers along road and stream corridors, and dense clumps for wildlife or leaving higher stand densities to prevent blowdown.

Bark beetle thinning treatments can provide an opportunity to enhance vegetative diversity. Selective thinning, for example, can be used to remove not only susceptible hosts but also less desirable trees, such as encroaching conifers, in order to favor the growth of more desirable

species such as aspen. Increase diversity can result in natural firebreaks, enhance browse for ungulate wildlife species, and enhance amenities for recreationists. Benefit of thinning treatments would also include deriving some commercial value from harvested trees.

Undesirable consequences of thinning treatments would include visual and site impacts, and probable damage to residual trees increasing the potential for infections by root disease and decay fungi. Depending on the thinning treatment, stands would also lose some percentage of large diameter overstory trees. Both beneficial and adverse impacts to wildlife species might occur. The production of green slash would necessitate implementing post-harvest treatments to mitigate potential colonization of host material by secondary beetles such as engraver beetles (*Ips spp.*) in pines, if treatments coincide with beetle flight periods. Post-harvest treatments should also address reducing hazardous woody fuels. Douglas-fir stands have an increased potential for blowdown in wind prone locations. This would necessitate monitoring treated areas on an annual basis to remove any infested host material until the residual stand is windfirm.

In addition to developing prevention strategies, I recommend monitoring susceptible stands annually for the early detection of bark beetle outbreaks. In the event of an outbreak, suppression strategies are usually implemented to reduce bark beetle population levels and rates of spread. Treatment alternatives associated with suppression, however, are usually limited often occurring at small scales. Because treatments may not sufficiently modify stand conditions, the benefits are often short term.

SANITATION. With the detection of low to building bark beetle populations, sanitation treatments may reduce local bark beetle levels and decrease stand susceptibility. Sanitation treatments involve the removal of infested and susceptible host trees. The removal of large diameter trees reduces stand densities and alters residual stand structure. To minimize the probability of re-infestation, particularly where risk remains high, sanitation treatments would need to address the entire susceptible host component. Created openings may promote some age class diversity in treated sites. Stands to consider for sanitation treatment would include infested stands with a susceptible host component that remains at risk to bark beetle attacks.

Benefits of this treatment would include deriving some commercial value from harvested timber and creating greater species and structural diversity while treating fewer acres. By reducing local susceptibility, this treatment would also offer long-term management for bark beetles and provide the greatest opportunity for maintaining mature trees within various sites. This treatment would require access to susceptible and infested trees increasing short-term site impacts. However, the necessity for stand re-entry would decrease. Other undesirable consequences of this treatment would include loss of large diameter trees, probable damage to residual trees and increased potential for windthrow.

Treatment success decreases with rapidly expanding bark beetle populations. Openings created in stands could predispose trees to blowdown. This treatment would not reduce the susceptibility of stands to subsequent bark beetle attacks and may require additional entries to treat or remove downed host material, or newly infested standing trees.

SUPPRESSION. In developed and dispersed recreation sites several short-term suppression strategies can be used to protect high value trees from bark beetle attack.

Chemicals

Chemical insecticides sprayed on the boles of susceptible trees prior to bark beetle flight can provide effective short-term protection from attack. Any flowable formulation of Carbaryl such as Sevin XLR, or Carbaryl 4L is effective. The insecticide is typically applied to runoff up to a bole height of 40-50 feet to maximize its effectiveness. All bole surfaces and the root collar **must** be sprayed completely to ensure thorough coverage of all bark crevices. Chemical treatments are difficult and expensive over large areas and not a recommended strategy for general use. Applications of a chemical insecticide would provide the best protection of high value trees. Re-application would be necessary every two years until the bark beetle populations collapse. Better access to trees selected for treatment might require the removal of obstructing vegetation. Pruning the lower branches on larger spruce would improve the coverage of spray applications. Restricted access, limitations inherent to treating large trees, and application error may result in some bark beetle attacks and tree mortality. To minimize exposure of chemical residues, 10 mil plastic can be use to cover picnic tables, fire pit grates, and any other nearby facilities before spraying. Washing treated surfaces with a detergent solution will also mitigate chemical exposure to recreation site users. Spray applications should occur during campground closures, and between adult beetle flight periods.

