

FOREST INSECT & DISEASE ACTIVITY ON THE APACHE-SITGREAVES N.F.,
AND FORT APACHE INDIAN RESERVATION, 1918-2009

Report for the
Apache-Sitgreaves N.F./Regional Analysis Team

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SUMMARY

A century-long history of forest insect and disease activity in the White Mountains was compiled from aerial and ground surveys, program and project reports, monitoring and research studies, and observational and professional accounts. At one time or another, all of the forest vegetation types in the White Mountains have incurred extensive damage by one or more agents, particularly during drought periods. The agents causing the most extensive damage have been pinyon ips in piñon, *Ips* bark beetle species in ponderosa pine, Douglas-fir beetle in Douglas-fir, the cumulative effects of several insects on Engelmann spruce, and the effects of multiple biotic and abiotic agents in aspen. The most severe damage (the greatest amount of mortality) has been in Engelmann spruce and in piñon. The most extensive and damaging persistent agent is southwestern dwarf mistletoe in ponderosa pine.

Insect and pathogen populations have responded to changing forest character (especially to changing structure and species composition) and variability in climate. Contemporary outbreaks differ from pre-1950s regimes in that *Ips* bark beetle species became more significant than *Dendroctonus* species in ponderosa pine than at the beginning of the 20th century when the reverse was once the case; damage to white fir has increased; dwarf mistletoe incidence and infection severity have increased in ponderosa pine, Douglas-fir, and spruce; and the cumulative effects of several biotic and abiotic agents, which individually are seldom fatal, is causing significant, widespread mortality and decline in aspen. Damage in the piñon-juniper and spruce-fir vegetation types is unprecedented in the historic record, in terms of both the severity damage in both forest types and in the identity and variety of insects causing damage in the spruce-fir forest. Coniferous species are replacing aspen in extensive areas and aspen die-off and decline caused by a suite of biotic and abiotic factors has intensified the loss of this species. Extensive areas of damaged piñon-juniper are becoming juniper woodlands or grasslands. The potential for catastrophic insect outbreaks and pathogen-related mortality continues, especially during drought periods. There is also an enduring threat of new exotic insects and pathogens establishing. Contemporary trends have enough differences from historic trends to anticipate altered ecosystem processes in the future.

INTRODUCTION

Forest insects and diseases have a significant role in forest ecosystem dynamics and the resources that come from these systems. Resources such as recreation, wildlife, watershed, aesthetics, and quality and quantity of wood biomass can all be significantly affected by these agents of change. Change can be rapid or incremental, but in either case, forest insect and disease-driven change alters forest ecological processes, forest structure and composition, and resource availability. Information on the frequency, extent, severity, and variability of damaging insect outbreaks and pathogen infestations is needed as part of the Forest Plan revision process for the Apache-Sitgreaves National Forest (N.F.).

In this report we summarize historic and contemporary disturbance information of the major forest insects and diseases on the Apache-Sitgreaves N.F. and Fort Apache Indian Reservation (I.R.) for approximately the last century. We refer to the entire area as "the White Mountains", and are more specific where appropriate. This information comes from aerial and ground surveys, program and project reports, monitoring and research studies, as well as observational and professional accounts. This will provide the scientific basis for the ecological sustainability analysis phase of the Forest Plan revision process and reference conditions from which to discuss future pest disturbance events and trends in these areas.

We used digitally mapped annual aerial detection survey data that is compiled annually in U.S. Forest Service Region 3 Insect and Disease Annual Conditions Reports for the recent period, 1975 to present. Written reports without mapped data are used for discussing earlier forest insect and disease disturbance events. We discuss insect and disease conditions separately for each vegetation type (ponderosa pine, piñon-juniper, aspen, mixed-conifer, and spruce-fir), followed by a discussion of historic and possible future trends. For several vegetation types, particularly ponderosa pine, aspen, and spruce, reported damaged areas include areas where the species of interest is present, not just dominated by that species. For example, aspen occurs across wide elevation ranges, often mixed with various conifer species rather than solely in single-species stands. There may be aspen defoliation in all of these areas, regardless of species dominance, and therefore the reported area would be larger than the area mapped on a vegetation survey as “aspen”. Also, more than one damaging agent can occur at the same time in the same area and yet are reported separately, such as Douglas-fir beetle and fir engraver in a mixed-conifer stand.

Detection and monitoring of persistent and transitory agents are typically done differently. Persistent agents, such as dwarf mistletoes and root diseases, persist in the environment over long periods of time, while transitory agents, such as bark beetles and defoliators, are continually present at endemic levels and experience intermittent outbreak events. This distinction is important since aerial detection surveys are designed to detect damage from transitory agents and other methods must be used to detect and monitor persistent agents.

This report focuses only on insect and pathogen species that cause major damage on the Forest and Reservation (Table 1), not a review of all insects and diseases that cause damage on the Forest and Reservation. There are many additional insect and disease disturbance agents in Southwestern forests (Fairweather *et al.* 2006a, Furniss and Carolin 1977) that are not included in this summary. This report does not cover the contributions that insect and pathogen species make to faunistic and floristic biodiversity. Finally, though we cite the especially relevant literature, this report is not intended to be an exhaustive review of the literature relevant to each insect and pathogen species, insect population dynamics, the impact of climate change on insect outbreaks, or the role of insects and diseases in forested ecosystems.

AERIAL DETECTION SURVEYS IN NORTHERN ARIZONA

Information on damage by major forest insects and pathogens on the Apache-Sitgreaves N.F. and Fort Apache I.R. was summarized for 1918 through 2006 from U.S. Forest Service Region 3 Insect and Disease Annual Conditions Reports. Hereafter, these reports are referred to as the “Conditions Reports”, and only specific reports referred to in the narrative are cited individually. The Conditions Reports summarize significant annual damage from transitory agents as seen during surveys undertaken by Forest Health Protection (formerly Forest Pest Management).

Over the period of record, data for the Apache N.F., Sitgreaves N.F., and Fort Apache I.R. are sometimes reported separately and sometimes in various combinations. The nature of the historic data makes it impossible to consistently differentiate each unit. Initially, the Conditions Reports reported damage separately for the Apache N.F., Sitgreaves N.F., and Fort Apache I.R. Later damage for the Apache N.F. and Sitgreaves N.F. were reported together. During the 1980s, the Southwestern Region’s Conditions Reports reported the area damaged by each insect for the entire Region, with a list of individual Forests, Parks or Reservations affected, but without information on how much area was damaged on each Forest. The aerial detection survey map data, captured in a GIS, is available beginning in 1977 for the Apache N.F. and Fort Apache I.R., but is not available for the Sitgreaves N.F. until 1993. Therefore, we report on the combined data, but distinguish between the units where possible and relevant. The combined areas cover one relatively distinct ecological area, the White Mountains. For the years where data are available individually for the Apache N.F. and Sitgreaves N.F., insect activity increases or decreases along similar temporal trends.

The Conditions Reports usually provide excellent information on the acreage affected by damage agents in each vegetation type. Information on specific locations and severity of impact is less well recorded. Older records are often narrative in nature, and frequently do not quantify the area damaged. Contemporary reports usually cross-tabulate affected acreage by insect agent and National Forest, and provide descriptive information in the text. Narrative references to more specific locations and damage severity are not consistent.

The Annual Detection Survey

Damage reported in the Conditions Reports is based mostly on aerial detection surveys that are usually flown in July and August by U.S. Forest Service Forest Health Protection professionals. Trained sketchmappers draw polygons of insect, disease, and abiotic damage (e.g. blowdown and drought) that are visible from the air onto paper maps. 1:126,470 scale Forest Travel maps (similar to maps provided to visitors) were used from the early 1970s through 1997. Beginning in 1998, 1:100,000 topographic contour maps were used. The accuracy of the Conditions Reports is dependent upon the accuracy of the sketch mapping process more than any other factor.

The aerial surveys are conducted during late summer for optimal detection of damage from insects that have historically affected the most forested area in the Region – defoliators in mixed-conifer, especially western spruce budworm, and bark beetles in all vegetation types. This timing does not work well for detecting damage from a few agents, especially pathogen and insect defoliators of aspen, and spruce aphid in spruce. Chronic pathogens such as dwarf mistletoe are usually not included in the aerial survey, but damage by transitory pathogens such as foliar rusts are included. The piñon-juniper and low elevation woodland forest types are usually not surveyed. Acreage of piñon-juniper affected is usually mapped only when adjacent to the ponderosa pine type. The exceptions for this are 2003, where the magnitude of die-off in the piñon-juniper prompted a special survey to document it, and 2009, where the cumulative area affected by aspen decline was mapped. Low visibility during the summer monsoon season may present difficulties as well, particularly when surveying the highest elevation forests.

The aerial detection surveys are designed to comprehensively detect all significant forest resource impacts from insects, disease, and abiotic events. Resource values have changed over time, and the Conditions Reports have evolved to match resource needs. Historically, survey efforts across the West have tended to be less extensive during wars and economic depressions. During other times, staffing and budget restrictions occasionally limit the extent of the annual survey in individual Regions. Modern reports tend to be more detailed and comprehensive. In recent years, there has been so much insect activity over such immense areas, Region-wide, that ground truth surveys have not been possible for much of this damage.

Annual Detection Survey maps and Condition Reports are missing for the Southwestern Region for 1959-1963 and 1965-1970.

Quantifying Survey Data

Until recently, the area damaged by each agent was determined by planimetry or grid counting the polygons sketched during the aerial surveys. For this report, the survey maps for 1975 through 2006 were digitized using raster-based LTPlus software and quantified using GIS spatial analysis (ArcView 3.3). There were few discrepancies in acreages reported by the available regional reports and the GIS-determined acreages for the 1976-2006 period for the White Mountains.

The text portions of both the older and recent Conditions Reports often refer to activity that is not tabulated and for which no acreage is reported. These references are usually of nominal utility (e.g., “some roundheaded pine beetle activity adjacent to the road construction”) or to non-timber-damaging activity (e.g. “in the campground”). This damage is not accounted in this report.

The annual surveys and Conditions Reports provide accounts of damage that occurred each year, or since approximately the same time the previous year. They do not, however, retain much cumulative information. Maps have not been retained for Conditions Reports prior to approximately 1975. Therefore, these data cannot be used to determine how much total area was impacted during the course of an outbreak. Insect outbreaks typically start in one or more places and spread in subsequent years to additional areas. Some of the same areas are damaged repeatedly one year after another, some new areas may be damaged each year, and some areas may no longer be attacked later in the outbreak. So, for instance, if western pine beetle damages 5,000 ac in one year, and 7,000 ac the following year, the cumulative area damaged over the two year period is likely less than 12,000 ac. Occasionally there are references in the reports that indicate the size of the area damaged over several years.

