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# **Forest Insect and Disease History of the Carson National Forest - DRAFT**

**Input for the Carson NF Plan Revision**



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# Introduction

Insects and diseases are important components of forest ecosystems and greatly influence forest structure and species composition over time. While insects and diseases have ecological roles, their impacts often conflict with human objectives and forest management goals. Thus, we refer to their effects as damage, which is true on an individual tree basis or sometimes with respect to resource management objectives; however, whether these effects are detrimental or beneficial to the forest depends on an ecological perspective.

It is not just good forest stewardship to consider the role of insects and disease in our planning; it is also Forest Service policy (FSM 3401.1). Pursuant to the National Forest Management Act of 1976, the Forest and Rangeland Renewable Resources Planning Act of 1974, and the National Forest System Land Management Planning Rule (36 CFR Part 219, Subpart A, RIN0596-AD02 as corrected FR Doc. 2012-18322), consideration of the roles of insects and diseases is required, not only as disturbance agents, but as critical contributors to ecosystem function.

This report summarizes the most common forest insects and diseases on the Carson National Forest (NF) using information from historical reports, published documents, aerial survey information, and Forest Health staff knowledge. Aerial surveys were started in the Southwestern Region during the 1950s; however, early surveys were often for specific evaluations or projects. The original maps from these early aerial surveys are typically no longer available, but the information was summarized in various reports. Routine annual aerial surveys began in the mid-1970s and have continued to the present. Summarized annual regional insect and disease conditions reports from 1918 to the present were used extensively for this report with additional information from other reports and survey data and maps when available. National conditions reports were used for time periods when the regional reports are no longer available. When we refer to conditions reports in this document we are referring to these regional and national annual reports. While we present the history for each agent separately since that is often how they are recorded and discussed, the effects of insects and diseases are often closely interconnected. While one agent may be identified as a mortality agent, multiple factors often contributed to the tree's death. For example, trees most susceptible to attack by bark beetles often are stressed by pre-existing conditions, including overcrowding, dwarf mistletoe infection, root disease, and drought periods. In this report we also consider some possible effects of climate change on insect and disease activity in the Southwest.



# Pinyon-Juniper Woodlands

## Bark Beetles

Localized mortality of pinyon trees caused by the native pinyon ips bark beetle (*Ips confusus*) is not uncommon throughout New Mexico and on the Carson NF. During periods when pinyon ips populations are at endemic levels, individual or small groups of stressed, damaged, or diseased trees are attacked. These smaller events create openings and diversity in the woodland structure, providing opportunities for tree regeneration. Pinyon-juniper woodlands in New Mexico typically occur at elevations from 5,000 to 7,000 ft, however pinyon has a much larger elevation range, with individuals occurring from 3,000 ft up to over 10,000 ft (Burns and Honkala 1990). The trees on dry, low elevation sites at the edge of their elevation range are the most susceptible to attack by bark beetles. Additionally, high stand density and infection by pinyon dwarf mistletoe (*Arceuthobium divaricatum*) contribute to increased susceptibility (Wilson and Tkacz 1992, Negrón and Wilson 2003). Slash generated during thinning operations can provide breeding material where bark beetles reproduce and can attack residual trees. Trees can also be attacked by bark beetles drawn to the area by the volatile compounds released during thinning, chipping, and mastication operations in the spring and summer. Extensive outbreaks of pinyon ips, however, are primarily initiated and sustained by extended drought. Drought-stressed trees have reduced defenses against bark beetle attack and can provide ideal conditions for bark beetle colonization and reproduction. Widespread changes in the pinyon-juniper woodlands can be brought about by extended drought combined with resulting bark beetle activity, such as when the pinyon ips caused a significant loss of the pinyon component in some woodlands of central and northern New Mexico during the early 2000s.

Drought conditions can also cause outbreaks of the cedar bark beetle (genus *Phloeosinus*) and other woodboring beetles in juniper, however juniper mortality is usually less commonly observed than pinyon mortality. Three species of roundheaded borers (family Cerambycidae) can be found attacking drought-stressed juniper. They include: the juniper borer (*Atimia huachucae*) and the black-horned juniper borer (*Callidium texanum*), each commonly found in branches and the main stem, and the juniper twig pruner (*Styloxus bicolor*) that attacks the smaller branches or twigs. Multiple species of flatheaded borers (family Buprestidae) including *Trachykele blondeli* and *Chrysobothris* spp. can be found boring in the larger branches and main stem of weakened trees (Itami and Craig 1989, Cain and Parker 2004).

Dendrochronological analyses of pinyon demography from the Sevilleta National Wildlife Refuge in central NM provide a unique long-term perspective of pinyon recruitment and mortality in the state (Swetnam et al. 1998). Based on the dendrochronological records, an extreme drought during the late 1500s is thought to have caused or contributed to substantial pinyon mortality in this area, similar to and potentially greater than the better-known 1950s drought period (Swetnam et al. 1998). Pinyon ips beetles were likely a contributing factor to the tree mortality during this event. More recently, the 1950s drought and associated beetle activity contributed to pinyon mortality throughout the state. Conditions reports describe *Ips* spp. beetle populations starting to build in the early 1950s and by 1956 and 1957 attacking and killing pinyon over extensive areas in New Mexico. The mortality of pinyon on the Sevilleta NWR during the 1950s was greater in the older pinyon age classes, leaving younger trees in many locations. Swetnam and others (1998) observed from their dendrochronological studies that “*this mortality episode stands out as a singular event in the five century history of these pinyon-juniper stands.*”

The most recent outbreak on the Carson NF occurred primarily during 2002 – 2004 and was initiated by the drought that began in the late 1990s. This drought was considered to be similar to

the one during the 1950s, but with anomalously high temperatures (Breshears et al. 2005). The affected areas on the Carson NF were mostly on the southern portions of the Canjilon, El Rito, and Tres Piedras Ranger Districts (RD). Based on our aerial surveys, the area surrounding Ojo Caliente and La Madera was some of the most severely impacted in the state. Of the 284,500 acres mapped with pinyon mortality during aerial detection surveys on the Carson NF from 2002 – 2005, the El Rito RD had the largest portion of the affected area. These low elevation pinyon sites were most affected and in some cases may have been supporting pinyon trees that had encroached upon drier juniper grassland sites during the wetter periods following the 1950s drought. It is common to observe shifts in tree species along the edges of ecotones such as those between woodlands and grasslands. Even in areas of high mortality, however, observations and measurements showed varying degrees of pinyon survival from seedlings to some mature trees.

Localized outbreaks of pinyon ips will continue to be a part of pinyon-juniper woodland ecology and should be expected in dense stands, especially in low elevation sites along ecotones, older stands, and those under stress from other factors, such as dwarf mistletoe. During drought periods, widespread outbreaks of pinyon ips and juniper mortality from various beetles and borers are probable. The likelihood of pinyon ips activity in the next few decades for those areas most severely affected during the recent outbreak has been greatly reduced due to (1) less competition among the now more widely spaced remaining trees, (2) previous mortality of the most at-risk trees, including those on very poor sites or those at the edge of the natural range of pinyon, and (3) less host type. Overall there is, however, still a substantial amount of pinyon on the Carson NF that could be affected by future outbreaks. Betancourt and others (1993) estimate in their history of pinyon woodlands that there is a high probability of a catastrophic “killing” drought occurring during the potential life span of pinyon trees. Based on these observations, pinyon populations rarely reach equilibrium and are often affected by disturbance.