Pheromones

Pheromones are message-bearing chemicals emitted by adult bark beetles and the host tree. These chemical signals regulate the behavior of beetles during their mating and aggregating phases (Schmitz and Gibson 1996). Aggregation pheromones are chemical cues used by the insect to manipulate mating behavior. As a result, the pheromone attraction causes bark beetle aggregation that overcomes a host trees' defenses. Anti-aggregation pheromones such as methylcyclohexenone (MCH) for Douglas-fir beetle and verbenone for mountain pine beetle serve to disrupt attraction after beetles have invaded host trees (Furniss and Orr 1978). Pheromone treatments have been proposed where environmental and safety concerns prohibit chemical use such as in developed and dispersed campsites adjacent to surface water.

Trap Trees (Felled)

Trap trees are often used to contain and reduce local populations of spruce and Douglas-fir beetles in stands with isolated pockets and/or low populations. Trap trees are generally large, green trees with diameters exceeding 16" dbh felled prior to the onset of flight to capture dispersing adult beetles. Felling trap trees in sites comprised of non-host trees or small diameter trees (< 8" dbh) will reduce the number of spillover attacks on adjacent susceptible hosts. Infested trap trees should be removed or treated by burning or debarking the tree following adult flight of that year. To attract beetles, trap trees should be felled in cool moist locations retaining limbs to provide shading and support off the ground for greater surface colonization. Until sufficiently infested, trap trees should also remain unbucked to prevent desication. Careful consideration should be given trap trees felled in close proximity to uninfested stands to avoid the risk of attracting beetles to those stands. Avoid felling trap trees adjacent to standing host trees to prevent spillover. In stands with heavy pockets of infestation, one trap tree per two to three infested standing trees is recommended. One trap tree per three infested trees is the recommended ratio for most of the infested sites to suppress building spruce beetle populations.

The range is variable depending on the diameter class of spruce used as trap trees. Larger diameter spruce will absorb more beetles than smaller diameter trees. In centers of spruce beetle activity, clustering trap trees has proven effective. Two to four trees are felled one chain apart to concentrate attacks.

Trap Trees (Standing & Baited)

Baiting green trees with aggregation pheromones is an effective method for attracting flying beetles and inducing attack. The baits are stapled on the north side of standing, green trees prior to flight. Secondary attraction to the treated tree often develops and it is not uncommon to have five to ten susceptible trees also attacked. Tree baits are often deployed to focus beetle attacks into sites where trees can easily be treated and/or to reduce spread from infested sites. Where possible, trees should be baited close to active bark beetle pockets centers (within 100-200 feet), or within the pocket. Cluster baiting appears to maximize attraction. This method consists of baiting three trees spaced 50 to 100 feet apart in a deltoid pattern within infested pockets. Once colonized, the baited trees are removed, or treated in the same manner as trap trees during the year of attack. Baiting strategies are most effective if used in units with isolated infestations in conjunction with sanitation/salvage treatments.

Funnel Traps

This technique uses Lindgren funnel traps (12 tiered) baited with either a two or three component lure containing aggregation pheromones. For the spruce beetle, three-component lures will attract more adult beetles, however, the effects of spillover are greater. If three-component lures are used, the minimum distance from a susceptible spruce to a baited trap should be 75 feet. For the two-component lure, 50 feet is recommended. In centers of infestation, funnel traps are deployed in clusters of three with individual funnel traps spaced 50 feet apart. Funnel trap clusters are spaced at approximately 300-foot intervals. To minimize spillover, funnel traps should be placed within clumps of non-hosts or dead trees. This is the least effective means of reducing beetle numbers, however, when used in conjuction with other suppression strategies, funnel traps will assist in reducing populations (Bentz and Munson 2000).

Dwarf Mistletoe Management Strategies

A small percentage of Douglas-fir was infested by dwarf mistletoe and many of the large trees with evidence of infection had been killed by bark beetles. Many ponderosa, limber, and bristlecone pines throughout the Thunder Ridge project area were also infected by dwarf mistletoe. Although dwarf mistletoe is common, only those stands with important timber and recreation values would require treatment in the near future.