Data assumptions and limitations

There are some known issues with such survey data when used for evaluating the period of record. Identification of damage from various insects from the air is challenging, and it can be difficult to distinguish damage from different insects that cause similar types of damage on the same tree species; e.g. roundheaded pine beetle and western pine beetle in ponderosa pine. Some ground-truth sites may be visited after the aerial survey in order to confirm the damage agent, but this activity has not been done consistently. Ground-truth site visits are usually done for atypical damage, such as recent damage on Engelmann spruce by mountain girdle.

There are some relatively long periods in the record without reported insect activity in particular vegetation types. This should not be taken to mean that there was no insect activity, but rather that activity was minor and not quantified, mapped, or reported. Affected acreage reported here was considered to be null for years where conditions were described as “normal” or insect populations were said to be “at endemic levels”. Additionally, there are reports of activity in the text in many instances of minor infestations that are not included here.

The aerial detection surveys, from which the Conditions Reports are compiled, map activity each year. Some of the same acres may be mapped in consecutive years for the same damage agent, usually indicating that the insect outbreak attacks more trees on the same sites in subsequent years, as well as the outbreak expanding to additional areas. A GIS-based analysis would account for some of this overlap, but maps are not available for the entire record.

When summarizing historic reports, it is often necessary to make some judgment calls regarding the reported data. Though the data for the White Mountains are pretty consistent, some inconsistencies arise. We made the following assumptions and decisions regarding the data in the Conditions Reports: True fir beetle and fir engraver activity occurred in the mixed-conifer unless they were specifically reported as in the spruce-fir. In the Southwest, these insects mostly occur on white fir and Douglas-fir. However, they also attack corkbark fir, and the Conditions Reports sometimes indicated damage to corkbark fir. Corkbark fir occurs in both the spruce-fir and mixed-conifer forest types (by spruce-fir and mixed-conifer we mean forest types as described by Daniel 1980, not habitat type) We assumed that bark beetles attacking corkbark fir occurred in the mixed-conifer, unless western balsam bark beetle and/or the spruce-fir type was specified, in which case we assumed that the activity occurred in the spruce-fir. Most of the reports for either true fir beetle or fir engraver specifically mention attacks on white fir and Douglas-fir. This assumption is probably wrong in some instances.

The detection surveys may under-represent recent insect activity in the high elevation forests of Arizona. Defoliation and mortality by spruce aphid is not mapped at all, due to the timing of the aerial survey flights, when mountain tops are obscured by monsoon storms and when aphid damage is not easy to detect.

Data integrity

Regardless of any inherent problems in the data and reports, the Conditions Reports provide an excellent long-term record of forest insect and disease activity that is quite useful. When looking at long-term records of biotic and abiotic events, it is usually more useful, for instance, to know that damage increased from 25 ac to 12,000 ac than it is to know exactly which canyons or mountainsides were damaged, or to distinguish between 12,000 ac and 12,025 ac.

RESULTS

Activity of insects and transitory pathogens is summarized by vegetation type: ponderosa pine, piñon-juniper, mixed-conifer, spruce-fir, and aspen, followed by sections on persistent pathogens and discussion of historic and future trends. At one time or another, all of the vegetation types in the White Mountains have incurred extensive damage by one or more agents. The transitory agents causing the most extensive damage have been pinyon ips in piñon, *Ips* bark beetle species in ponderosa pine, Douglas-fir beetle in Douglas-fir, the cumulative effects of several insects on Engelmann spruce, and the effects of multiple biotic and abiotic agents in aspen. The most severe damage (the greatest amount of mortality) has been in Engelmann spruce and in piñon. The most extensive and damaging persistent agent is southwestern dwarf mistletoe in ponderosa pine.

Ponderosa Pine

Bark beetles

The Southwest, including the White Mountains, has a large complex of bark beetles composed of many genera and species (Wood 1982). In the West, most conifers, excluding ponderosa pine, are normally attacked and killed by a single species of bark beetle (Furniss and Carolin 1977, Lessard 1976a). For example, pockets of Douglas-fir mortality are most often associated with Douglas-fir beetle. In contrast, ponderosa pine is attacked and killed by several different bark beetles in the genera *Dendroctonus* and *Ips*, and it may be difficult to discern what species initiated the attack. Although *Dendroctonus* species are the most notorious tree killers in the western United States, *Ips* species play a very important role in Southwestern pine forests.

By selectively killing trees of certain sizes and species, bark beetles change the density, species composition, and size structure of the forest (Schmid and Frye 1977). Most bark beetles are considered secondary mortality agents because they prefer weakened host trees. When populations are at endemic levels, bark beetles typically attack scattered individual trees that have been weakened by lightning, disease, old age, or competition, or they are attracted to fresh logs and slash created by logging, windthrow, or snow breakage. However, when environmental factors and stand conditions favor beetle development, populations may increase rapidly and successfully attack healthy trees. During outbreaks, small groups of killed trees become larger and more numerous, and eventually merge into large stands of dead trees. Bark beetle outbreaks are initiated and sustained through the supply of susceptible host population and suitable stand conditions, favorable weather, and a relative scarcity of natural enemies (Fettig et al. 2007). Factors that lower tree resistance, such as poor site quality, overcrowding, drought, injury, and disease, favor outbreaks. Depletion of suitable hosts, extreme cold temperature, and natural enemies (arthropod predators and parasites, fungal diseases, and birds) contribute to population declines (Furniss and Carolin 1977).

Early reports indicate that bark beetle activity in ponderosa pine was less frequent, extensive, and damaging in the Southwest than in other Western regions (Hopkins 1909, Woolsey 1911). However, there have been periodic reports of bark beetle activity associated with drought in the Southwest ponderosa pine forest since the late 1890s (Plumber 1904 as cited by Keen 1926). Widespread occurrence of Southwestern dwarf mistletoe on ponderosa pine, relatively frequent drought, lightning strikes, trees growing on marginal sites, controlled fire use, other bark beetle

outbreaks, and the accumulations of logging debris result in chronic *Ips* problems in the Southwest (Lessard 1976a).

In the White Mountains, there have been periodic reports of bark beetle activity in the ponderosa pine forest since the late 1910s, with significant bark beetle outbreaks in the 1920s, late 1950s, and early 2000s (Fig. 1). The 1950s and 2000s outbreaks appear to be more extensive than were previous outbreaks, with damage to more than 200,000 ac during both episodes (Fig. 1). Both of these outbreaks were associated with drought (Fig. 1). Ponderosa pine stands on the Black Mesa Ranger District (R.D.) near Heber-Overgaard seem to have a long history of *Ips*-caused mortality (Plumber 1904 as cited by Keen 1926, Conditions Reports, Joel McMillin (personal observations)).

The recent widespread ponderosa pine mortality event during 2001 – 2004 impacted more than 200,000 ac in the White Mountains (Fig. 1) (USDA Forest Service 2004). Mortality of ponderosa pine, by basal area, averaged approximately 9.6% across the Apache-Sitgreaves N.F., and approached 100% in some stands (Negrón *et al.* 2009). Initial *Ips* activity and subsequent tree mortality is associated with low elevation, high stand density, dry rocky slopes and ridges, southern exposures, and steep slope (Pooler 1936; Negrón *et al.* 2009; USDA Forest Service 1975, 1996, 2003). Severity of dwarf mistletoe infection also influences attack patterns of bark beetles on ponderosa pine during drought events (Kenaley *et al.* 2006). Also, localized outbreaks of *Ips* beetles occur in the White Mountains when populations increase in logging residue and thinning slash (Parker 1978, Rogers and Hessburg 1985, USDA Forest Service 1977).

There seems to have been a shift in bark beetle activity over time, with pre-1950 outbreaks mostly being *Dendroctonus* species (western pine beetle, roundheaded pine beetle), and the 1950s and contemporary outbreaks being comprised mostly *Ips* species (pine engraver beetle, Arizona fivespined ips) (USDA Forest Service 2004, Yasinski and Pierce 1958). This probably reflects the size and density of host trees available as ponderosa pine forests transitioned from open stands with uneven diameter class distributions (including plenty of large old-growth) to denser stands dominated by pole-sized trees in the 1950s, and small sawtimber-size trees today (Covington and Moore 1994). *Dendroctonus* species, such as western pine beetle, commonly attack large-diameter ponderosa pine, while most *Ips* species focus their attacks on smaller diameter pine or the tops of large diameter trees (Demars and Roettgering 1982, Furniss and Carolin 1977, Kegley *et al.* 1997, Kolb *et al.* 2006, Massey *et al.* 1977).

It should be kept in mind that separating ponderosa pine mortality caused by *Ips* and *Dendroctonus* beetles during aerial detection surveys can be difficult. Therefore, too much emphasis should not be placed on a particular beetle species being responsible for pine mortality; frequently they are even collectively termed “pine bark beetles”. However, during periods, initial tree mortality is typically caused by *Ips* species, and then more mature (larger) trees are impacted by *Dendroctonus* species one to two years after the onset of the outbreak. Ponderosa pine mortality over the last 5 years was primarily attributed *Ips* species; however, western pine beetle and roundheaded pine beetle also contributed to mortality, particularly at the end of the outbreak (Joel McMillin, personal observations).

Mountain pine beetle attacked southwestern white pine after the 2007 Chitty Fire (McMillin and Fitzgibbon 2008). Damage was limited to the 200-ac burn (McMillin 2009), but we mention it here because mountain pine beetle is not previously known to occur or cause damage in the White Mountains (McMillin and Fitzgibbon 2008). Previous records of mountain pine beetle damage in Arizona are limited to the Arizona Strip, entomology collections, and notes that mountain pine beetle was one of several bark beetle species causing damage in ponderosa pine near Flagstaff and in the Chiricahua Mountains (Wood 1982). In 2007 and 2008 mountain pine beetle also attacked southwestern white pine in the Pinaleño Mountains on the Coronado N.F., killing several small patches of trees near, but not damaged by, the Nuttall-Gibson Fire (McMillin 2009).

Tip moths and shoot borers

There are several moths that mine in pine buds, shoots, and cones of saplings and pole-sized trees, impairing height and radial growth, altering tree form, and reducing seed production, but rarely causing tree mortality (Jennings 1975; Jennings and Stevens 1982; Lessard and Buffam 1976, Lessard and Jennings 1976, Long and Wagner 1992, Sower and Shorb 1984; Sower *et al.* 1989; Wagner and Chen 2004; Yates 1960). Southwestern pine tip moth, Nantucket pine tip moth and western pine shoot borer are the most common and damaging tip moths in Arizona, but other species occur as well (Long and Wagner 1992). Damage to the primary leader can also deform the main stem. Repeated attacks by tip moths and western pine shoot borer severely deform host trees and retard height growth, but rarely cause tree mortality (Jennings and Stevens 1992, Stevens and Jennings 1977). In recent decades these insects have not been considered to be major pests on the Apache/Sitgreaves N.F., but impact timber resources on the Fort Apache I.R. Major infestations can persist in regenerated burns (USDA Forest Service 1976). The importance of these insects may increase as large disturbed areas are regenerated.