Climate change is already modifying ecosystems (Walther et al. 2002) and it is expected to substantially change forest insect and disease dynamics (Dale et al. 2001, Bale et al. 2002, Williams and Liebhold 2002, Logan et al. 2003, Ryan et al. 2008). In New Mexico, the effects of climate change could have significant impacts on our woodland ecosystems. The rising temperatures and reduced snowpack conditions observed in the western U.S. (Knowles et al. 2006) are already putting stress upon our forest ecosystems. If the most widely accepted climatic models are correct, warmer temperatures, less snowpack, more variable precipitation and extreme events (State of New Mexico 2005, Knowles et al. 2006, Seager et al. 2007) would in general create greater stresses on woodlands. Even in the presence of normal precipitation levels in the Southwest, warmer temperatures alone could lead to tree mortality from moisture deficits caused by an increase in evapotranspiration (Adams et al. 2009). Periods of drought or even average precipitation levels exacerbated by higher temperatures and the high stand densities could contribute to future widespread bark beetle outbreaks and tree mortality in pinyon-juniper woodlands.

## **Defoliating Agents**

Insects and diseases that defoliate pinyon trees typically do not cause substantial or long-term damage. Needle diseases appear infrequently and often have temporary impacts. Direct mortality from needle diseases is rare (Cranshaw et al. 2000), however successive years of infection can result in growth loss and can predispose trees to other agents. Needle diseases of pinyon are caused by several fungal agents. Abnormally high rainfall or humidity levels during the spring

and early summer are necessary for the development of an outbreak of needle disease. During 2007, a widespread outbreak of a needle blight in New Mexico affected much of the pinyon woodlands, especially in the central and southern portions of the state.

Defoliating insects associated with pinyon include pinyon needle scale (*Matsucoccus acalyptus*), pinyon needle miner (*Coleotechnites edulicola*), pinyon sawflies (*Neodiprion edulicolus* and *Zadiprion rohweri*), and tiger moth (*Lophocampa ingens*). The damage from these insects is typically either temporary or limited in long-term impacts and has not been of major concern. Pinyon needle scale has had more chronic infestations, but typically is not a major pest in a forest setting. It is, however, often observed on trees in developed areas. Pinyon needle scale has at times has been mapped during aerial detection surveys on the Camino Real and Questa RDs, affecting between 1,000 and 2,000 acres. Tiger moth and needle miners have both been observed and recorded occasionally on the Carson NF. In contrast to pinyon, insect defoliators of juniper are less common.

## Mistletoes

Pinyon dwarf mistletoe (*Arceuthobium divaricatum*) occurs in pinyon woodlands throughout the state. Its behavior and effects are similar to those of southwestern dwarf mistletoe (*A. vaginatum* ssp. *cryptopodum*) on ponderosa pine (see following ponderosa pine section). Little direct quantitative information is available on current or historic distribution and abundance of this dwarf mistletoe. Its current distribution may be similar to that in the 1800s, but the intensity of infestations is possibly greater due to increased host densities that allow a higher probability of explosively released seeds to land on adjacent host trees. Juniper mistletoe (*Phoradendron juniperinum*), a true mistletoe, is common and widespread throughout most of the host type. Heavy infestation of juniper mistletoe increases host mortality during drought. Seeds of *Phoradendron* spp. are distributed by birds, as they are an important winter avian food source.



# Ponderosa Pine Forests

## Bark Beetles

There are several species of bark beetles that attack ponderosa pines in the Southwest. The primary species on the Carson NF are: the western pine beetle (*Dendroctonus brevicomis*), the mountain pine beetle (*Dendroctonus ponderosae*), numerous species of ips engravers (*Ips* spp.), and less commonly the roundheaded pine beetle (*Dendroctonus adjunctus*) and red turpentine beetle (*Dendroctonus valens*). The various species of bark beetle often selectively attack specific sizes of trees or partition their attacks in different parts of the same tree: *Dendroctonus* species favoring larger diameter trees while *Ips* species favor smaller diameter trees or the smaller diameter portions (tops, branches) of larger trees. Stand density is an important factor in determining the risk of bark beetle activity and the extent of resulting mortality (Fettig et al. 2007). Various studies have found that the susceptibility of a stand to bark beetle activity starts when stand basal areas reach the range of 60-100 ft<sup>2</sup>/acre and increases with increasing basal area, reaching a high level of susceptibility at basal areas in the range of 120-150 ft<sup>2</sup>/acre (Kegley et al. 1997, Negrón 1997). Additionally, slash generated from thinning in the spring can provide breeding material that occasionally results in mortality of residual trees. Standing trees can also be attacked by bark beetles following chipping and mastication treatments completed in the spring and summer. As with the pinyon ips, extensive outbreaks of ponderosa pine bark beetles in the Southwest are primarily triggered and sustained by extended drought. Drought-stressed pine trees have much less resistance to bark beetle attacks due to reduced sap pressure. Additionally, dense, crowded stand conditions can contribute to greater levels of tree mortality during outbreaks because of competition for moisture.

Records of bark beetle activity in ponderosa pine on the Carson NF occur in the earliest available conditions reports dating back to 1918. An infestation by *Dendroctonus* beetles was noted in Garapata Canyon on the Questa RD that continued until 1925. More extensive activity by mountain pine beetle, specifically, was noted in the late 1930s and early 1940s on the Carson NF and surrounding lands. Specific locations identified included Agua Caliente Canyon, Cieneguilla Creek, Moreno Creek, Rancho del Rio Grande Grant, and Rio Pueblo. During this period, there was often an emphasis on implementing control measures when possible. In 1938 and 1942, cutting, peeling and burning were conducted on over 6,600 acres in an effort to suppress mountain pine beetle outbreaks.

The next major record of ponderosa pine mortality occurred in NM during the 1950s drought. This drought period resulted in tree mortality throughout the Southwest. Epidemic levels of pine engraver beetles along with *Dendroctonus* spp. were noted in the 1950s throughout the state. In 1957, 1.7 million acres with ponderosa mortality were noted in Arizona and New Mexico. The specific reports of activity on the Carson NF were recorded as mountain pine beetle. Activity was recorded across the northern portion of the Tres Piedras RD, and Lama Canyon on the Questa RD. Minor activity was recorded in 1961 on Felipito Canyon on the El Rito RD. In 1969, an outbreak of mountain pine beetle affecting Carracas Mesa was suppressed by salvage logging. Only minor isolated tree mortality from bark beetles was noted during the 1970s and early 1980s.

During the most recent drought period, ponderosa pine forests on the Carson NF were not as severely affected as the pinyon-juniper woodlands. Some ponderosa mortality, however, was mapped during aerial surveys. From 2000 to 2006, a total of approximately 9,600 acres with ponderosa pine mortality were mapped within the Carson NF. The bark beetle species observed

during ground evaluations over the past decade, however, have been primarily a combination of western pine beetle and *Ips* spp. Only a small number of isolated, individual trees attacked by mountain pine beetle have been observed in northern NM during this time period. Most ponderosa pine mortality aerially mapped in the late 1990s and early 2000s was attributed to mountain pine beetle as that had been the predominant bark beetle species observed in northern NM in the past. It is unknown why the prevalence of mountain pine beetle activity has declined and most recent ponderosa mortality on the Carson NF seems to be resulting from western pine beetle and *Ips* spp. It may be that northern NM has not had a significant enough mountain pine beetle event to be of attention and identified on the ground or that in some cases the species of bark beetle involved was misidentified. While important from an entomological perspective for understanding population dynamics, the forest conditions most susceptible to ponderosa bark beetles and the resulting outcomes are the same regardless of the specific bark beetle species involved.

Localized activity of bark beetles in single trees and small groups will continue to be a part of the ponderosa pine forest ecology and should be expected in dense stands, especially those under stress from dwarf mistletoe, other agents, or abiotic factors. The greater abundance of dense, crowded stands due to fire exclusion and past management activities has increased the potential for bark beetle activity over pre-settlement stand conditions and contributed to higher mortality levels when drought-related outbreaks develop. The most extensive ponderosa mortality from bark beetles recorded on the Carson NF has occurred primarily during dry periods.