Several features of dwarf mistletoes allow for effective treatment using cultural methods. Dwarf mistletoes require a living host to survive and are host specific. Spread rates of the disease are relatively slow and the visibility of signs and symptoms (i.e. plants, branch swellings, brooms) make infected trees easy to detect. In portions of the Thunder Ridge project area managed for timber removing dwarf mistletoe infected trees is recommended. If necessary, leaving lightly infected trees (DMR's ≤ 3) would be admissible if overstory removal occurred before the regeneration was taller than 3', or older than 10 years. Favoring non-host species during these

treatments helps reduce long-term dwarf mistletoe damage. Without treatment, the level of dwarf mistletoe infections will increase over time and result in continued loss of tree growth and vigor, and mortality. Regeneration would also have greater likelihood of becoming infected. Stand openings resulting from tree mortality can also reduce hiding cover for many wildlife species.

The emphasis of dwarf mistletoe management in recreation sites is placed on introducing and/or favoring non-host tree species. If this option is not feasible, or where tree retention is a high priority, pruning mistletoe-infected branches provides another option for management. Because cost and labor usually prohibit this treatment, pruning is only done to improve the vigor of high value trees, remove dangerous brooms, and reduce hazardous fuels. Criteria for selecting trees as candidates for pruning include those having DMR ratings < 3 with infections limited to the lower crown half.

Subalpine Fir Mortality Complex

Devising appropriate and effective strategies for managing subalpine fir mortality is difficult because the complex of agents that contribute to decline is poorly understood. The sensitivity of high elevation sites and rugged terrain where subalpine fir typically occurs also makes treatments seldom feasible. Managing recent windthrow, logging slash and root-diseased trees can help prevent western balsam bark beetle outbreaks. Local areas where mortality has resulted in excessive fuel loads might be of greatest concern in the Thunder Ridge project area at this time. Management activities should primarily emphasize fuels reduction and restoration in these areas.

Root Diseases

Although no root-diseased trees were detected in the project area, they are present in intermountain forests and usually present cause for concern in recreation sites. Periodic inspection of all trees in recreation sites will help detect root-diseased trees. Remove any trees that pose a threat to public safety and replace them with more disease tolerant species. In the intermountain region, aspen and Douglas-fir have demonstrated the greatest resistance to both Tomentosus and Armillaria. Measures taken to improve tree vigor and protect trees from damage in recreation sites can also reduce their susceptibility to root disease and decay fungi.

The implementation of silvicultural treatments may exacerbate root disease problems in portions of stands where root disease is prevalent. These sites will lose long-term productivity if root disease centers regenerate with susceptible host species. Treatments to encourage the growth of tolerant species can minimize root disease problems.

Aspen Management

The high levels of insect activity and diseases acting over prolonged periods seriously affect the ability of aspen to regenerate, and as clones begin to die, the number of management alternatives for rejuvenating aspen become limited. With the general poor health of aspen in the Thunder Ridge project area, particularly in Stands 13, and 15 that surround Camp Thunder, treatments to rejuvenate/restore aspen need to occur immediately. Retaining structurally weakened trees within these stands also poses a serious safety risk.

Aspen stands can be managed using a wide variety of silvicultural techniques. In clones where the likelihood of regeneration is good, I recommend implementing small clearcuts in stages thus treating portions of the area over a number of years. These treatments would eliminate unhealthy and hazard trees, effectively reduce the incidence of insects and disease and encourage the growth of aspen suckers.

In severely damaged sites, where significant overstory removal may not effectively stimulate suckering, treatments would consist of selectively removing severely damaged, diseased and infested trees that directly threaten camp sites, structures and trails. Relatively healthy aspen could be left on site to meet recreational needs (screening, shading, and aesthetics). This treatment would also encourage some aspen regeneration, improve vigor of residual trees and reduce hazards, but would not be as effective with respect to the management of insects and disease. Lower aspen densities could even exacerbate the activity of poplar borers.

Few strategies exist for effectively managing canker diseases in campgrounds and recreation sites. Trees with large and multiple bole cankers should be monitored on a regular basis, removing those trees that exhibit symptoms of decline (i.e. top kill, insects, decay, etc.), particularly those that pose a hazard to people, property and structures. Reducing the incidence of disease can be accomplished by removing young trees with stem cankers. With any aspen removal, planting tree species and shrubs suited to the local climate and resistant to borer damage, root disease and decay fungi should improve site conditions. The resultant biodiversity will decrease the susceptibility of vegetation to insects and diseases and perhaps enhance the site for recreators.