Tip moths have had repeated outbreaks in the White Mountains (Fig. 2), causing extensive damage in the 1940s and 1970s (Fig. 2) (Acciavatti and Weiss 1974, Germain *et al.* 1973; Lessard and Buffam 1976; Lessard and Jennings 1976; Long and Wagner 1992). During endemic periods, these insects are chronic problems, especially where ponderosa pine is managed for timber resources.

Defoliators and scale insects

There are a variety of insects that feed on ponderosa pine foliage in Arizona (Fig. 2, Furniss and Carolin *et al.* 1977, Fairweather *et al.* 2006). None of them have severe, catastrophic outbreaks.

Prescott scale is a persistent insect that has occasional outbreaks. This insect sucks sap from the base of older needle fascicles, causing phloem necrosis in the bark, girdling the twigs and branches, and resulting in branch mortality ("flagging") (McKenzie *et al.* 1948). Minor tree mortality (1-2%) can result after multiple years of heavy flagging, mainly in subcanopy trees less than 2 m tall and less than 75 years in age (Fitzgibbon 2004, McKenzie *et al.* 1948, Wilson and Frank 1993). Outbreaks coincide with warm dry winter and spring weather and are more severe on sites with greater stand density (Furniss and Carolin 1977, McKenzie *et al.* 1948). Outbreaks occurred in 1918, 1932-1934, and 1942 in areas of the Apache-Sitgreaves, Cibola, Coconino, Coronado, Prescott, and Santa Fe National Forests (McKenzie *et al.* 1948). In 1990 and 1991, over 74,000 acres were damaged on and near Cheylon R.D. on the Apache-Sitgreaves N.F., plus 700 ac on Fort Apache I.R. (Fig. 2, Wilson and Frank 2004). Because Prescott scale does not have a winged dispersal stage, outbreaks occur only in areas with pre-existing populations and do not spread rapidly. Infestations can spread into adjacent host type, and one on Fort Apache I.R. expanded from 800 ac in 1994 to 4,000 ac in 2004.

Ponderosa pine needleminer defoliated approximately 35,000 ac in 1957, and 10,000-15,000 ac in 1999 and 2000 (Fig. 2). This winter-feeding insect defoliates ponderosa pine by mining inside the needles (Stevens *et al.* 1996, Tunnock and Meyer 1978). Ponderosa pine needleminer and closely related species are capable of large outbreaks in extensive areas of host trees, and are capable of causing mortality (Furniss and Carolin 1977, Tunnock and Meyer 1978, Stevens 1973, Stevens *et al.* 1996).

Several species of *Neodiprion* and *Zadiprion* sawflies feed on ponderosa pine (Dunbar and Wagner 1990, Furniss and Carolin 1977). While outbreaks of these insects occur, outbreaks usually last only 1 to 2 years before a complex of natural enemies reduces population levels (Overhulser 2004). Mortality is usually minor (Fitzgibbon 2007, Furniss and Carolin 1977). Pine sawflies are typically found on open-grown pines on marginal or stress-prone sites (McMillin and Wagner 1993) and on drought-stressed trees and sites (Fitzgibbon 2007, Tisdale and Wagner

1991). Increased damage by sawflies in the White Mountains was reported in 1986 and 2007 (Rogers and Maffei 1988, USDA Forest Service 2008).

Pandora moth is a defoliator of ponderosa pine. Outbreaks occur where soils are loose enough for larvae to bury themselves prior to pupation, such as pumice soils and degraded granite (Carolin and Knopf 1968, Furniss and Carolin 1977). Outbreaks of this insect occur in Arizona on the Kaibab N.F. and Grand Canyon National Park, but not frequently (Garcia-Gonzalez 2005, Lynch 2008a, Schmid and Mata 1996). Carolin and Knopf (1968) indicate that outbreaks occur in the White Mountains, but further information is not available. When and where they do occur, outbreaks can be spectacular, and fascinating to forest visitors, due to the size of the insects (larvae can be 3 in. long and adults can have a 4 in. wing span) and nearly complete defoliation of the host trees.

Tiger moths are minor pests which form webbed tents at the tops and upper branches of pines. Because of their size and the visibility of their tents, these insects are very noticeable to forest visitors, but damage is limited to topkill and branch dieback. An outbreak occurred in 2006 around Alpine and Nutrioso and other locations in the Southwest. Recently, adult insects have been found flying much earlier than usual, possibly a response to warmer temperatures (Fitzgibbon and Lynch, personal observations).

Piñon-juniper Forest

Bark beetles

Both localized and widespread mortality events have occurred over time in the White Mountain piñon-juniper woodlands. These events have typically been pinyon ips outbreaks associated with drought. At least for the historic period, the size and severity of the recent drought- and pinyon ips-related die-off is unprecedented for the White Mountains (Fig. 3) and the Coconino Plateau (Lynch *et al.* 2008b). High levels of piñon mortality were detected by aerial survey in 2003 with almost 2,000,000 acres impacted Region-wide and more than 150,000 acres in the White Mountains. The cause of mortality was primarily attributed to pinyon ips attacking drought-stressed piñon, with twig beetles (*Pityophthorus* spp.) observed killing smaller piñon in 2003. Mortality on the Apache-Sitgreaves N.F. reduced piñon stand density by approximately 60% (Negrón *et al.* in preparation). In northern Arizona, mortality averaged 41% with an 80 km radius of Flagstaff (Gitlin *et al.* 2006). Mortality patterns in the White Mountains have been similar to patterns in other locations of northern Arizona: most severe at low elevations, in stands with greater stand density, in the larger size classes, on southern aspects, on shallow soils, and in trees with severe pinyon dwarf mistletoe infection (Gitlin *et al.* 2006, Mueller *et al.* 2005, Negrón and Wilson 2003, Negrón *et al.* in preparation). Factors that may have contributed to the size and severity of this outbreak include changes in woodland character over time, drought, and altered temperature regimes (especially drought combined with warmer temperatures) (Allen 2007, Mueller *et al.* 2005).

In addition to killing small trees during the recent drought, *Pityophthorus* spp. also had a small outbreak in the early 1940s (Randles 1946).

Cedar bark beetle (*Phloeosinus* spp.) activity in junipers has increased in recent years in Arizona, especially in the White Mountains (USDA Forest Service 2007). These insects, also known as cypress beetles, are occasionally a problem, especially in the Southwest. Damage to 750 acres in the White Mountains, mostly on the Apache-Sitgreaves N.F. (USDA Forest Service 2007), is an indication of severe drought (Furniss and Carolin 1977). High levels of Arizona cypress mortality were observed on the Clifton R.D. in 2003 and 2004 (USDA Forest Service 2005).

Defoliators and other insects

Pinyon needle scale sucks sap from one-year old needles, killing small trees and predisposing large trees to attack by pinyon ips (Furniss and Carolin 1977, McCambridge 1974). Like Prescott scale, pinyon needle scale does not have a winged dispersal stage, so pinyon needle scale is a persistent pest with occasional outbreaks in the same areas that have persistent infestations. Chronic infestations on the same trees can be very debilitating (Furniss and Carolin 1977), and trees stressed by drought and pinyon needle scale are susceptible to pinyon ips. Outbreaks are associated with drought. There have been outbreaks near Nutrioso in 1983, 1996, and 2002. A more widespread outbreak occurred on the Apache-Sitgreaves N.F. from 2002 through 2005.

Several minor defoliators of piñon are found in the White Mountains. Tiger moth feeds on piñon in addition to ponderosa pine. Two sawflies, pinyon sawfly and *Zadiprion rohweri*, defoliate piñon. Heavy defoliation can cause in growth loss, and some tree mortality in small trees (McGregor and Sandin 1969). Needle miners and tip moths, as discussed under ponderosa pine, as well as pinyon pitch nodule moth and piñon spindle gall can cause growth loss, tree deformity, and rarely tree mortality.

Mixed-conifer Forest

Because there are several tree species present in mixed-conifer forests, there are a corresponding variety of insects that cause damage in this forest type (Fairweather *et al.* 2006a, Furniss and Carolin 1977). In the White Mountains, the insects that cause the most significant damage in mixed-conifer are western spruce budworm, white fir needleminer, Douglas-fir beetle, and fir engraver.

Bark beetles

Damage from true fir beetles, especially fir engraver in white fir, has increased in recent years in the White Mountains (Fig. 4). Though the area affected is small, less than 6,000 ac each year, a similar pattern is seen in northern Arizona (Lynch *et al.* 2007a, b). There is no record of significant bark beetle damage in white fir prior to the 1980s in the White Mountains. Since fire exclusion, white fir has become a greater component of mixed-conifer forests. Much of this white fir is just now reaching a size where it would be susceptible to bark beetles. Additionally, little value was placed on white fir as a timber species, and earlier bark beetle-related mortality may have gone unnoted. Increased amounts of damage reported on true firs in the mixed-conifer vegetation type reflects both an increase in white fir representation in the forest and changing resource values. Fir engraver attacks white fir trees stressed by drought, defoliation, root disease, and competition (Ferrell *et al.* 1994). White fir mortality from fir engraver was reported in the early 1980s throughout the White Mountains and northern Arizona, killing old decadent true firs (Rogers 1981, Telfer 1982).

Recently, in the last 10 years, Douglas-fir beetle activity has also increased (Fig. 4). This activity has been primarily driven by drought conditions. Because Douglas-fir beetle has only one generation per year, its populations typically do not respond as fast to weather factors as do *lps* populations in pine that have 2 or more generations per year. This pattern can be seen in the most recent drought in which Douglas-fir beetle impacts were greatest in 2003 – 2005, whereas the largest pine bark beetle impacts occurred in 2001 – 2003 (Figs. 1 and 4). During this drought, there has been a strong pattern of Douglas-fir beetle attacks on large trees heavily infected with Douglas-fir dwarf mistletoe and possibly root disease (McMillin *et al.*, unpublished data). Douglas-fir beetle activity and Douglas-fir mortality have not reached the levels they were at in the 1950s, but have increased in the White Mountains and throughout the Southwestern Region during the past several years.