Climate changes will affect bark beetle activity in the ponderosa pine forest type. Lower elevation ponderosa pine sites, along the edge of the woodland – ponderosa ecotone will be most susceptible. Dense ponderosa pine forests experiencing increased levels of water stress have a greater potential for widespread bark beetle activity. Shorter drought periods, which previously may not have triggered more extensive bark beetle outbreaks, could under warmer conditions, be sufficient to cause greater mortality (Adams et al. 2009).

## Defoliating Agents

Defoliating agents of ponderosa pine have historically been of minor significance on the Carson NF. Needle diseases on ponderosa pine are observed throughout New Mexico on occasion as was the case in the late 1980s when widespread infections were observed. These are often thought to be caused by *Lophodemella cerina*, but other fungi may be involved as well. Needle diseases appear infrequently when high rainfall occurs in spring and early summer. Infections often have temporary impacts and direct mortality from needle casts is rare, though successive years can result in growth loss and predispose trees to other agents (Cranshaw et al. 2000). Because needle diseases often have limited effects, they are not often noted in records. Other defoliating agents observed sporadically on the Carson NF include pine sawflies (*Neodiprion* spp. and *Zadiprion* spp.), pine tip moth (*Rhyacionia* spp), tiger moth (*Lophocoampa ingens*), pine butterfly (*Neophasia menapia*), and pine budworm (*Choristoneura lambertiana*). Tiger moth activity is commonly seen in ponderosa pine stands because of the conspicuous webs it forms in the tops of trees, but it rarely occurs at levels that would cause concern.

## Dwarf Mistletoe

Southwestern dwarf mistletoe (*A. vaginatum* ssp. *cryptopodum*), a parasitic plant, is often considered the most damaging pathogen of ponderosa pine on the Carson NF. In the mid-1980s, an estimated 33% of the host type on the Carson NF was infected (Beatty et al. 1987), which was close to the regional average (Maffei and Beatty 1988). The Camino Real RD has both the highest and lowest incidence observed on the Carson NF, with incidence on the northern portion of the district measured at 21% and the southern portion of the district measured at 66%. Dwarf mistletoes are a persistent, chronic infection, and the overall incidence (acres affected) changes only slightly from year to year. Horizontal spread through forest stands averages one to two feet per year (Hawksworth 1961). Because of spread from ballistic seed and other ecological factors, dwarf mistletoes usually have a patchy distribution within infested stands and across the landscape.

All ages and sizes of ponderosa pines can become infected. Usually, once a tree becomes infected, the disease slowly intensifies until the tree dies. Heavily infected trees are often the first trees attacked and killed by bark beetles, especially during dry periods (Kenaley et al. 2006 and 2008). However, most infected trees can survive for several decades, with gradual decline in growth and vigor. Trees infected at a young age become stunted and deformed, limiting growth and development into large trees. While impact from dwarf mistletoe can represent a significant economic loss, dwarf mistletoes, like other native insects and diseases, are natural parts of the ecosystem and tend to increase biodiversity (Hawksworth and Wiens 1996, Geils et al. 2002).

Little direct quantitative information is available on the changes in dwarf mistletoe distribution and abundance since pre-settlement conditions. Heavy logging in the late 1800s is thought to have reduced mistletoe in some areas of northern New Mexico where stands had large trees and overall lack of an understory component (Hawksworth 1961). Management activities, specifically timber harvest, stand thinning, and fire suppression that began with the designation of National Forests in the early 1900s have influenced the abundance and/or distribution of dwarf mistletoes on the landscape (Conklin and Fairweather 2010). For several decades, harvest and thinning activities throughout the region favored the removal of infected trees, theoretically reducing infection levels within a project area. However, the vast majority of entries involved some form of selective cutting, which, over the long-term left more infected trees than it removed and tended to favor the spread of dwarf mistletoe (Hawksworth 1961). While past silvicultural treatments have generally increased stand growth and productivity, they have had little overall effect on the distribution of dwarf mistletoe, since the parasite can only be eradicated with a properly conducted seed tree treatment or a clearcut. After standard harvesting practices where efforts were not made to remove all visibly infected trees, stand infection levels were found to return to pre-treatment levels in about 20 years (Geils unpublished data). Today, older infected stands are relatively uncommon, especially trees with large witches' brooms which have the greatest ecological value (Conklin and Fairweather 2010).

Beatty and others (1987) report that the incidence of pine dwarf mistletoe on the Carson NF remained essentially unchanged since a similar 1950s survey (Andrews and Daniels 1960), based on a comparison of roadside surveys that were conducted over the same area. However, there is general agreement that incidence throughout the Southwest has increased over the past century, due to uneven-aged conditions that allowed young trees to become established under infected overstory trees, leading to an increase in the number of infected trees. Today's forests contain

many more trees than those in the mid to late 1800s due largely to fire suppression and lack of widespread forest management.

Fire is an important natural control of dwarf mistletoe. Following stand replacement fires, trees usually return to burned areas well in advance of the pathogen (Alexander and Hawksworth 1975). Lower intensity fires tend to reduce infection levels via differential tree mortality and the scorch pruning of lower limbs of surviving trees where dwarf mistletoe infection is typically concentrated (Harrington and Hawksworth 1990, Conklin and Armstrong 2001, Conklin and Geils 2008). Data from six prescribed underburns in northern and central New Mexico indicate that a uniform underburn generating 50% average crown scorch sets dwarf mistletoe back about ten years (Conklin and Geils 2008). In addition to these direct controlling effects, a historic fire regime of frequent low intensity fires would keep forests more open and park-like, limiting tree-to-tree spread of dwarf mistletoe.

## Root Disease

Root diseases typically occur at low levels in ponderosa pine stands in the Southwest, but can be more severe in localized areas. In general, root diseases reduce tree growth and longevity, often resulting in small forest openings. Occasionally, they become more active and damaging following harvest activities, since large stumps serve as persistent food bases for causal fungi.

Armillaria root rot (*Armillaria solidipes*<sup>1</sup>), annosum root rot (*Heterobasidion irregulare*<sup>2</sup>), and Schweinitzii root and butt rot (*Phaeolus schweinitzii*) are the most common root diseases of ponderosa pine in New Mexico. Infected ponderosa pines may be more susceptible to bark beetle attack because of reduced vigor.

While projections on climate changes for the Southwest vary, if the most widely accepted climatic models are correct, warmer temperatures and more variable precipitation (State of New Mexico 2005) would in general create greater stresses upon forest conditions. Root diseases that are already established and adapted to the Interior West, such as Armillaria root rot, would be expected to proliferate in stressed forest environments (Klopfenstein et al. 2009).

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<sup>1</sup> = *A. ostoyae*

<sup>2</sup> = *H. annosum*

# Mixed Conifer Forests

## Bark Beetles

The primary bark beetles in the mixed conifer forests are the Douglas-fir beetle (*Dendroctonus pседotsugae*) in Douglas-fir, and the fir engraver (*Scolytus ventralis*) in white fir. Because the Douglas-fir beetle has often been considered the primary mortality agent in Douglas-fir, the role of many of the other bark beetles and woodborers has probably been underestimated. The Douglas-fir pole beetle (*Pseudohylesinus nebulosus*) and Douglas-fir engraver (*Scolytus monticolae*) are two that contribute significantly to Douglas-fir mortality. Although technically classified as a borer, the flatheaded fir borer (*Phaenops drummondi*) feeds and develops in the phloem/cambium interface, much like bark beetles, and can be a mortality factor in weakened, drought stressed, or fire-affected Douglas-fir. The Douglas-fir pole beetle typically attacks smaller trees or the tops of large trees. As with the bark beetles in pines, attacks during endemic population levels are typically limited to injured or diseased trees. Stand density, species composition, and host tree diameter are all important factors in determining susceptibility of attack by these bark beetles (Ferrell et al. 1994, Schmitz and Gibson 1996). While outbreaks of these bark beetles can occur as a result of drought, other forest disturbances, particularly fires, wind throw events, and for the fir engraver, defoliation, can trigger outbreaks. Since these beetles are host selective, outbreaks can shift the tree species composition of mixed conifer forests.