Regardless of the methods used for aspen management, it is necessary to control the amount of herbivore grazing on the aspen suckers to ensure the survival of the new regeneration. If an aspen clone loses more than one crop of sucker sprouts, the rate of sprouting is greatly reduced and the clonal root system can be killed. Some techniques that can be used to protect regeneration from herbivory include satiating the demand (from herbivores) for sprouts, leaving logging lash as a physical barrier to protect sprouts from browsing, repellents, or fencing. Fencing is the only guaranteed means of directly protecting sprouts from browsing animals. Research by Shepperd and Fairweather (1994) has shown that fencing is operationally feasible but must be maintained every 8-10 years, or until dominant stems are ca. 1 inch in diameter which requires 2 to 5 years depending on site conditions. Wire fences constructed from two widths of 1 m wide field fencing, or one height of 1.4 m wide fencing with one or two high tensile smooth wires strung above, have been found effective.

Finally, minimizing aspen injuries caused by humans (e.g. ax and vehicle damage) would effectively reduce the incidence of insects and diseases in high value recreation sites. I recommend developing an aspen health awareness program that uses a variety of tools (interpretive signs, educational brochures, video presentations, etc.) to educate Boy Scouts and other users about the importance of aspen and the adverse consequences of aspen damage. Users may also develop a more vested interest in aspen health by engaging in activities designed to protect trees such as erecting exclosures around suckers, or removing miscellaneous ropes, wires, nails from tree boles.

Restoration

The majority of stands inventoried lacked sufficient mixtures of regenerating species and younger age classes of trees for maintaining stocking levels of desired species and a mature tree component over the long-term. A comprehensive vegetation management plan should include guidelines for enhancing species, age-class and structural diversity. Consider planting a mixture of tree species to create an environment that supports diversity and reduces long-term insect and disease impacts.

Conclusions

Based on the results of our survey the incidence of insects and diseases affecting conifers in the Thunder Ridge project area was presently low. Large percentages of Douglas-fir, and subalpine fir, however, were dead. Dead trees have primarily impacted timber and important recreation values and pose hazards. The fall of dead trees will also contribute to hazardous fuels accumulations and potential fire behavior. The Douglas-fir beetle was responsible for all Douglas-fir mortality. Douglas-fir dwarf mistletoe infected a small percentage of living trees. Although the primary cause of subalpine fir mortality was undetermined, drought in conjunction with other damaging agents is a likely suspect. Low percentages dwarf mistletoe infected ponderosa, limber, and bristlecone pines, otherwise the overall health of these species was good.

Aspen throughout the project area generally exhibited poor health and has also experienced considerable mortality. Stress induced by competition, drought and canker diseases contributed to the majority aspen mortality. Many stands were also overstocked and lacked sufficient regeneration of desirable species. Conventional hazard rating systems indicated that the stands surveyed had low to moderate susceptibility to bark beetle infestation.

The vegetation management plan for the Thunder Ridge project area should be revised to reflect resource objectives and treatment strategies for long-term for insect and disease management based on present stand conditions. Stands to prioritize for treatment should include those where tree mortality may increase hazardous fuels accumulations and potential fire behaviors, and where dead trees pose hazards to humans and property. Efforts should be undertaken to begin rejuvenating aspen in high value sites where possible. Consideration should be given to restoration treatments which enhance the amount and diversity of regeneration. The timely implementation of recommended treatments will help minimize the potential for further impacts to important resource values and promote long-term forest health.