While Douglas-fir mortality in Arizona seems to be primarily driven by Douglas-fir beetle attacking drought-stressed, dwarf mistletoe- and root disease-infected large diameter trees (Wood 1983, McMillin 2005), and perhaps severely defoliated trees (Bennett 1983, Lindh 1950, Lynch *et al.* 2008a), Douglas-fir beetle outbreaks in other geographic locations have also been initiated by fire

damage (Pasek and Schaupp 1992, Weatherby *et al.* 1994) and sustained by certain stand conditions (Furniss *et al.* 1981, Steele *et al.* 1996, Negrón 1998, Negrón *et al.* 1999). For example, in Wyoming, a Douglas-fir beetle outbreak was initiated by the 1988 Yellowstone and Clover Mist Fires. The outbreak was sustained for more than a decade through suitable stand conditions characterized by dense, nearly pure stands of large diameter Douglas-fir (McMillin *et al.* 2003a).

Though acreage affected recently by Douglas-fir beetle in the White Mountains is small with respect to the extensive mortality in ponderosa pine and piñon-juniper, the insect has the potential to cause considerable damage, as seen in the 1950s. The 1950s Douglas-fir beetle outbreaks on the Apache-Sitgreaves, Kaibab, and Prescott National Forests are unique in the historic period in that they were much larger than any other outbreak before or after (Fig. 4, Lynch 2008a and c). Resource impacts can be considerable because of the insect's preference for the largest trees, which are often highly valued. Large trees also disproportionately contribute to Douglas-fir beetle population growth, as Douglas-fir beetle prefers large trees and large amounts of beetle brood are produced in large infested trees.

Defoliators and other insects

There are two defoliating insects of consequence in mixed-conifer in the White Mountains, western spruce budworm and white fir needleminer (Fig. 4). Western spruce budworm has been a much less serious pest in the White Mountains than in northern Arizona and elsewhere in the West. There have been two periods of activity during the historic period, 1950s and 1980s that coincide with increased western spruce budworm activity elsewhere in the West. The total amount of area damaged is relatively small, with less than 7,000 ac of damage in 1995, and less than during the 1950s. By comparison, outbreaks on the Kaibab N.F. reach 200,000 ac (Lynch *et al.* 2008a), and elsewhere in the West can exceed 10 million ac (Stipe 1987). Conditions favoring western spruce budworm outbreaks and damage include predominance of shade-tolerant host species (white fir and Douglas-fir) in multi-storied canopies (Fellin *et al.* 1983).

White fir needleminer feeds inside the needles of white fir, causing extensive branch killing, top tilling, and, after several consecutive years of heavy defoliation, increased susceptibility to attack by fir engraver beetle (Furniss and Carolin 1977, McGregor and Washburn 1968, Washburn and McGregor 1974). The biology and ecology of white fir needleminer has not been well studied, so little is known about vegetation or climatic factors associated with population fluctuations or damage. It is in the same taxonomic family as many tip moths and shoot borers, but is adapted to mine individual needles rather than buds and shoots, causing heavy defoliation and branch mortality (Furniss and Carolin 1977, McGregor and Washburn 1968, Yarger and Leatherman 1975). There have been two outbreaks recorded on the Apache-Sitgreaves N.F., one that persisted through most of the 1970s and another in the late 1990s, each damaging 10,000-13,000 ac (Fig. 4). Both outbreaks caused significant defoliation, topkill, and branch dieback, but not much mortality (Acciavatti and Geils 1975; Frye 1973a, 1973b, 1975; Yarger and Leatherman 1975). Damage was most severe on west-facing slopes and poor sites, and in understory trees (Acciavatti and Geils 1975; Frye 1973b, 1975). Damage by this insect is capable of initiating fir engraver outbreaks, which can result in significant mortality, as happened in the early 1990s on the Kaibab N.F. (Lynch *et al.* 2008a, Schneckpeper 1994).

Spruce-fir Forest

During the historic record for the White Mountains, there have been four insect species causing significant damage in the spruce-fir: spruce beetle and spruce aphid on spruce, and *Nepytia janetae* and mountain girdle on spruce and corkbark fir. Three of these, spruce aphid and the two defoliators, are new problems not seen in the historic record. The other, spruce beetle, has a history of repeated outbreaks in the White Mountains.

Bark beetles

Outbreaks of spruce beetle occur infrequently because it prefers areas dominated by dense stands of large diameter spruce (Veblen *et al.* 1994, Schmid and Frye 1976, Schmid and Mata 1996). When populations are at endemic levels, spruce beetle is found in individual diseased or damaged spruce. When outbreaks do occur, their impacts can be significant and can convert spruce-fir forests to fir-dominated stands (Schmid and Hinds 1974, Schmid and Frye 1977). Spruce beetle outbreaks are typically associated with disturbance events such as windthrow, logging slash, and stand conditions conducive to supporting outbreaks (Schmid and Frye 1977), and with warm temperatures during the growing season (Barber *et al.* 2000; Werner and Holsten 1985; Werner *et al.* 2006).

There have been at least five spruce beetle outbreaks in the White Mountains in the historic period: in the years just preceding 1904 and in 1948-1952 (Lessard 1976b, Youtz 1994), 1968-1972 (Frye 1973, Lessard 1976b, Youtz 1994), 1981-1986 (Linnane 1985, Telfer 1982, Youtz 1994), and 2002-2005 (Frye 1973; Lessard 1976b; Linnane 1985; USDA Forest Service 2004, 2005) (Fig. 5). There was also a small outbreak during the 1968-1972 period in the Escudilla Mountains on the Apache N.F. Most of these outbreaks have occurred on the Fort Apache I.R., where there are more extensive stands of spruce-fir. Linnane (1985) and Youtz (1994) reported that approximately 400,000 spruce were killed on about 20,000 acres between 1981 and 1984 on commercial timberland on Fort Apache I.R., about 26% of the spruce sawlogs. An additional 9,180 ac were damaged in the Mount Baldy Wilderness (Youtz 1994).

The recent spruce beetle outbreak is in areas previously damaged by spruce aphid, *Nepytia janetae*, and mountain girdle. The population dynamics of all three insects, spruce beetle, spruce aphid, and *Nepytia* have probably been influenced by warm temperatures, as *Nepytia* and spruce aphid are winter-feeding insects and spruce beetle life cycle and its outbreaks are known to respond to warm temperatures (Barber *et al.* 2000, Lynch 2003, Lynch *et al.* in preparation, Werner and Holsten 1985, Werner *et al.* 2006). More recently, spruce beetle has been attacking trees in the same areas defoliated by mountain girdle (see discussions below on these insects).

Because initiation of spruce beetle outbreaks is typically associated with disturbance events, it is difficult to predict when and where outbreaks will occur. However, given that such events do occur, certain stand conditions and site characteristics are conducive to sustaining outbreaks. Physiographic location, site index, tree diameter, stand basal area, and proportion of spruce in a stand are related to stand susceptibility to spruce beetle (Schmid and Frye 1977). Very little activity by western balsam bark beetle is documented in the White Mountains, though it has been a serious problem in other Arizona forests. In other geographic locations, including Arizona, outbreaks of this beetle have been associated with drought, disturbance events, such as windthrow and defoliation, and with certain stand conditions (high stand density index) that can sustain an outbreak (McMillin *et al.* 2003b). Once stand conditions are suitable for western balsam bark beetle populations, populations can persist for many years, slowly killing the entire mature fir component (Garbutt 1992). Similarly, subalpine fir stand density index, subalpine fir basal area, and proportion of subalpine fir in a stand have been correlated with subalpine fir mortality (McMillin *et al.* 2003b). Endemic populations are typically restricted to root disease-infected corkbark and subalpine fir (Doidge 1981). No large scale, seriously damaging western balsam bark beetle outbreak has occurred in the White Mountains during the period of record, but one could occur here. Extremely damaging outbreaks of both western balsam bark beetle and spruce beetle occurred in the late 1990s and early 2000s in the Pinaleno Mountains in southern Arizona after winter storm damage and severe defoliation by *Nepytia janetae* (Lynch 2006).

Defoliators

Until 10 years ago, there is no record of significant damage by defoliating insects in the spruce-fir forest in the White Mountains (Fig. 5). In the last 10 years, however, two species have seriously defoliated significant areas of the spruce-fir forest.

Beginning in 1998 a geometrid, *Nepytia janetae*, severely defoliated both Engelmann spruce and corkbark fir in the spruce-fir type in the White Mountains. The next year, almost 10,500 ac were completely defoliated (Fig. 5) (USDA Forest Service 1999, 2000). The majority of the outbreak occurred on the Fort Apache I.R., with less than 1,000 ac of damage on the Apache N.F. A similar outbreak occurred at the same time in the Pinaleno Mountains, where it was detected one year earlier. The outbreak lasted 4 years, completely defoliated Engelmann spruce and corkbark fir, and caused severe tree mortality in the highest elevation spruce-fir forest. Tree mortality data were not recorded within the Mount Baldy Wilderness Area, but areas in the Pinaleno Mountains that were as severely defoliated suffered 76% mortality (Lynch and Fitzgibbon, unpublished data). In 2002, mortality outside of the Wilderness Area was only 5% (Lynch and Fitzgibbon, unpublished data). In the Pinaleno Mountains, defoliation by the *Nepytia* sp. and spruce aphid contributed to the development of outbreaks of both spruce beetle and western balsam bark beetle (Koprowski et al. 2005). In the White Mountains, spruce beetle activity increased after defoliation from spruce aphid and *Nepytia*, but western balsam bark beetle activity did not.

The specie was originally identified as *N. janetae* (USDA Forest Service 1999). However, another insect causing severe defoliation in mixed-conifer in the Sacramento Mountains of New Mexico in the mid-2000s was also identified as *N. janetae* (Lynch *et al.* in preparation, USDA Forest Service 2008). These two insect are very similar, and probably closely related. However, there are several differences between them. The insect found in the White Mountains and the Pinaleno Mountains fed on Engelmann spruce and corkbark fir but not Douglas-fir or southwestern white pine, chewed entire parts of the needles, and overwintered as active large larvae. The insect found in the Sacramento mountains is a generalist, feeding on Douglas-fir, white fir, Southwestern white pine, ponderosa pine, and Engelmann spruce, feeds by scoring the top needle surface, and overwinters as small larvae (in this context, the size of the larvae indicates phenological development, not health). There are differences in the markings on the larvae as well. These two insects are probably closely related species, but it is unlikely that they are the same species. *N. janetae* was taxonomically described from collections in the Sacramento Mountains (Rindge 1967).

Regardless of the taxonomic identification, the outbreaks in the White Mountains and the Pinaleno Mountains are unprecedented in the historic record. Until 1997, this insect was known only from its taxonomic description, and was not reported to cause damage.

Very recently, another little known geometrid, mountain girdle, has defoliated patches of Engelmann spruce in the White Mountains. The area defoliated in 2007 was relatively small (118 ac on the Apache-Sitgreaves N.F. and 500 ac on the Fort Apache I.R.) (USDA Forest Service 2008), but prior to 2007 in the period of record this species was not recorded as a damaging agent in the Southwest and is described as a "common innocuous defoliator". The recent outbreak is on Engelmann spruce, but mountain girdle is known to feed on subalpine fir and Douglas-fir and is widely distributed in western North America (Stevens *et al.* 1983).