Douglas-fir beetle activity first occurs in our records for the Carson NF during the mid-1930s. The first reports were only brief mentions, until reports described a region-wide epidemic level of Douglas-fir beetle starting in the mid-1950s and continuing until the early 1960s. Specific locations of activity were not mentioned. Not until the early 1980s was Douglas-fir beetle activity again recorded. At this point, activity in scattered individual trees and small groups was observed, especially in areas defoliated by the western spruce budworm (Bennett 1983). This outbreak expanded and evaluations of the activity on the Carson NF found that these areas were predisposed to attack by:

“(1) Several years of severe western spruce budworm defoliation, (2) dwarf mistletoe, *Arceuthobium douglasii*, infections, (3) various root diseases, and (4) poor site conditions” (Rogers and Maffei 1987).

Increased mortality of Douglas-fir was next observed during the mid-2000s most likely related to the drought period.

Fir engraver outbreaks and overall mortality of white fir are often closely tied to drought periods (Fairweather et al. 2006). Fir engraver activity was first noted in conditions reports for the Carson NF in 1960. Other periods of increased fir engraver activity were noted in 1983, during the late 1980s, and most recently in the mid-2000s.

It is widely accepted that fire exclusion and past management activities in mixed conifer forests have contributed to higher stand densities and greater proportions of white fir and Douglas-fir than pine. White fir is particularly vulnerable to fire, thus the interruption of natural fire cycles has favored it as a component of mixed conifer stands. These changes have probably increased the potential for bark beetle activity above what would have been expected in pre-settlement conditions and contributed to greater tree mortality when outbreaks do develop. The limited length of records for bark beetle activity in the mixed conifer forests of the Carson NF exhibits no major changes in outbreak frequency or duration.

The projections of continued temperature increases and reduced snowpack levels in New Mexico (State of New Mexico 2005) along with competition in dense forest stands could result in water stressed mixed conifers forests that have greater susceptibility bark beetle activity. Large scale disturbances such as fire may contribute to initiating some outbreaks, especially those of Douglas-fir beetle.

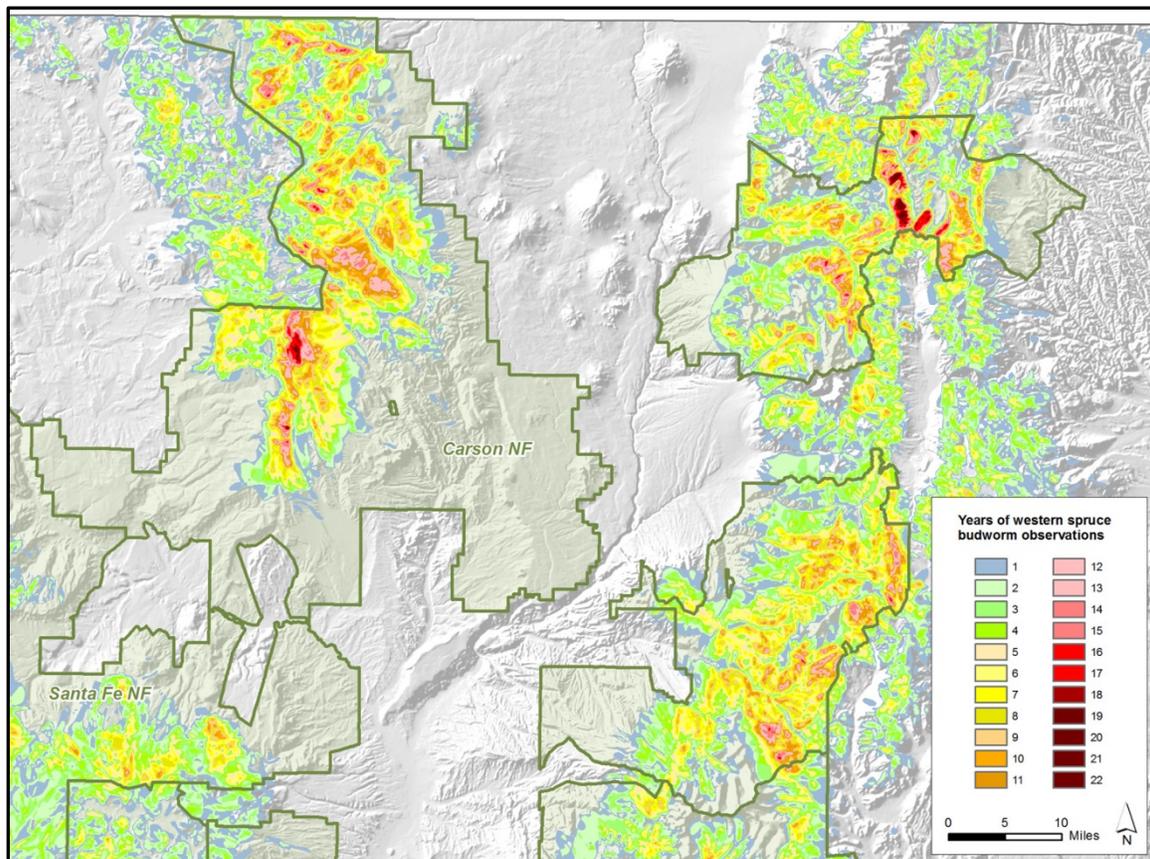
## Defoliating Agents

### Western Spruce Budworm

The western spruce budworm (*Choristoneura freemani*, formerly *C. occidentalis*) is a native defoliating moth larvae that feeds upon Douglas-fir, white fir, spruce, and corkbark fir. It often causes the greatest defoliation to its preferred hosts, Douglas-fir and white fir. Multiple consecutive years of heavy feeding of western spruce budworm can result in reduced tree growth, top-kill, and predisposition to bark beetle attack (Fellin and Dewey 1986). Direct tree mortality can result from repeated defoliation and often occurs in the understory, where the trees are heavily fed upon by budworm larvae descending from the upper canopy.

Dendrochronological reconstructions in the southern Rocky Mountains have shown that outbreaks of the western spruce budworm have long been a part of western forests, occurring repeatedly over at least the past several centuries (Swetnam and Lynch 1993, Ryerson et al. 2003). From their reconstructions in northern New Mexico, Swetnam and Lynch (1993) found evidence of regional outbreaks occurring during 1710-1835, 1745-1775, 1790-1840, 1950-1860, 1870-1880, 1885-1900, 1910-1925, 1940-1965, and 1975-1989 (the outbreak during which the study was completed). Budworm has only been known in western North America since 1909 when it was first observed in British Columbia (Brookes et al. 1987). The first documented record of western spruce budworm activity on the Carson NF was in 1922 (Lessard 1975). It is a constant presence in the mixed conifer forests of New Mexico and over the past few decades, budworm activity has been an ongoing and chronic disturbance in northern New Mexico. Activity has fluctuated with increased defoliation observed on the Carson NF in 1929-1932, 1935-1937, 1940-1942, 1944-1946, 1953-1955, 1960-1968, 1975-1991, and 1994-present.

Aerial detection surveys have mapped a consistent and extensive area affected by western spruce budworm defoliation in northern New Mexico. Data from 1985 to the present show varying levels of activity throughout this period with peaks of activity in 1994, 2001, and 2009. Defoliation has been most often mapped on the Camino Real, Questa, and Tres Piedras RDs and along the Mogote Ridge (figure 1). Activity has fluctuated during this period with less affected area mapped in 1989, 1992-1993, 1996, 2000, and 2003-2006. These periods typically correspond with the long-term patterns observed in dendrochronological reconstructions that show fewer outbreaks often coinciding with periods of decreased moisture (Swetnam and Lynch 1993, Swetnam and Betancourt 1998, Ryerson et al. 2003).