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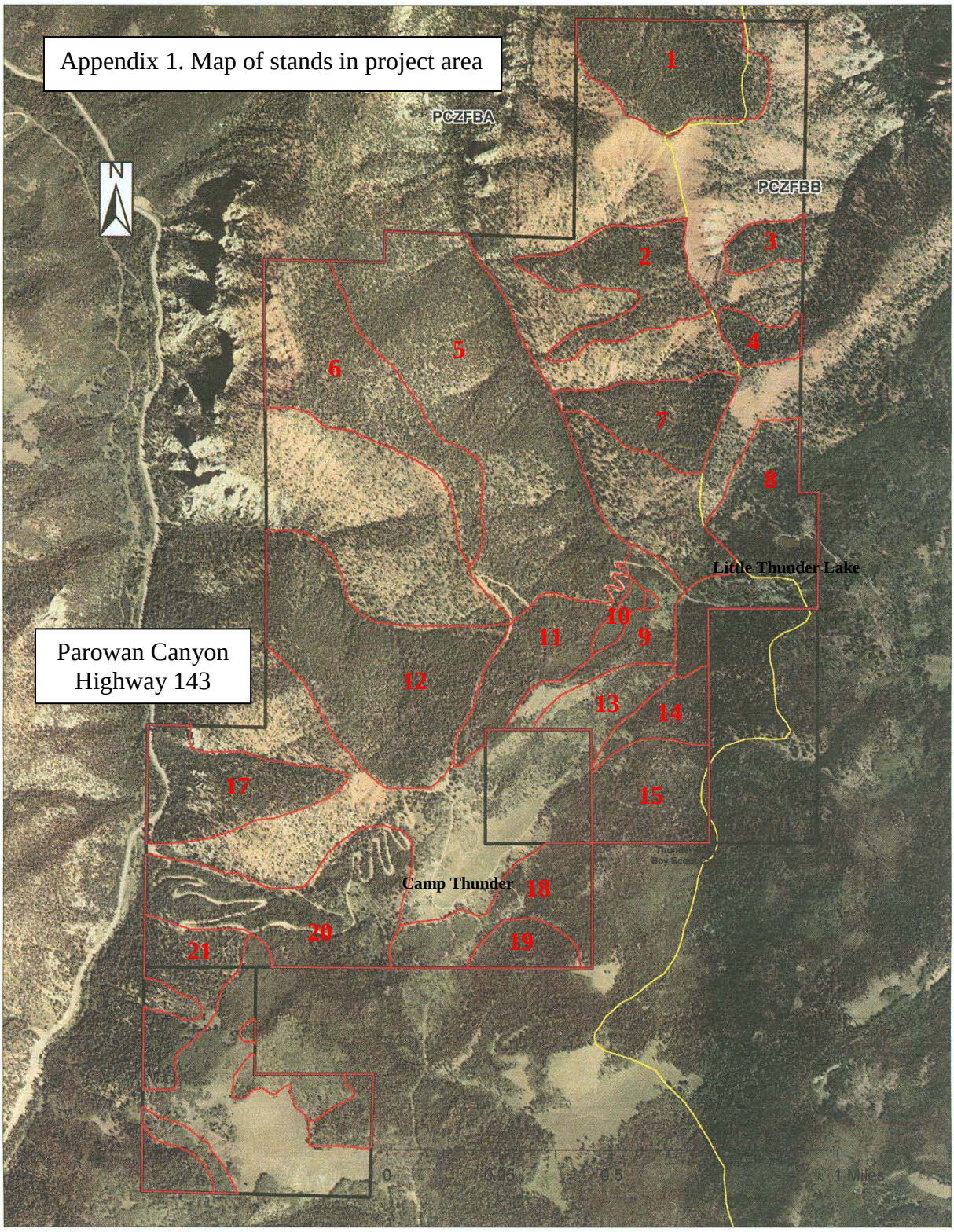
APPENDICES


Appendix 1. Map of stands in project area
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PCZFBB
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2
3
4
5
6
7
8
9
10
11
12
13
14
15
17
18
19
20
21
Little Thunder Lake
Parowan Canyon
Highway 143
Camp Thunder
0
0.25
0.5
1 Miles

Appendix 2. Summary of data for stands surveyed in the Thunder Ridge Project Area.

Table 3. Summary of data for Stand 1.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	45(20)	100	10.3	20	-	NA
WF	185(80)	0	12.3	93	192	NA
Total	230	-	-	113	192	

*Tree species; DF = Douglas-fir; WF = white fir; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating.

Table 4. Summary of data for Stand 2.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	86(28)	82	11.8	40	-	L
WF	168(55)	0	8.3	50	128	NA
PP	519(17)	0	6	20	-	L-M
Total	305	-	-	110	128	

*Tree species; DF = Douglas-fir; WF = white fir; PP = ponderosa pine; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating; L= low; M = moderate; H = high.