Spruce aphid

Spruce aphid is exotic to North America, and is found in Arizona on the Apache-Sitgreaves, Coconino, and Coronado National Forests and Fort Apache I. R., nearby urban areas, as well as in the Pacific Northwest. It was first reported in the White Mountains in the late 1980s (Rogers and Maffei 1988).

Spruce aphid sucks sap from needle phloem cells, causing needle necrosis, dehydration, and premature needle drop. In the Southwest, outbreaks occur in autumn and early winter, and in warm winters may persist through spring (Lynch 2004). Elsewhere, spruce aphid is a problem in areas with maritime climate, and outbreaks occur in the spring (Day *et al.* 1998). In both maritime and montane ecosystems, outbreaks are associated with warm weather (Day *et al.* 1998, Lynch 2004).

Since the late 1980s there have been three extensive spruce aphid outbreaks and several smaller one (Fig. 5). The location of damage varies between years (Lynch 2004), but roughly speaking, in the worst years, two-thirds to three-fourths of the damaged area is on the Fort Apache I.R. and the rest is on the Apache-Sitgreaves N.F., reflecting the amount of spruce found in each unit. Spruce aphid damages Engelmann spruce of all size classes, killing 25-40% of severely damaged trees after a single defoliation episode in the White Mountains. Twenty-one percent of Engelmann spruce in the Pinaleno Mountains died three years after establishment there (Lynch 2004, 2009). In the White Mountains, defoliation severity is much greater on Engelmann spruce than on Colorado blue spruce and is more severe in the lower canopy layers (Lynch 2004). Retention of foliage in the upper-crown third of individual trees is a critical factor in tree survivorship. Tree mortality is associated with defoliation severity and severe infection by western spruce dwarf mistletoe. The combined effects of both high levels of defoliation and severe mistletoe infection are lethal, resulting in almost 70% mortality. Mortality continues to occur at least 4 years after trees are defoliated (Lynch 2004).

Repeated defoliation events in the same areas have led to widespread decline of Engelmann spruce in the White Mountains, and probably contributed to the development of a spruce beetle outbreak in the early 2000s.

Aspen Forests

Aspen in the White Mountains of Arizona are occasionally defoliated by western tent caterpillar, large aspen tortrix, melampsora rust, and/or black leaf spot (Fig. 6). Though extensive, these defoliation events seldom cause significant mortality, but they can weaken clones by exhausting carbohydrate reserves. Defoliators can make clones more susceptible to damage by other insects and diseases and play a role in the complex of agents involved in aspen decline

Defoliation has been periodically reported since the 1940's (Fig. 6), particularly by western tent caterpillar and large aspen tortrix. Specific causal agents are difficult to identify from the air and ground checking is limited, so defoliation is now mapped and reported as a complex rather than by individual insects and diseases. Western tent caterpillar and large aspen tortrix are early-season defoliators, allowing aspen to re-leaf later in the summer, but also making it difficult to detect from the air. This depletes tree resources, causing growth loss, but mortality does not usually occur unless trees are severely defoliated more than 3 consecutive years (Jones *et al.* 1985). Four years of successive defoliation by western tent caterpillar in other parts of the Region in the 1950's and 1960's caused topkill and mortality (Jones *et al.* 1985).

Aspen-dominated forests in Arizona and New Mexico have been rapidly changing to conifer-dominated forests as the aspen components are lost. The decrease in aspen communities over the past several decades is believed to be the result of: 1) Altered fire regimes since European settlement which promoted succession to conifer forests or other vegetation types (USDA Forest Service 1994, Dahms and Geils 1997, Coker *et al.* 2005); and 2) Heavy browsing by large ungulates, especially Rocky Mountain elk. Large populations of grazing animals prevent successful regeneration of aspen in burned or harvested forests by browsing sprouts that are produced when aspen is disturbed (Shepperd and Fairweather 1994, Rolf 2001). Region 3 forest managers estimate a decrease in aspen forests from nearly 500,000 acres in 1962 to 263,000 acres in 1986 (USDA Forest Service 1994).

Recently, even more pronounced aspen dieback and mortality occurred in Arizona, due to weather, defoliation and fire events (Fig. 6) (USDA Forest Service 2006). Coupled with the inability of aspen regeneration to survive browsing (Bailey and Whitham 2002, Fairweather *et al.* 2006b) these events are resulting in rapid loss of aspen-dominated forests, and the loss of the aspen component in many stands (Bailey and Whitham 2002, 2003; Fairweather *et al.* 2006b). The combination of predisposing, inciting, and contributing factors in the loss of aspen in Arizona fits the model of a tree decline (Manion 1991).

A frost event across northern Arizona in June, 1999, caused defoliation, branch mortality, and topkill of aspen clones that were in the process of leaf development and most vulnerable to damage. Although only about 6,500 acres of damage were detected in the White Mountains in 1999, the larger acreages reported in 2000 and 2001 are likely the result of damage from the 1999 frost event. More noticeable mortality occurred during the severe drought of 2002-2003, and increased western tent caterpillar activity followed in 2004 and 2005. Fig. 6 mostly depicts annual defoliation, but many of the acreages detected actually exhibited dramatic reduction in health of the aspen forest, with severe branch dieback and mortality (USDA Forest Service 2006). Ground surveys of affected sites on the Apache-Sitgreaves N.F. found over 40% mortality of aspen stems occurred over a 5-year period, following the events noted above (Fairweather *et al.*, *in preparation*).

Ungulate browsing has impacted aspen regeneration in the White Mountains since the mid-1980s. Rocky Mountain elk, which were introduced into the region after Merriam's elk was extirpated in the early 1900's, is the major browser where domestic animals are excluded. Merriam's elk were found in greatest abundance throughout the White Mountains of eastern Arizona, and the Mogollon and Sacramento mountains of New Mexico. Rocky Mountain elk are now present in great abundance in areas where Merriam's elk were found infrequently in Arizona (Truett 1996, Heffelfinger *et al.* 2002) and northern New Mexico (Allen 1996, 1998). Although Merriam's was considered a subspecies of Rocky Mountain elk, recent research suggests it was a separate species (Heffelfinger *et al.* 2002).

Across the White Mountains elk feed to different degrees on new sprouts and create wounds by antler rubbing and barking on larger trees. This damage has been positively correlated to damage by pathogenic fungi causing stem cankers and decay (Hart and Hart 2001). Stem decay fungi contribute to stem instability as the trees grow (DeByle 1985). Permanent exclusion fences are required where elk impact aspen (Fairweather *et al.* 2006b), except in areas where large fires have burned and elk browsing, although present, is not eliminating aspen from the stand.

The cumulative effects of these biotic and abiotic agents, which individually are seldom fatal, are causing significant, widespread dieback and decline in aspen. Although recent events have caused dieback and decline of mature aspen to varying degrees across the White Mountains, aspen is in crisis in most areas due to the inability to regenerate unless protected by 6 to 7 foot fencing. Starting in 2009, the Forest Service began distinguishing between aspen defoliation (from insects and pathogens) and aspen decline. 35,424 ac of decline were mapped in 2009, 22,269 on the Apache-Sitgreaves N.F. (Anhold 2009; USDA Forest Service 2010 *in preparation*). These figures represent the total area affected, not just new areas in decline in 2009 (Anhold 2009; USDA Forest Service 2010 *in preparation*).

Two bark beetle species are known to attack aspen in the Southwest, *Procryphalus mucronatus* which lives mostly in dead bark, and *Trypophloeus populi* which attacks weakened trees (Furniss and Carolin 1977; Jones *et al.* 1985). Although associated with mortality in aspen stands, neither species is thought to be a primary causal agent in aspen decline.

Persistent Pathogens

Dwarf Mistletoe

Dwarf mistletoes are the most prevalent disease-causing agents in Southwestern forests. There are several species in the White Mountains of Arizona, each with one preferred tree host species: southwestern dwarf mistletoe infects ponderosa pine; Douglas-fir dwarf mistletoe infects Douglas-fir and, infrequently, white fir and corkbark fir; pinyon dwarf mistletoe infects piñon; and western spruce dwarf mistletoe infects Engelmann spruce and Colorado blue spruce.

Unlike many insects, dwarf mistletoes slowly infect stands and then persist as long as living hosts are present. Dwarf mistletoes are obligate parasites, depleting host trees of water and nutrients.

Infected host trees are slowly weakened and eventually killed. Spread and intensification of dwarf mistletoe within a stand is a function of stand density, age, and site index, and averages one or two feet a year (Geils and Mathiasen 1990). Spread is most efficient and rapid from an infected overstory to an understory and slowest through a dense even-aged stand (Geils and Mathiasen 1990). Overall effects of long-term infestation on a site that has been infected for many years include: increased stand openings (both more openings and increased size of existing openings), lower-hanging crown canopies, denser canopy due to witches' brooms, and fewer large-diameter trees. These effects may have negative impacts to timber-related resources (Mathiasen *et al.* 1986, 1990a; Hawksworth and Weins 1996), while providing beneficial resources for birds and mammals (Bennetts *et al.* 1996; Parker 2001; Garnett *et al.* 2004; Hedwall *et al.* 2006a, b). Incidence and severity of dwarf mistletoe infection increase where understory trees develop under a canopy of infected trees, especially in uneven-aged stands (Hessburg and Beatty 1985). Survival of host trees is influenced by the species of dwarf mistletoe, severity of infection, and site factors.

Hawksworth and Geils (1990) found that more than 90% of uninfected and lightly infected ponderosa pine trees survive over a 30-year period. However, only 5% of heavily infected trees over 9 in. dbh, and none of the trees 4- to 9 in. dbh survived. Heavily infected trees are frequently attacked by secondary bark beetles (Kenaley *et al.* 2006).

Fire history is one of the primary ecological factors in determining the distribution and intensity of dwarf mistletoes in coniferous forests (Alexander and Hawksworth 1976, Hawksworth and Weins 1996). Relatively complete burns may have a sanitizing effect on infected stands; while partial burns can lead to rapid infection of regeneration if scattered infected trees remain overtop newly established regeneration. Fire, both prescribed and natural, can have a sanitizing effect, in which heavily infected trees and the lower branches of moderately and lightly infected trees are killed by fire, thereby lowering infection levels (Conklin and Geils *in preparation*, Koonce and Roth 1980).