**Figure 1. Number of years that western spruce budworm defoliation has been mapped during aerial detection surveys from 1985 to 2013 on the Carson NF.**

Due to widespread and almost yearly defoliation caused by western spruce budworm in northern New Mexico, several studies and control projects have been conducted since the mid-1950s. Small scale aerial application of DDT to minimize damage was tested in New Mexico in 1953 and 1954 (Bongberg and Bennett 1955). Following Bongberg and Bennett's 1955 appraisal of activity in the region, more significant control projects were conducted, starting with an application of DDT on over 104,000 acres of the Tierra Amarilla area during 1955 (Massey 1955). DDT applications continued through the 1960s while a few treatments used dimethoate or malathion instead (Lessard 1975). There was a transition to using Carbaryl in the 1970s and additionally *Bacillus thuringiensis* var. *kurstaki* (Btk) in the 1980s. As an example of the scale of the control efforts, in 1962 nearly 445,000 acres on the Carson and Santa Fe NFs were sprayed for budworm. Large scale control efforts were continued through the 1980s.

The long-term tree-ring based reconstructions in northern NM show a trend toward more synchronous and widespread outbreaks (Swetnam and Lynch 1993). These trends suggest that fire suppression and past logging practices that have led to more contiguous denser stands, composed primarily of white fir and Douglas-fir, have contributed to more widespread and intense budworm outbreaks. Based on past activity, budworm will continue to be a persistent defoliator in the mixed conifer and spruce-fir forests of the Carson NF. Since outbreaks have been associated with periods of increased moisture (Swetnam and Lynch 1993, Swetnam and Betancourt 1998,

Ryerson et al. 2003), the warmer and drier conditions projected in future climate change scenarios could reduce budworm activity and temper severity of future budworm outbreaks.

### **Douglas-fir Tussock Moth**

The Douglas-fir tussock moth (*Orygia pseudotsugae*) is a more serious defoliator of the mixed conifer forests than the western spruce budworm because it often can completely defoliate trees during high population levels. Outbreaks of this insect occur on the Santa Fe NF, specifically the canyons near Los Alamos and Santa Clara. While this insect has been noted on ornamental Douglas-fir trees in Taos and Raton, there are no known or recorded outbreaks of Douglas-fir tussock moth on the Carson NF.

### **Dwarf Mistletoe**

Douglas-fir dwarf mistletoe (*A. douglasii*) is common and widespread on the Carson NF. Less long-term monitoring has been conducted on this mistletoe in the Southwest than on southwestern dwarf mistletoe, but in 1960 Andrews and Daniels estimated that approximately 50% of the Southwest's Douglas-fir type was infested. Similar to southwestern dwarf mistletoe, the overall incidence and total acres infected by Douglas-fir dwarf mistletoe has likely increased somewhat over the past century due to fire suppression and uneven-aged forest conditions. The large witches' brooms on older infected host trees are beneficial for wildlife, serving as nesting, foraging, and caching sites for birds and small mammals (Hedwall et al. 2006). Hedwall and others (2006) found sixty-seven percent of surveyed Douglas-fir dwarf mistletoe witches' brooms in Arizona and New Mexico were used by red squirrels (Hedwall et al. 2006). Raptors, including Mexican spotted owls, and several passerine birds nest in Douglas-fir dwarf mistletoe brooms (Hedwall 2000).

White pine dwarf mistletoe (*A. cyanocarpum*) infects limber pine through much of its range in the western states. It is not found in the Southwest, however, with the possible exception of limited locations in northern New Mexico. This species will also infect bristlecone pine.

### **Root Disease**

Root diseases are more common in mixed conifer than in ponderosa pine forests because the mesic conditions are more favorable to both fungi and the susceptible host tree species. Root disease impacts likely increased over the past century due to the fire-suppression induced shift from pine-dominated forests to forests having a greater proportion of shade tolerance species.

In general, root diseases reduce tree growth and longevity, often resulting in small forest openings. Occasionally, root disease become more abundant and damaging in the years following harvest activities, since large stumps can serve as a persistent food base for the causal fungi. Although all age classes of trees can be affected, root disease is more prevalent in older trees.

Armillaria root rot, annosum root rot (*H. occidentale*), and Schweinitzii root and butt rot are the most common root diseases in New Mexico mixed conifer forests. While each of these has a broad host range, annosum root rot is most often found on white fir, while Armillaria root rot is found on Douglas fir, subalpine fir and spruce. Schweinitzii root and butt rot is most common in old-growth Douglas-fir.

Root diseases often appear to proliferate on stressed trees, so their significance increases following drought, which may be more common with climate change. Infected trees, especially true firs and Douglas-fir, are more susceptible to bark beetle attack than are uninfected trees.

While projections on climate change for the Southwest vary, if the most widely accepted climatic models are correct, the warmer temperatures and more variable precipitation (State of New Mexico 2005) would create greater stresses upon Southwestern forests. Root diseases that are already established and adapted to the Interior West, such as *Armillaria* root rot, would be expected to proliferate in stressed forest environments (Klopfenstein et al. 2009).

## Broom Rust

Fir broom rust (*Melampsorella caryophyllacearum*) is found throughout New Mexico on white fir and corkbark fir. These infections cause growth loss, top-kill, and occasional tree mortality. It has historically not been a major problem on the Carson NF. Although not considered a “primary mortality agent,” broom rust contributes to tree stress and likely subsequent fir mortality observed during drought periods. Although broom rust infections can serve as nesting platforms for wildlife, they are considered hazardous in developed recreation sites because of tree failure at the site of bole infections.

## White Pine Blister Rust

White pine blister rust (WPBR), caused by the fungus *Cronartium ribicola*, is a recently introduced invasive disease in the Southwestern Region and is one of the most damaging tree diseases in North America. It was first detected on the Lincoln NF in 1990 and subsequently has been found on the Cibola, Gila, and Santa Fe NFs.

No known infections of WPBR currently exist on the Carson NF; however it is likely to be found in the near future. Eventually the disease is expected to impact white pine populations in many areas of the Southwest and may even eradicate white pine from the most susceptible sites. Moist drainages and higher elevation stands are the most vulnerable, especially where orange gooseberry (*Ribes pinatorum*), the preferred alternate host, is present. Even where conditions are especially favorable for blister rust, some trees may be resistant, providing a seed source for natural selection and eventual recovery. On drier, low hazard sites, infection rates and mortality are expected to be relatively low; these sites will serve as important genetic refugia for white pines. Maintaining and promoting genetic diversity among white pines should help ensure the long-term survival of these unique trees. We are advocating the retention of white pine during thinning treatments in order to conserve the broadest possible genetic diversity. While the presence of the alternate host, *Ribes* spp. (gooseberry or currant), is necessary to complete the rust’s life cycle, *Ribes* spp. removal is not considered a viable control strategy. See Conklin et al. 2009 for more on these topics.



# Aspen Forests

## Defoliating Agents

The western tent caterpillar (*Malacosoma californicum*) and the large aspen tortrix (*Choristoneura conflictana*) are the insects most often found defoliating aspen on the Carson NF. Typically these defoliators are not considered detrimental to aspen stands because the trees refoliate during the same season. However, repeated defoliation over successive years can reduce the growth and vigor of trees and potentially predispose them to other agents. Activity from these insects along with occasional other defoliating insects including the aspen leaf blotch miner (*Phyllonorycter apparella*) and the aspen leafminer (*Phyllocnistis populiella*) are observed frequently on the Carson NF.