Table 5. Summary of data for Stand 3.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	92(61)	0	11.8	40	-	L
WF	59(39)	0	8.3	20	104	NA
Total	151	-	-	60	104	

*Tree species; DF = Douglas-fir; WF = white fir; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating; L= low

Table 6. Summary of data for Stand 6.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	4(8)	0	19	8	-	L
WF	14(25)	0	26.2	20	140	NA
PP	6(11)	0	15.8	16	125	L
LM	31(56)	0	12.5	5	300	NA
Total	55	-	-	59	188	

*Tree species; DF = Douglas-fir; WF = white fir; PP = ponderosa pine; LM = limber pine; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating; L = low

Table 7. Summary of data for Stand 7.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	169(60)	0	9	70	152	L-M
WF	96(34)	0	6.5	20	-	-
PP	17(6)	0	10.3	10	-	L-M
Total	282	-	-	100	152	

*Tree species; DF = Douglas-fir; WF = white fir; PP = ponderosa pine; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating; L = low; M = moderate.

Table 8. Summary of data for Stand 8.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	24(19)	0	9	8	-	L
WF	17(16)	0	12	20	53	NA
PP	21(18)	0	21	35	156	L
LM	5(4)	0	13	5	-	NA
ASP	50(43)	0	9	35	-	NA
Total	117	-	-	103	128	

*Tree species; DF = Douglas-fir; WF = white fir; PP = ponderosa pine; LM = limber pine; ASP = aspen; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating.

Table 9. Summary of data for Stand 9.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
WF	160(30)	0	11.6	80	-	NA
ASP	288(54)	0	7.7	70	-	NA
SAF	86(16)	0	8.7	30	72	NA
Total	534	-	-	180	72	

*Tree species; WF = white fir; ASP = aspen; SAF = subalpine fir; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating.

Table 10. Summary of data for Stand 11.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	142(45)	56	15	120	81	(L-M)
LM	9(3)	0	14	10	-	NA
ASP	162(52)	0	9	70	-	NA
Total	313	-	-	200	81	

*Tree species; DF = Douglas-fir; LM = limber pine; ASP = aspen; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating.

Table 11. Summary of data for Stand 12.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	96(26)	100	10	48	86	NA
WF	180(49)	0	9	60	91	NA
LM	92(25)	0	6	4	107	NA
Total	368	-	-	112	92	

*Tree species; DF = Douglas-fir; WF = white fir; LM = limber pine; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA=mean basal area; BB HR = bark beetle hazard rating.

Table 12. Summary of data for Stand 13.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
WF	44(35)	0	12	50	53	NA
ASP	80(65)	100†	11	70	-	NA
Total	124	-	-	120	53	

*Tree species; WF = white fir; ASP = aspen; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA=mean basal area; BB HR = bark beetle hazard rating.
†Not attributed to bark beetles.

Table 13. Summary of data for Stand 14.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	195(81)	100	16	160	-	NA
WF	25(10)	0	12	20	203	NA
SAF	22(9)	0	13	20	-	NA
Total	242	-	-	200	203	

*Tree species; DF = Douglas-fir; WF = white fir; SAF = subalpine fir; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating.

Table 14. Summary of data for Stand 15.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	49(9)	87	14	53	60	L
LM	12(2)	0	14	13	-	NA
ASP	137(24)	100†	8	33	-	NA
SAF	371(65)	49	6	67	-	NA
Total	569	-	-	166	60	

*Tree species; DF = Douglas-fir; LM = limber pine; ASP = Aspen; SAF = subalpine fir; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating; L = low.
†Not attributed to bark beetles.

Table 15. Summary of data for Stand 17.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	83(37)	4	14	50	205	L-M
WF	143(63)	0	12	110	84	NA
Total	226	-	-	160	145	

*Tree species; DF = Douglas-fir; WF = white fir; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA=mean basal area; BB HR = bark beetle hazard rating; L = low; M = moderate.

Table 16. Summary of data for Stand 18.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	11(4)	0	23	27	-	L
WF	174(68)	0	9	53	110	NA
ASP	70(18)	0	11	47	105	NA
Total	255	-	-	127	107	

*Tree species; DF = Douglas-fir; WF = white fir; ASP = aspen; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA=mean basal area; BB HR = bark beetle hazard rating; L = low.

Table 17. Summary of data for Stand 19.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
WF	121(91)	0	6	20	81	NA
ES	12(9)	0	25	40	-	L
Total	133	-	-	60	81	

*Tree species; WF = white fir; ES = Engelmann spruce; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA=mean basal area; BB HR = bark beetle hazard rating; L = low.