Based on present understanding of mistletoe ecology (Parmeter 1978, Hawksworth and Weins 1996), increases in host abundance over the past 150 years, and decreases in fire frequency; it can be inferred that dwarf mistletoe abundance was likely lower in the historic period (Dahms and Geils 1997). Although dwarf mistletoe has been eliminated in some areas where large crown fires burned both the host and its dwarf mistletoe, in other parts of the White Mountains dwarf mistletoe has spread into previously uninfected areas. Although silvicultural prescriptions intending to reduce negative impacts of dwarf mistletoe were implemented over the past 30 years, the total removal of dwarf mistletoe infection was carried out only in some select areas.

Southwestern dwarf mistletoe: Incidence of Southwestern dwarf mistletoe increased in the White Mountains from 41% to 52% of the commercial acres of ponderosa pine between the 1950s and 1980s (Andrews and Daniels 1960, Hessburg *et al.* 1985 [Hessburg & Beatty in LC]). Although southwestern dwarf mistletoe is found throughout the Apache-Sitgreaves N.F., incidence is higher on the Springerville, Black Mesa, and Alpine Ranger Districts (R.D.), with 50-66% of the commercial ponderosa pine type infected in the 1980s, compared to 40% on the Lakeside R.D. (Hessburg *et al.* 1985). The Clifton R.D. was not surveyed due to its limited commercially suitable acres.

Douglas-fir dwarf mistletoe: The incidence of Douglas fir dwarf mistletoe infection of Douglas fir in the White Mountains of Arizona is believed to be similar to southwestern dwarf mistletoe infection of ponderosa pine. Although individual National Forest estimates are not available, Andrews and Daniels (1960) estimated that approximately 50% of the Southwest's Douglas-fir type was infested by Douglas-fir dwarf mistletoe.

Mortality of Douglas-fir in stands severely infested with dwarf mistletoe is three to four times the mortality in healthy stands (Mathiasen *et al.* 1990b). Mortality of infected mature Douglas-fir is greater at lower infection levels than is found for southwestern dwarf mistletoe of ponderosa pine (Mathiasen *et al.* 1990b). This is likely related to a higher incidence of insect and disease

associates: Douglas-fir beetle, which attacks individual severely-infected Douglas-fir trees; root diseases (e.g., *Armillaria* spp.), which are more common in higher elevation forests; and western spruce budworm.

Western spruce dwarf mistletoe: Western spruce dwarf mistletoe occurs in over 60 percent of the spruce type in the White Mountains and is the primary factor associated with spruce mortality (Hawksworth and Graham 1963). Mortality of Engelmann spruce and Colorado blue spruce in transition mixed-conifer stands that are moderately to heavily infested with western spruce dwarf mistletoe is 2 to 5 times greater than for uninfected or lightly infected stands (Mathiasen 1986; Mathiasen *et al.* 1986). Although mortality of heavily infected pole-sized Engelmann spruce is higher than for Colorado blue spruce, this trend is reversed in larger tree size classes, where Colorado blue spruce has a more rapid increase in mortality as dwarf mistletoe infection severity increases. Mortality of mature spruce is greater with lower infection levels than is found for southwestern dwarf mistletoe of ponderosa pine (Mathiasen *et al.* 1986). Spruce aphid damage is greater on Engelmann spruce than on Colorado blue spruce, but in either species, severe damage by spruce aphid to spruce severely infected by western spruce dwarf mistletoe results in 70% mortality (Lynch 2004).

Root Disease

Root disease pathogens affect conifers throughout the Southwest. Wood (1983) found that over 25% of mortality in the ponderosa pine type in Arizona is associated with root disease and associated pests such as bark beetles and dwarf mistletoe. Root diseases have become more prevalent in areas of the intermountain West where susceptible nonresinous conifers, such as true firs, Douglas-fir, and spruces, have become more dominant (Hagle and Goheen 1988). Similar shifts in species composition are occurring in Southwestern mixed-conifer and spruce-fir forests, however, root disease infection centers tend to be small (a couple of acres in size) compared to other western States.

The most common root disease fungi in spruce-fir and mixed-conifer forests of the Southwest are *Armillaria* spp., Annosus root rot, tomentosus root disease, and Schweinitzii root and butt rot. These fungi can persist for decades in the roots of stumps and snags and infect susceptible regeneration through root contact (Tkacz and Baker 1991, Shaw and Kile 1991). Root disease infection reduces growth and survival and increases risk of mortality by bark beetles and windthrow (Cobb 1989, Fairweather 2003, Hadfield *et al.* 1986, Tkacz and Schmitz 1986). The presence of root decay fungi are often missed during site surveys because they are difficult to detect and mortality is often also associated with bark beetles and/or dwarf mistletoe, and impacts on forest ecosystems maybe underestimated. Root disease incidence is probably increasing in established recreation sites located in old growth stands, as older trees are more susceptible to infection.

White Pine Blister Rust

White pine blister rust (*Cronartium ribicola*) is an exotic branch and stem canker disease of five-needle pines. Although it was discovered in the New Mexican Sacramento Mountains in 1990 (Conklin 2004), it was not found in Arizona until 2009, where it was found in an approximately 20 mile radius of Mount Baldy on both Fort Apache I.R. and the Apache N.F. This disease is estimated to have been present in the White Mountains at low levels for nearly 20 years. A “wave year” of infections is thought to have occurred in 2004, which matured and sporulated in 2009.

In general, cooler, moister sites are more favorable for rust establishment and development than are warmer, drier sites. Higher hazard in the Sacramento Mountains is associated with higher elevation, slope position, and habitat type (Geils *et al.* 1999), and is especially high for moist canyon bottoms (Van Arsdel *et al.* 1998, Conklin 2004) and stands in white fir habitat types above 8000 ft (Geils *et al.* 1999). Another indication of hazard is the presence and abundance of various *Ribes* species, which are alternate hosts (Van Arsdel and Geils 2004). Different *Ribes*

species vary in susceptibility to blister rust, and the orange gooseberry (*R. pinetorum*) is the most important alternate host in the Southwest (Van Arsdel and Geils 2004).

White pine blister rust is currently infecting southwestern white pines on higher hazard sites in the White Mountains, particularly in moist canyon bottoms, where it is causing branch and whole tree mortality of seedlings and saplings, and branch mortality of pole sized trees (Fairweather, personal communication). It will eventually impact larger trees, causing top and branch dieback, and may predispose them to attack by mountain pine beetle (Conklin et al. 2009). Eventually, infected trees on the highest hazard sites will probably die. Fortunately, most of the white pines in the White Mountains are located in dry areas of low rust hazard. Damage in low hazard sites is expected to be much more limited and these sites will serve as important genetic refugia for southwestern white pine populations.

Based on observations in the Sacramento Mountains in New Mexico, some trees will be resistant to disease even where conditions are favorable for the rust fungus, providing a seed source for natural selection and eventual recovery of the southwestern white pine population.

DISCUSSION

Insects and pathogens are natural disturbance agents in forested ecosystems. Activity by these agents should always be expected, though extent and severity of damage will vary. A century-long record of insect and disease activity gives us some information on which species impact forests in the White Mountains, how often we might expect outbreaks of insects and transitory pathogens, and how much damage to expect from insects and diseases. Due to the episodic nature of insect outbreaks, damage must be evaluated over an extended period before designating any shorter period as “unusual”. Certainly insect activity in White Mountain forests has increased in the last decade or so. In most vegetation types, the acreage affected is greater than what was damaged during the 1950s drought period. It has not been determined if the difference between the 1950s and contemporary drought is due to changes in forest structure and composition, drought severity, or if different temperature regimes also play a role (see Breshears *et al.* 2005).

Insect and disease activity that might be considered “normal” in forests of the White Mountains, includes:

- Bark beetle damage associated with disturbances, such as road building, tree harvesting, wind events, and avalanches in piñon-juniper, ponderosa pine, mixed-conifer, and spruce-fir forests.
- Periodic localized outbreaks of *Dendroctonus* beetles, particularly western pine beetle and roundheaded pine beetle, in large-diameter ponderosa pine.
- Increased bark beetle activity in piñon-juniper and ponderosa pine, and to a lesser extent mixed-conifer, during droughts, with the timing and severity of the damage being dependent upon host species, insect species, drought severity, length of drought conditions, and coincidence with other disturbance agents.
- Persistence of dwarf mistletoe infestations, with spread and intensification.
- Defoliation by native defoliating agents, such as western tent caterpillar and black leaf spot on aspen, and several defoliators in mixed-conifer. Typically, except in aspen, damage from these agents is local rather than widespread.

Patterns in insect and disease activity that appear to have changed over the years in the White Mountains include:

- In ponderosa pine, pre-1950 outbreaks were mostly comprised of *Dendroctonus* species (western pine beetle, roundheaded pine beetle), and the 1950s and contemporary outbreaks being comprised mostly *Ips* species (pine engraver beetle, Arizona fivespined ips) followed by drought responsive *Dendroctonus* species such as western pine beetle and roundheaded pine beetle.
- The size and severity of the drought- and pinyon ips-related piñon die-off is unprecedented in the White Mountains, six times as large as the 1990 outbreak, which was the first notable outbreak recorded for the White Mountains. Mortality approached 100% in many areas.
- The spruce-fir vegetation type, especially the Engelmann spruce component, has suffered from unprecedented cumulative effects of several insects: native but previously innocuous defoliators, an exotic foliar aphid, and an aggressive bark beetle outbreak. These species' population dynamics may be influenced by warm temperatures.
- Mortality and decline is extensive in the aspen forest. In the past, insect and disease defoliation did not cause significant mortality to aspen in northern Arizona, but recent defoliation, drought, and frost events, combined with the failure of regenerating aspen to survive herbivory and damage by Rocky Mountain elk, are resulting in the loss of the aspen component in many areas. Areas burned in recent wildfires have failed to regenerate aspen due in part to uncontrolled browsing by the non-native Rocky Mountain elk.
- Fir engraver was not a significant damage agent until the 1980s.
- Dwarf mistletoe "behavior" has not changed, but incidence and infection severity have increased due to altered disturbance regimes.
- White pine blister rust, an exotic disease, now infects southwestern white pine. Spruce aphid, an exotic insect, now infests Engelmann spruce and Colorado blue spruce.

Several of these changes in disturbance regimes appear to be responses to changes in forest structure and composition that resulted from fire exclusion and past management practices: *Ips* species responding to an abundance of dense, small-diameter ponderosa pine; western spruce budworm responding to a proliferation of shade-tolerant host species in multi-storied canopies; fir engraver responding to a proliferation of white fir in ponderosa pine and mixed-conifer forests where white fir used to be less well represented; and at least to some extent, pinyon ips responding to increased extent and density of piñon. Drought is clearly a factor as well, and warming climate has been a factor in the spruce fir. Any role that warming climate has played in the other vegetation types is not known.

In the aspen forest, a recent coincidence of abiotic and biotic damage agents has accelerated decline over extensive areas in Arizona. In some areas across the Forest there is an almost complete failure of regeneration to establish due to herbivory and damage from Rocky Mountain elk, leading to a conversion of aspen forest to coniferous forest.