Tent caterpillar-caused defoliation was first recorded on the Carson NF in 1926. The first record of the large aspen tortrix was in 1940. Since those first reports, activity has been often recorded with periods of increased aspen defoliation observed during 1926-1936, 1940-1945, 1949, 1952-1966, 1971-1974, 1982-1987, 1991-1993, 1996, 1998, 2004-2005, 2007-present. Activity has been particularly noted across the Carson NF and surrounding area, with specific records in the El Rito drainage, Canjilon Lakes, Red River, Rio Pueblo, San Antonio Mountain, and in the vicinity of Chama. In general, the western portion of the Carson NF has historically had the most activity by these insects.

Fungal diseases, including black leaf spot (*Marssonina populi*) and leaf rust (*Melampsora* spp.), are common on aspen foliage, but since symptoms generally appear later in the summer, they are only occasionally observed during aerial surveys. Because the trees have completed most of their photosynthetic activity by this point in the season, the damage is primarily aesthetic, reducing fall color.

## Aspen Cankers

The soft bark of aspen is easily wounded by physical injury, various insects, and abiotic factors like winter injury. These wounds allow for the development of various canker diseases. Cytospora canker and sooty bark canker are both widespread and found throughout the range of aspen. Management activities within aspen stands can exacerbate canker issues due to physical wounding of trees. Additionally, these are of concern in recreation areas, administrative sites, and other developed locations where hazard tree management is an issue and inadvertent wounding is likely to occur.

### Cytospora Canker

Cytospora canker is the most common fungal disease found on aspen in the Southwest. It is considered an opportunistic pathogen, infecting primarily stressed trees affected by drought, winter injury, excess water (flooding) and other insects and diseases. It is particularly insidious because while the trees may be able to recover from the initial stress, many will have been killed by diffuse cankering.

### Sooty Bark

Sooty bark canker is less common than Cytospora canker, but is considered the most aggressive canker infecting aspen trees in the Southwest. It is found primarily on larger dominant or co-

dominant trees and can cause mortality within 3 to 10 years. Like *Cytospora* canker, sooty bark requires a wound to initiate infection.

## Aspen Root Rot

Ganoderma root rot (*Ganoderma applanatum*) affects living aspen in the Southwest but occurs throughout the range of aspen, primarily as a saprophytic wood decay fungus. The disease is most prevalent on sites most conducive to aspen growth with moist, deep soils. New infections are likely initiated through wounds at the base of trees or through root-to-root contact with adjacent infected trees. Because root rot compromises the anchoring integrity of the root system, windthrow of affected trees is a common issue in infected stands. The crown of an infected tree usually appears relatively healthy, complicating efforts to identify hazard trees during inspections of developed sites (e.g. campgrounds).

## Aspen Mortality

Aspen abundance is often closely tied to the amount of disturbance on the landscape. Compared with conifers, individual aspen trees are short-lived, in part due the effects of several insects and diseases, but the genetic clone from which they sprout can be long-lived. Usually found in early-successional stands, aspen are often replaced by conifer species in the absence of disturbance such as fire or logging. Various studies and authors have documented that aspen abundance in the Interior West has been declining since the mid-1900s due mostly to fire suppression and the encroachment of conifer species (Kay 1997, Bartos and Campbell 1998, Bartos 2001). White fir, which is less fire tolerant than Douglas-fir, has an increasing presence in aspen stands as a result of fire suppression. This trend observed throughout the Interior West could be due in part to increases in aspen abundance from the mid-1800s to the early 1900s in response to timber harvesting and associated fires. Fires were historically more frequent, but extensive disturbances starting in the 1800s may have provided for regeneration and increased abundance of aspen, perhaps higher than pre-settlement levels. Touchan and others (1996) found that much of the aspen in the nearby Jemez Mountains of the Santa Fe NF was established 1850 - 1910 and probably in response to patchy, intense stand-opening fires.

As landscape disturbances declined beginning in the early 1900s, aspen regeneration declined. The major missing disturbance agent on the landscape was fire, due to suppression efforts and the grazing related loss of fire-carrying fine fuels. Additionally, the aspen regeneration that did occur was subject to greater grazing pressure from both wildlife and domestic animals. Recently, we have been observing aspen mortality throughout NM during our aerial surveys. Aspen on southerly aspects are more susceptible to drought, particularly at the lower elevational limit of its range, and entire clones may be affected on such sites. On the Carson NF, most aspen mortality observed has been in the Canjilon and Hopewell Lakes areas, partly due to the chronic defoliation by western tent caterpillar and large aspen tortrix experienced over the last decade. Mortality has been observed throughout the forest, however, and like the rest of the state, this mortality appears to be an abrupt change rather than succession-related and may be the cumulative effect of years of drought in the early 2000s and 2010s combined with insect-caused defoliation and stem cankers. While this type of mortality event may not be unprecedented in the long-term history of aspen, the decreased abundance of this species on the landscape makes this recent mortality of concern.

# Spruce-Fir Forests

## Bark Beetles

The two primary bark beetles in the spruce-fir forests are spruce beetle (*Dendroctonus rufipennis*) in Engelmann spruce and western balsam bark beetle (*Dryocoetes confusus*) in corkbark fir. Spruce beetle outbreaks are often started by large disturbances, particularly windthrow events and tend to be associated with larger diameter (>12" DBH) trees. As with bark beetle activity in other forest types, higher stand densities increase the risk of bark beetle activity in the spruce-fir forests. Western balsam bark beetle attacks have been found to be associated with stands that have a higher fir stand density index and incidence of root disease. The stand characteristics that increase the risk of spruce beetle outbreaks are much the same: density, proportion of spruce in the stand, and size of the trees.

Risk factors for spruce beetle outbreaks (Schmid and Frye 1976)

Risk Category	Physiographic Location / Site Index	Average Diameter of Spruce Above 10" DBH	Stand Basal Area (ft <sup>2</sup> / acre)	Proportion of Stand that is spruce (%)
High	Spruce on well-drained sites in creek bottoms	>16	>150	>65
Medium	Spruce on sites with a site index of 80 to 120	12-16	100-150	50-65
Low	Spruce on sites with a site index of 40 to 80	<12	<100	<50

Spruce beetle has been known in the region back to the 1890s (Lessard 1976). Activity on the Carson NF specifically was observed beginning in 1945 in the Pot Creek drainage on the Rancho del Rio Grande Grant. Subsequent activity was observed in 1947, 1952, 1955-1957, 1959-1964, 1966-1971, and 1982-1986. Most of the early events were thought to be related to logging slash, while some of the later ones occurred in Wilderness areas and other remote areas and at least partially related to windthrow. In the early 2000s aerial detection surveys recorded some increased spruce beetle activity on the Carson NF, however these areas were not ground checked to confirm spruce beetle activity. Based on activity at the time, knowledge from the Carson NF personnel, and aerial signatures it is likely this mapped damage was primarily fading corkbark fir. Spruce beetle attacked trees, especially in smaller numbers, are much harder to detect aurally than fading corkbark fir trees. During 2012 and 2013 over 9,000 acres, primarily in the Pecos Wilderness of the Carson and Santa Fe NFs has been mapped with suspected spruce beetle activity. A large area of windthrow that occurred in early 2007 is likely the source of the recent increase in the spruce beetle populations within the Pecos Wilderness. Spruce beetle was found in fallen trees within the windthrow area in 2010. In 2013, ground checking in the vicinity of Aspen Basin found scattered trees affected by spruce beetle, but the majority of the activity mapped is along the Santa Barbara Divide and has yet to be evaluated on the ground.