Table 18. Summary of data for Stand 20.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	24(15)	100	19	40	182	NA
WF	96(61)	0	14	45	-	NA
ASP	22(14)	0	9	10	-	NA
SAF	6(4)	0	13	5	-	NA
ES	9(6)	0	10	5	86	L
Total	157	-	-	105	134	

*Tree species; DF = Douglas-fir; WF = white fir; ASP = aspen; SAF = subalpine fir; ES = Engelmann spruce; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating; L = low.

Table 19. Summary of data for Stand 21.

SP*	TPA (%)	% BB Mort	QMD(in)	BA (ft^2)	Age	BB HR
DF	83(28)	0	7	40	-	L
ASP	180(59)	0	9	120	-	NA
SAF	38(13)	0	7	20	-	NA
Total	301	-	-	180		

*Tree species; DF = Douglas-fir; ASP = aspen; SAF = subalpine fir; TPA=trees per acre; % BB Mort = the percentage of trees killed by bark beetles; QMD = quadratic mean diameter; BA= mean basal area; BB HR = bark beetle hazard rating; L = low.

Appendix 3. Potential Insect and Disease Agents of Southwestern Forest Types.

Insects				
Tree species	Bark Beetles	Defoliators	Terminal	Borers
Ponderosa Pine	MPB*	Pine sawfly	Shoot borers	Pitch mass borer
	WPB	Pine butterfly	Pine tip moths	
	RPB	Pine tortrix		
	RTB	Gouty pitch midge		
	Pine engravers	Needle miners		
		Weevils		
		Sheath miners		
		Pine needle scale		
Pinyon Pine	Pinyon Ips	Pinyon sawfly	Pitch nodule moth	Pitch mass borer
	Twig beetles	Needle scale		
		Tiger moth		
Juniper	Cedar BB	Spider mites	Twig pruner	Cedar borer
Gambel Oak		Fall cankerworm		
		Tent caterpillar		
		Leaf roller		
		Leaf tier		
		Leaf skeletonizer		
*MPB = mountain pine beetle; WPB = western pine beetle; RPB = roundheaded pine beetle; RTB = red turpentine beetle; BB = bark beetle				

Biotic Diseases				
Tree species	DM/Mistletoe	Rusts/Cankers	Root Disease	Foliar
Ponderosa Pine	Southwest DM*	Limb rust	Armillaria	Needlecasts
		Comandra rust	Schweinitzii	Pine shoot blight
		Atropellis canker		
Pinyon Pine	Pinyon DM	Pinyon blister rust	Black stain	Needle rust
Juniper	Mistletoe	Stem rust	Heartrot	
Gambel Oak				Anthracnose
*DM = dwarf mistletoe				

Abiotic Diseases	
Fire damage	Sunscald
Mechanical Injury	Herbicides
Frost Damage	

Appendix 4. Distinguishing between biotic and abiotic disease agents.

A. SYMPTOMS

Biotic Usually on specific plant parts; environmental conditions or inoculum dispersal factors account for unevenness of symptoms. Ex. Canker disease, rain dispersed foliage disease. Occurs as a progressive invasion and symptoms may include dead tissue surrounded by lighter green, yellowing tissue in foliar diseases or callous ridges with stem diseases.

Abiotic Usually uniform in symptom expression, unless portions of plant not exposed - winter dessication is uniform except for branches covered with snow. Not generally a progressive invasion.

B. SIGNS

Biotic Fruiting structures of pathogenic fungi such as conks or mushrooms and the effects of such fungi such as sunken, softer tissues of cankers, rust pustules of rust fungi.

Abiotic No signs of a biotic agent or only signs of non-pathogenic fungi. The latter, in some cases, may only be distinguished after laboratory examination.

C. HOST SPECIFICITY

Biotic Usually host specific or occur on a limited number of related or unrelated hosts.

Abiotic Symptoms may occur on two or more totally unrelated hosts.

D. SPATIAL DISTRIBUTION

Biotic Usually show clumpy type distribution because they are caused by pathogenic agents having a particular pattern of spread. Pattern may be related to favorable conditions for infection.

Abiotic Usually random except when the agent is distributed in a non-random fasion. Example, source pollution patterns are tied to the point source, i.e. factory, etc.