In the piñon-juniper, the extent and severity of the die-off, higher levels of mortality in the larger, reproductive trees, and preferential mortality of piñon vs. juniper, is causing a vegetation shift such that piñon-juniper woodlands are becoming dominated by juniper, a species typical of lower elevation and more arid conditions (Allen 2007, Mueller *et al.* 2005).

It is very difficult to predict insect and disease activity, especially for a specific 10- to 20- year period. However, some general scenarios seem likely:

- As forest structure and composition change, as environmental conditions change, so will the prevalent pest problems. Many insects and pathogens attack trees of specific species and sizes, or particular parts of trees. If small-diameter ponderosa pine continues to be abundant, especially in dense stands, *Ips* outbreaks will continue. If shade-tolerant fire-intolerant tree species continue to proliferate, so will their pests such as fir engraver, western spruce budworm, and root disease. Future regeneration of ponderosa pine in areas burned in large fires, and in areas that have incurred substantial bark beetle-related mortality, may be subject to tip moth damage. Tip moth damage could be worse than in the past because of warming temperature regimes. In the Southeast, severity of damage by Nantucket pine tip moth is affected by the number of tip moth generations per year, which is influenced by temperature (Berisford and Kulman 1967), so impact by Southwestern species of tip moths may be greater than it has been in the past.
- Some new problems are likely to develop. As environmental conditions change, they can become suitable for additional damaging insect and pathogen species, which can expand their range into the new territory or exhibit enhanced population dynamics under new conditions due to factors such as increased growth rates or increased survival. Previously innocuous insects and diseases that become serious problems are known as “emerging pests”, as has happened with *Nepytia janetae* and mountain girdle. These previously innocuous geometrid defoliators have severely damaged spruce-fir and mixed-conifer forests in the White Mountains and Pinaleño Mountains of Arizona and the Sacramento Mountains of New Mexico (Lynch 2007, Lynch *et al.* manuscript in preparation; USDA Forest Service 1999, 2007). Prior to these events, *N. janetae* was known only from its taxonomic description, and neither had been recorded as causing any damage in the Southwest. These outbreaks may be associated with warm climate trends or to altered forest character (Lynch *et al.* manuscript in preparation). *N. janetae* is well distributed throughout the Southwest and California, including northern Arizona, so an outbreak is quite possible. Outbreaks by previously innocuous species are likely in northern Arizona. Another example is southern pine beetle, which in 2000 damaged almost 12,000 ac in the Chiricahua Mountains in southern Arizona (Lynch 2006, USDA Forest Service 2000, Moser *et al.* 2005, Wilson 2000). This was the first record of an outbreak of this insect in Arizona, though the species has been known to occur in Arizona. Southern pine beetle is part of the complex of pine bark beetles in north-central Arizona, but its role in future outbreaks is unclear (Hofstetter *et al.* 2008), as is the role of mountain pine beetle. Forests of the White Mountains will continue to change with time and in response to changing environmental conditions, these and other new problems may emerge.
- Mortality will be elevated during droughts, perhaps dramatically so. Based on observations of the recent severe drought, ponderosa pine and piñon mortality during future drought episodes should be greatest at mid- to low-elevations, in areas of poor site quality (*e.g.*, shallow soils, southern aspects), and in high density stands. However, it should be noted that mortality on some of the high risk sites approached 100% in the recent outbreaks; therefore, those sites cannot experience the same severity of mortality until tree densities increase to pre-drought levels. During non-drought periods, ponderosa pine and piñon mortality should be higher in stands with high stand density indices and greater dwarf mistletoe infection. If ponderosa pine forests continue to be dominated by smaller diameter size classes, *Ips* species will probably continue to be of more significance than *Dendroctonus* species.
- Dwarf mistletoe populations will continue to spread and intensify in ponderosa pine and Douglas-fir, continuing to affect stand character, forest character, and bark beetle vulnerability. Increases in dwarf mistletoe infection will occur where understory trees are

exposed to infected overstory trees. Decreases in infection levels will occur in areas exposed to fire which will burn the lower, and usually more heavily infected, limbs.

- Exotic species will continue to present problems, and additional species will establish and become problems. White pine blister rust will continue to expand into uninfected stands, with topkill, branch dieback, and mortality of larger Southwestern white pine on high hazard sites. Continued spruce aphid outbreaks will lead to diminished representation of Engelmann spruce. In 2000 southern pine beetle and smaller Mexican pine beetle damaged almost 12,000 ac in the Chiricahua Mountains in southern Arizona (Lynch 2006, Moser *et al.* 2005, Wilson 2000). This was the first record of an outbreak of either bark beetle in Arizona, though southern pine beetle has been known to occur in Arizona. The smaller Mexican pine beetle was not previously recorded in Arizona (Moser *et al.* 2005).

CONCLUSIONS

It would not be prudent to expect the next 10 or 20 years to be similar to the 1970s and 1980s with regards to insect activity. Contemporary trends have enough differences from historic trends to anticipate altered ecosystem processes. The coincidental occurrence of competitive vegetation densities, drought, and warm climate has increased forest vulnerability to herbivorous insects, especially bark beetles. There is potential for catastrophic insect outbreaks to continue in the White Mountains, but it is difficult to characterize the risks in a temporal framework of 10 to 20 years. There is more uncertainty regarding future insect outbreaks than the past record indicates. We are in a period of ecological change, and should expect additional large-scale insect disturbances, though the details of those events cannot be predicted.

Other than continued spread and intensification of dwarf mistletoe populations, and subsequent increased tree and forest vulnerability to bark beetles, pathogen response to climate change, insect outbreaks, and altered forest composition and fire regimes is less predictable than insect population responses. Additionally, there is great uncertainty regarding the potential effects of exotic insect and pathogen species, such as spruce aphid and white pine blister rust, as well as the effects of exotic invasive plants on forest disturbance regimes, including insect and pathogen disturbance agents.

Even in the face of uncertainty regarding future climate and insect and pathogen activity, general management recommendations for reducing susceptibility and vulnerability to insects and diseases remain the same: Improve tree vigor and maintain forest health by maintaining natural species, size, and age class distributions.

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Table 1. Common and scientific names of insects and pathogens referred to in this report.

| INSECTS | | | |
|------------------------------|---|---|---|
| Arizona fivespined ips | <i>Ips lecontei</i> | spruce aphid | <i>Elatobium abietinum</i> |
| cedar & cypress bark beetles | <i>Phloeosinus</i> spp. | spruce beetle | <i>Dendroctonus rufipennis</i> |
| Douglas-fir beetle | <i>Dendroctonus pseudotsugae</i> | tiger moths | <i>Lophocampa ingens</i> and others |
| fir engraver | <i>Scolytus ventralis</i> | tip moths | <i>Rhyacionia</i> spp. |
| large aspen tortrix | <i>Choristoneura conflictana</i> | True fir beetles | bark beetles attacking <i>Abies</i> , usually fir engraver or w. balsam bark beetle |
| mountain girdle | <i>Enypia griseata</i> | western balsam bark beetle | <i>Dryocoetes confusus</i> |
| Nantucket pine tip moth | <i>Rhyacionia frustrana</i> | Twig beetles (in piñon) | <i>Pityophthorus</i> spp. |
| Nepytia (no common name) | <i>Nepytia janetae</i> | western pine beetle | <i>Dendroctonus brevicomis</i> |
| Pandora moth | <i>Coloradia pandora</i> | western pine shoot borer | <i>Eucosma sonomana</i> |
| pine engraver | <i>Ips pini</i> | western spruce budworm | <i>Choristoneura occidentalis</i> |
| Phloeosinus beetles | <i>Phloeosinus</i> spp. | western tent caterpillar | <i>Malacosoma californicum</i> |
| pinyon ips | <i>Ips confusus</i> | white fir needleminer | <i>Epinotia meritana</i> |
| pinyon needle scale | <i>Matsucoccus acalyptus</i> | PATHOGENS | |
| pinyon pitch nodule moth | <i>Rotinia arizonensis</i> | Annosus root rot | |
| pinyon sawfly | <i>Neodiprion edulicolus</i> | Armillaria root rot (shoestring root rot) | <i>Armillaria</i> spp. |
| pinyon spindlegall midge | <i>Pinyonia edulicola</i> | black leaf spot | <i>Marssonina populi</i> |
| ponderosa pine needleminer | <i>Coleotechnites ponderosae</i> | Douglas-fir dwarf mistletoe | <i>Arceuthobium douglasii</i> |
| Prescott scale | <i>Matsucoccus vexillorum</i> | pinyon dwarf mistletoe | <i>Arceuthobium divaricatum</i> |
| roundheaded pine beetle | <i>Dendroctonus adjunctus</i> | Schweinitzii root and butt rot | <i>Phaeolus schweinitzii</i> |
| smaller Mexican pine beetle | <i>Dendroctonus mexicanus</i> | Southwestern dwarf mistletoe | <i>Arceuthobium vaginatum</i> subsp. <i>cryptopodum</i> |
| Sawflies | <i>Neodiprion</i> spp., <i>Zadiprion</i> spp. | Tomentosus root disease | <i>Inonotus tomentosus</i> |
| southern pine beetle | <i>Dendroctonus frontalis</i> | western spruce dwarf mistletoe | <i>Arceuthobium microcarpum</i> |
| Southwestern pine tip moth | <i>Rhyacionia neomexicana</i> | white pine blister rust | <i>Cronartium ribicola</i> |

Fig. 1: The area (bars) of ponderosa pine damaged by *Ips* (green) and *Dendroctonus* (blue) bark beetles in the White Mountains, in acres. Years for which bark beetle activity was reported without reference to the size of the area damaged are shown as dots, as inferred from text references. Areas and years for which *Ips* and *Dendroctonus* were not distinguished are shown in black. Instrumental Palmer Drought Severity Index for Arizona and New Mexico (Cook et al. 2004; NCDC 2006) is shown in red. Data are missing for the Southwest Region for 1959-1963 and 1965-1970.