Ground checking has found scattered individual spruce trees affected and confirmed activity mapped on the Tres Piedras RD in the vicinity of the Cruces Basin Wilderness during aerial detection surveys. An extensive spruce beetle outbreak has been occurring just across the New Mexico – Colorado border on the Rio Grande and San Juan NFs. This outbreak which started in the early 2000s and was still active in 2013, affected approximately 387,000 acres on these two NFs in 2012 (Harris et al. 2013). As of 2013, however, no extensive spruce beetle outbreaks are

occurring in New Mexico. The northern end of the Tres Piedras RD adjoining the Rio Grande NF would be the area we would mostly likely expect to see spruce beetle activity in the near future. The Colorado forests have relatively pure stands of large diameter spruce while the stands we have observed on the Carson NF tend to be a greater mix of spruce and corkbark fir, potentially reducing the risk of the same scale event occurring on the Carson NF.

While spruce beetle outbreaks are often triggered by windthrow or other disturbances that create a large amount of breeding material, western balsam bark beetle activity in corkbark fir is not as strongly associated with these types of events. Root diseases are often found in conjunction with western balsam bark beetle causing mortality of corkbark fir. Western balsam bark beetle activity has been noted on the Carson NF back to 1950. Increased activity was observed in 1954, 1957, 1960-1967, and 2005-2010. Additionally, dead corkbark fir trees often show evidence of western balsam bark beetle galleries, indicating this bark beetle is a common in corkbark fir.

The infrequent stand-replacing fire regime of spruce-fir forests results in densely stocked forests with large diameter trees susceptible to spruce beetle and western balsam bark beetle outbreaks (Dahms and Geils 1997, USDA Forest Service 1994). With the available history of insect activity in the spruce-fir forests on the Carson NF, there does not seem to be a change in bark beetle outbreak patterns. Bark beetle outbreaks will continue to be part of the infrequent, but often dramatic disturbance pattern of spruce-fir forests.

## Defoliating Agents

Western spruce budworm also defoliates corkbark fir and spruce, but often to a lesser degree than the preferred white fir and Douglas-fir hosts. The spruce-fir forests on Carson NF, however, have been subject to severe western spruce budworm defoliation. See the mixed conifer defoliating agent section for more information on western spruce budworm.

## Broom Rust

Spruce broom rust (*Chrysomyxa arctostaphyli*) is found throughout the region on Engelmann and blue spruce. These infections cause growth loss, top-kill, and occasional tree mortality. It has historically not been a major problem on the Carson NF. Although not considered a “primary mortality agent,” broom rust likely contributes to the stress and subsequent tree mortality observed during drought. From a positive aspect, however, broom rust infections can serve as nesting platforms for wildlife.

## Root Disease

Root diseases are common on both Engelmann spruce and corkbark fir throughout New Mexico. Infected trees, especially true firs, are often attacked by bark beetles. Root diseases also are a major contributor to windthrow. Over time, mortality associated with these typically small-scale disturbances creates openings and increases forest spatial heterogeneity. Spruce is most often affected by Armillaria root disease and tomentosus root/butt rot (*Onnia tomentosus*<sup>3</sup>) and corkbark fir can be affected by both Armillaria root rot and annosum root disease.

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<sup>3</sup> = *Inonotus tomentosus*

While projections on climate change for the Southwest vary, if the most widely accepted climatic models are correct, warmer temperatures and more variable precipitation (State of New Mexico 2005) would in general create greater stresses upon Southwest forests. Root diseases that are already established and adapted to the Interior West, such as *Armillaria* root rot, would be expected to proliferate in stressed forest environments (Klopfenstein et al. 2009).



# Risk Modeling

The 2012 National Insect and Disease Risk Map (NIDRM) is a strategic project to assess the potential risk of tree mortality from insects and diseases across the U.S. over a 15 year time period. While it started as a national strategic map to graphically represent risk of tree mortality, better data and models have improved the scale and potential uses of the assessment. The improved resolution (240 m) of the forest parameter data of the new 2012 NIDRM version (Krist et al. 2014) allows for more regional and National Forest level analysis and summaries. These insect and disease risk models evaluate the potential loss of basal area based upon current forest conditions. While climate change scenarios are not included as part of the primary risk modeling effort, many of the risk models include climate variables that potentially could be modified to examine how predicted changes in climate could affect insect and disease risk. One scenario was analyzed in the 2012 NIDRM report and it predicted that future climate could further increase risk to the Carson NF from pinyon ips and ips engraver in ponderosa pine, fir engraver, and aspen decline.

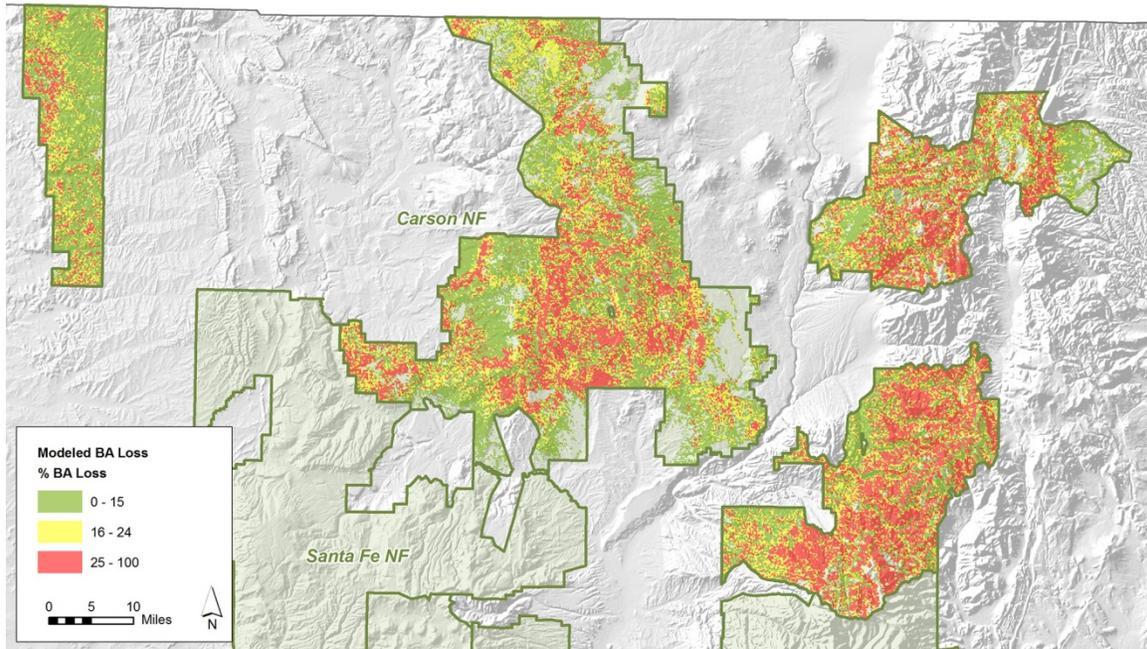
On the Carson NF, approximately 443,000 acres are modeled as being “at risk” of losing  $\geq 25\%$  of the basal area over the next 15 years. The threshold is set at 25% basal area loss as this is considered to represent “*an uncommon, rather extraordinarily high amount of mortality*” (Krist et al. 2014).

Summary of insect & disease risk for lands within the Carson National Forest boundary (Krist et al. 2014)

<b>% Basal Area Loss Class</b>	<b>Hazard</b>	<b>Acres</b>
0 – 15%	Low	592,500
16 – 24%	Moderate	348,400
25 – 100%	High	443,000

Percent of host basal area modeled to be at risk by agent.

<b>Risk Agent</b>	<b>Percent Mortality</b>
Spruce beetle	34.6%
Douglas-fir beetle	30.6%
Engraver beetles ( <i>Ips</i> spp.)	20.4%
Aspen / cottonwood decline	16.9%
Fir engraver beetle	11.0%
Root diseases	11.0%
Western balsam bark beetle	9.2%
Western pine beetle	8.1%
Western spruce budworm	2.6%
White pine blister rust	2.3%
Mountain pine beetle	0.7%
Dwarf mistletoes	0.1%
Roundheaded pine beetle	0.1%



**Figure 2. Modeled percent basal area at risk from insect and disease activity on the Carson NF.**

# Conclusion

Insects and diseases are integral components of forest and woodland ecosystems. There are numerous positive impacts of insects and diseases on the forest ecosystem including creating small openings, increasing biodiversity, enhancing nutrient cycling, creating wildlife habitat, and many other ecologically significant benefits. Under severe disease infection levels or episodic outbreaks of insects, however, their effects are more evident, sometimes negative, and cause greater forest change. With the exception of exotic agents such as white pine blister rust, the primary forest insects and diseases in the region and on the Carson NF are native organisms that have long been part of the ecosystem and have evolved with their plant hosts.

Forest and woodland distributions and characteristics are often viewed as static due to the difference in the human life span and the time scale of many ecological changes. Thus evaluation of ecological change or trends in insect and disease patterns depends upon the scale of the time period examined. Long-term paleoecological records provide insight into the presence, changes, and movements of vegetation communities over long time scales. These records reveal that the communities observed today are not static. Instead they are dynamically changing with various influences upon them including climate changes, human impacts, fire patterns, and ecological processes. Human activities have dramatically affected and changed forest and woodland ecosystems directly and indirectly. In response to these altered environments, the extent and activity of insects and diseases change. In turn, the way we perceive the effects of insects and diseases on the landscape has also changed.

Beginning in the middle to late 1800s, particularly with the arrival of logging railroads, widespread forest changes began. Grazing and later fire suppression efforts continued to change forest and woodland structure. Today's pine and mixed conifer forests are at greater densities and therefore more susceptible to bark beetle outbreaks and more vulnerable to the spread of dwarf mistletoes. While mistletoe distribution has likely remained relatively static, harvest activities have probably decreased the abundance of large infected trees in many areas. Although, in some cases, past harvesting activities that left mistletoe infected seed trees likely increased infestation levels in many regenerating stands. Past harvesting preferences that reduced the pine component of mixed conifer stands have shifted forest composition to greater dominance by shade tolerant species favored by western spruce budworm, Douglas-fir tussock moth, and root disease. Outbreaks of western spruce budworm, in particular, are probably more extensive in the mixed conifer simply because there is a greater abundance of host trees.

The relatively short length of most historical insect and disease records and their varying level of detail, however, often prevent quantitative identification of changes or trends in insect and disease activity from pre-settlement conditions to today. With the exception of unique paleoecological records, such as dendrochronological reconstructions, we are primarily restricted to records extending back to the middle or early portion of the 20<sup>th</sup> century for our understanding of historical insect and disease activity. Thus bark beetle activity in the open park-like stands of pre-settlement conditions typically cannot be directly compared to activity in today's denser stands and likely occurred as isolated incidences. Instead, these types of evaluations are made by comparing contemporary insect and disease activity within stands of various conditions, including those similar to pre-settlement.

Overall, the available historical record shows no clear changes in insect or disease outbreak patterns on the Carson NF. These records, however, are more recent and often concentrate on insect activity, particularly large events. Based on these records, the widespread bark beetle outbreaks in the lower elevation forest types, particularly pinyon-juniper and ponderosa pine, in

the Southwest are primarily drought induced. While altered stand conditions have exacerbated the consequences of these events and led to greater mortality, they have not been the reason these large outbreaks started. Smaller bark beetle events initiated by management, dense stands, or other site disturbances are not always well documented. Thus evaluation of these records reveals more about the role of climate variability in triggering insect activity than changes in insect and disease activity resulting from altered forest and woodland structure. Outbreaks of bark beetles in mixed conifer are related to both drought, especially fir engraver beetle, and disturbance. Spruce beetle outbreaks in contrast are more related to disturbances, such as windthrow, that occur in stands composed of dense, large diameter trees.

Invasive insects and diseases pose new threats to forest and woodland ecosystems. The lack of adaptation by host species to invasive species can result in unprecedented changes. White pine blister rust is now established on the Santa Fe NF and expansion of the disease, including to the Carson NF, is expected over the next few decades. An introduced biological control agent to limit the expansion of tamarisk, the tamarisk leaf beetle (*Diorhabda* spp.) has arrived in the region and has begun defoliating stands of this invasive plant. The lasting effect of this interaction is yet to be determined.

As has occurred throughout the evolution of ecosystems, changes in climate patterns will affect southwestern forests and woodlands. Climate change is already modifying ecosystems (Walther et al. 2002) and it is expected to substantially change forest insect and disease dynamics (Dale et al. 2001, Bale et al. 2002, Williams and Liebhold 2002, Logan et al. 2003, Ryan et al. 2008). The rising temperatures and reduced snowpack conditions observed in the western U.S. (Knowles et al. 2006) are already putting additional stress upon southwestern forests with high tree densities. If the most widely accepted climatic models are correct, warmer temperatures, less snowpack, more variable precipitation, and increased potential for extreme events (State of New Mexico 2005, Knowles et al. 2006, Seager et al. 2007) would in general create greater stresses. These stresses will add to the probability of increased bark beetle activity and could exacerbate the effects of root and other diseases. Stress in general predisposes trees to various insects and diseases, but not all agents will respond in a similar way. Mistletoes are dependent upon their hosts for growth, so weaker, stressed trees could actually result in reduced spread and intensification; however, mistletoe effects may become more damaging since mortality among infected trees will likely increase. Some defoliators, such as western spruce budworm, often have outbreaks during periods of increased moisture, so outbreaks might be less severe under a drier, warmer climate. The direction of changes in insect and disease activity will not be uniform.

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# Appendix

Acres with insect and disease activity as detected from aerial detection surveys of the Carson National Forest. Individual bark beetle species are grouped by host / forest type. All land ownerships within the National Forest boundary are included. Values are rounded to ten. \* indicates activity detected, but on less than 5 acres.

Year	Bark Beetles				Defoliators					
	Pinyon Ips	Ponderosa Pine	Mixed Conifer	Spruce-Fir	Western Spruce Budworm	Ponderosa Needleminer	Pinyon Needle Scale	Aspen Defoliation	Needle Cast	Aspen Decline
1985		400	510	1,260	231,320			4,810		
1986		170	1,280	760	176,540			28,040		
1987		220	1,360	710	155,030			4,770		
1988		480	1,470	50	147,260			10,110		
1989		60	800	230	28,460			780	28,500	
1990		10	250		144,600			3,030	10,160	
1991			50	*	127,470			8,830		
1992		*	10		200	480		10,480	7,190	
1993					13,300		1,630	4,480	420	
1994		70	140		282,660			350		
1995		*	110	110	116,240			3,980		
1996		*	30	70	65,650			10,210		
1997		120	*	390	157,350			2,660	340	
1998			20	440	196,450		1,020	12,560		
1999		680	130	1,000	130,010			4,700	260	
2000		590	120	950	79,110			4,470		
2001		1,780	280	1,230	290,750			650		
2002	16,240	3,280	540	1,680	114,680			2,650	1,490	
2003	277,210	3,320	6,330	5,840	62,700			680		
2004	33,270	1,430	16,070	3,910	114,980			7,560		
2005			15,990	10,150	80,270			8,530		
2006		270	6,550	8,810	54,080			1,520		
2007		3,880	7,450	11,260	160,250			10,560		3,200
2008	*	50	400	17,980	165,460			8,610		10,020
2009		20	530	12,380	214,510			21,760		14,970
2010		10	100	11,730	100,370			11,950		1,540
2011	*	30	2,880	4,530	172,060			41,610		1,440
2012		20	3,280	3,660	166,820			65,370		830
2013	*	330	9,560	8,060	98,250			68,530		780