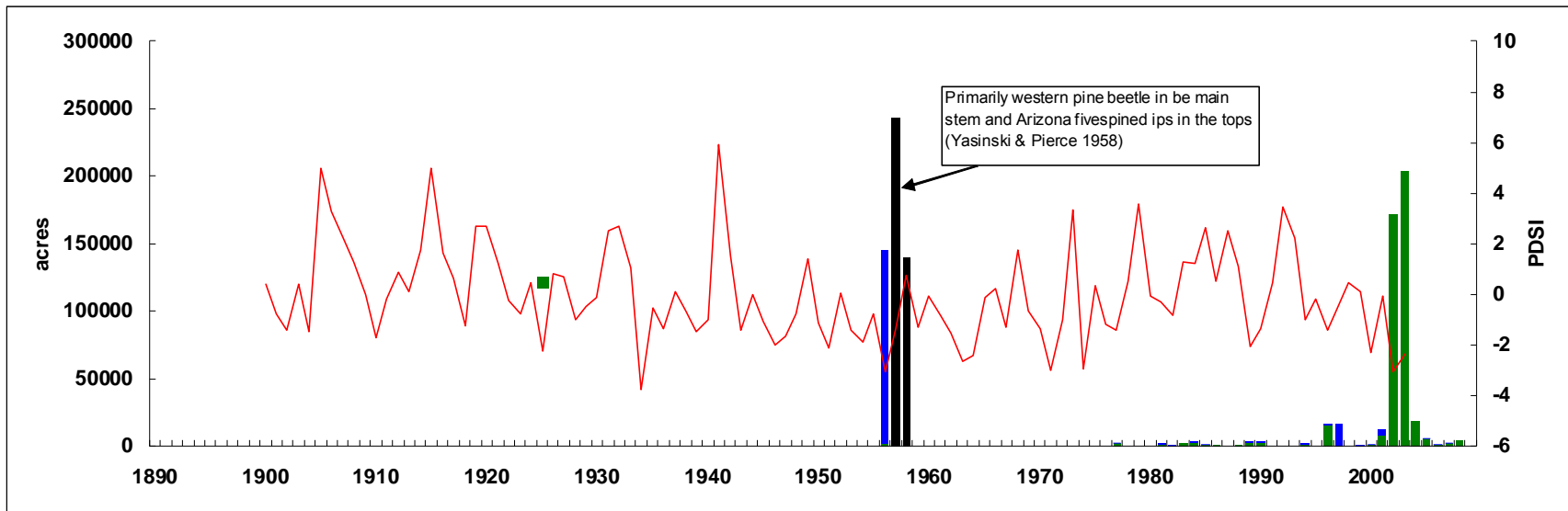


Fig. 2: The area (bars) of ponderosa pine damaged by needle-mining insects (green), tip moths (blue), and Prescott scale (magenta) in the White Mountains. Years for which tip moth activity was reported without reference to the size of the area damaged are shown as dots as inferred from text references. Note that the years with acreage show for Prescott scale are those with increased severity; Prescott scale persists in the same areas continually. Data are missing for the Southwester Region for 1959-1963 and 1965-1970.

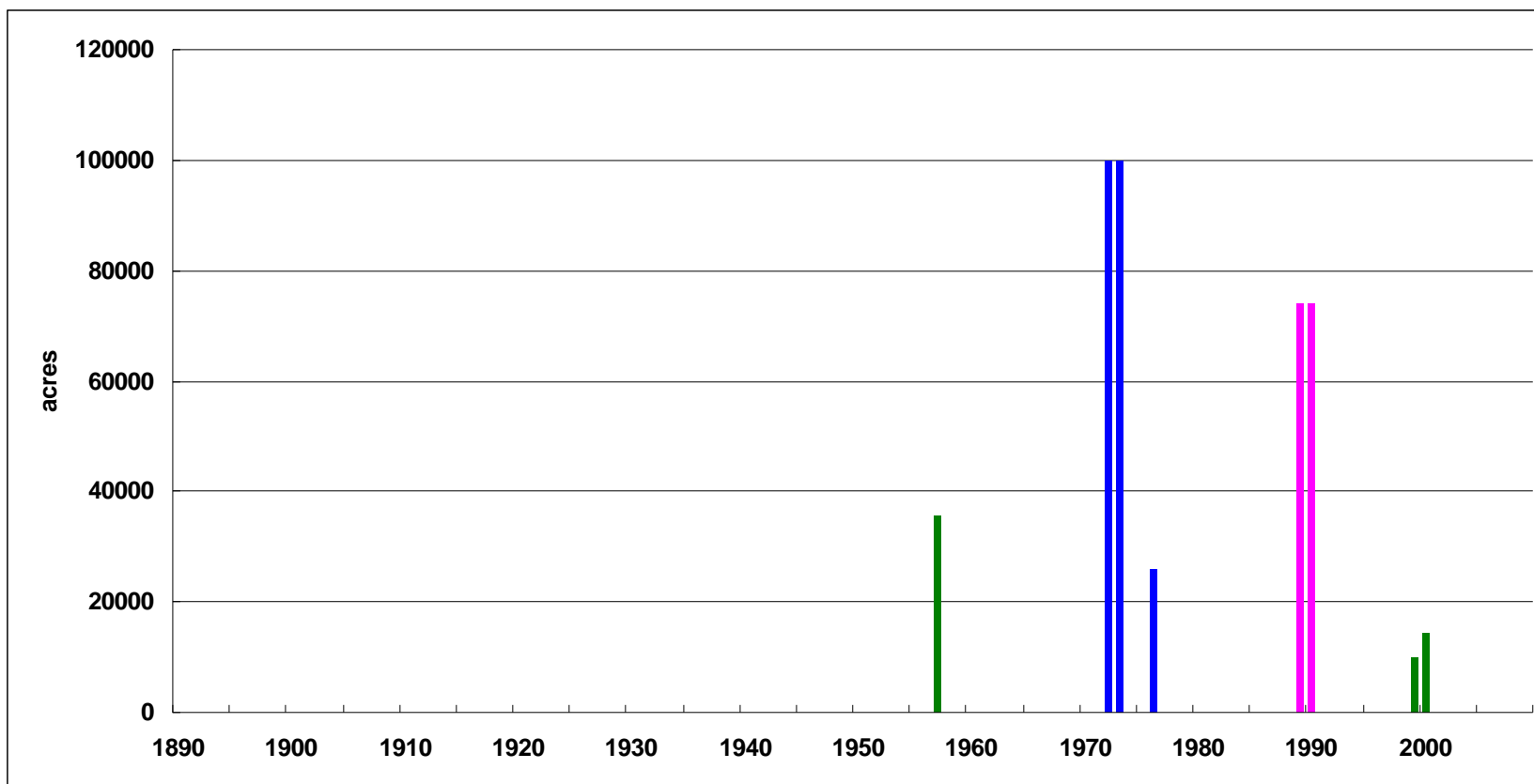


Fig. 3: The area of piñon-juniper forest (bars) damaged by pinyon ips in the White Mountains. Years for which pinyon ips activity was reported without reference to the size of the area damaged are shown as dots as inferred from text references. Data are missing for the Southwester Region for 1959-1963 and 1965-1970.

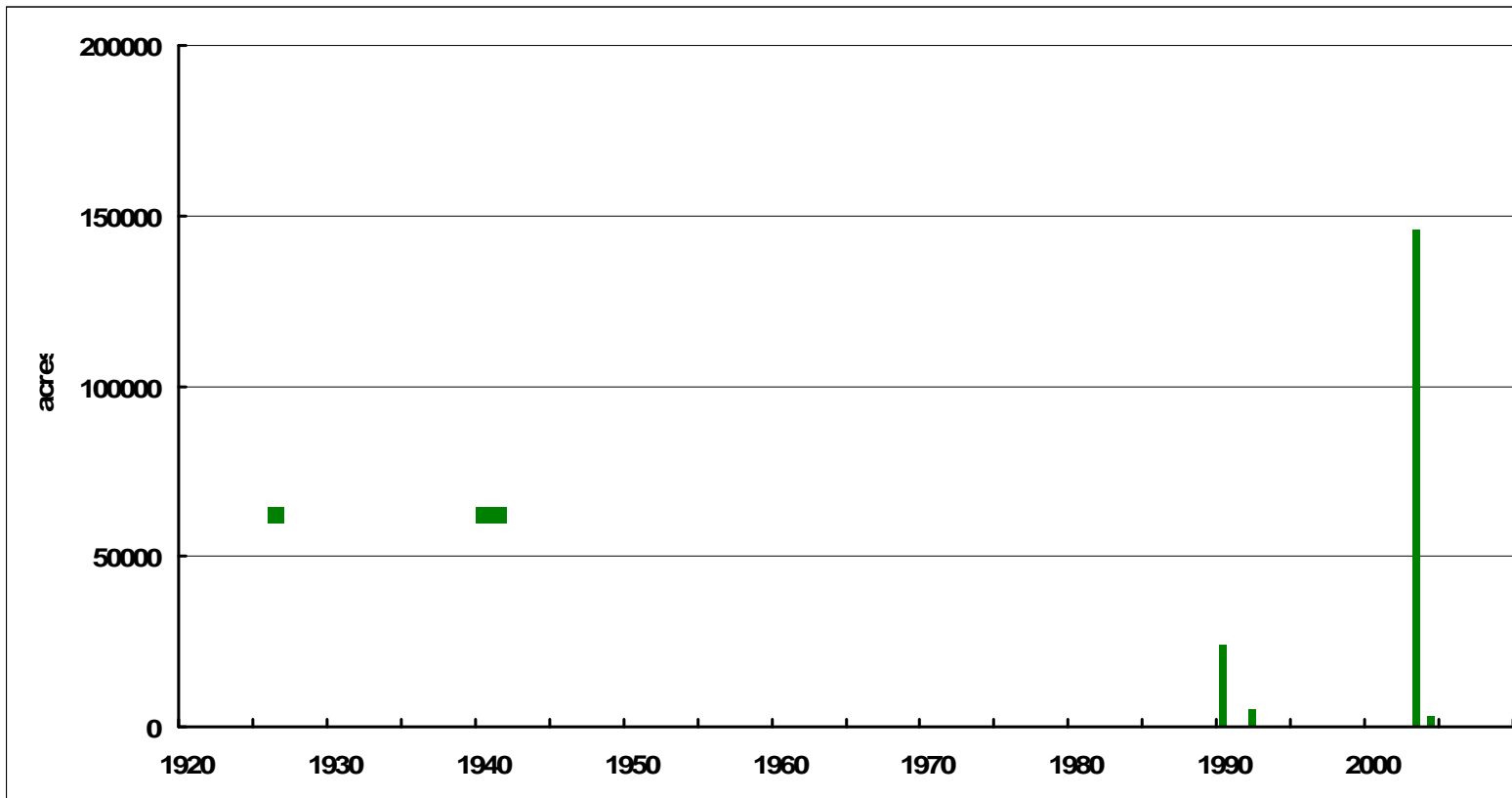


Fig.4: Mixed-conifer area (bars) affected by Douglas-fir beetle (brown), true fir beetles (magenta, mostly fir engraver), western spruce budworm (blue), and white fir needleminer (green) in the White Mountains. Years for which insect activity was reported without reference to the size of the area damaged are shown as dots, as inferred from text references. Data are missing for the Southwest Region for 1959-1963 and 1965-1970.

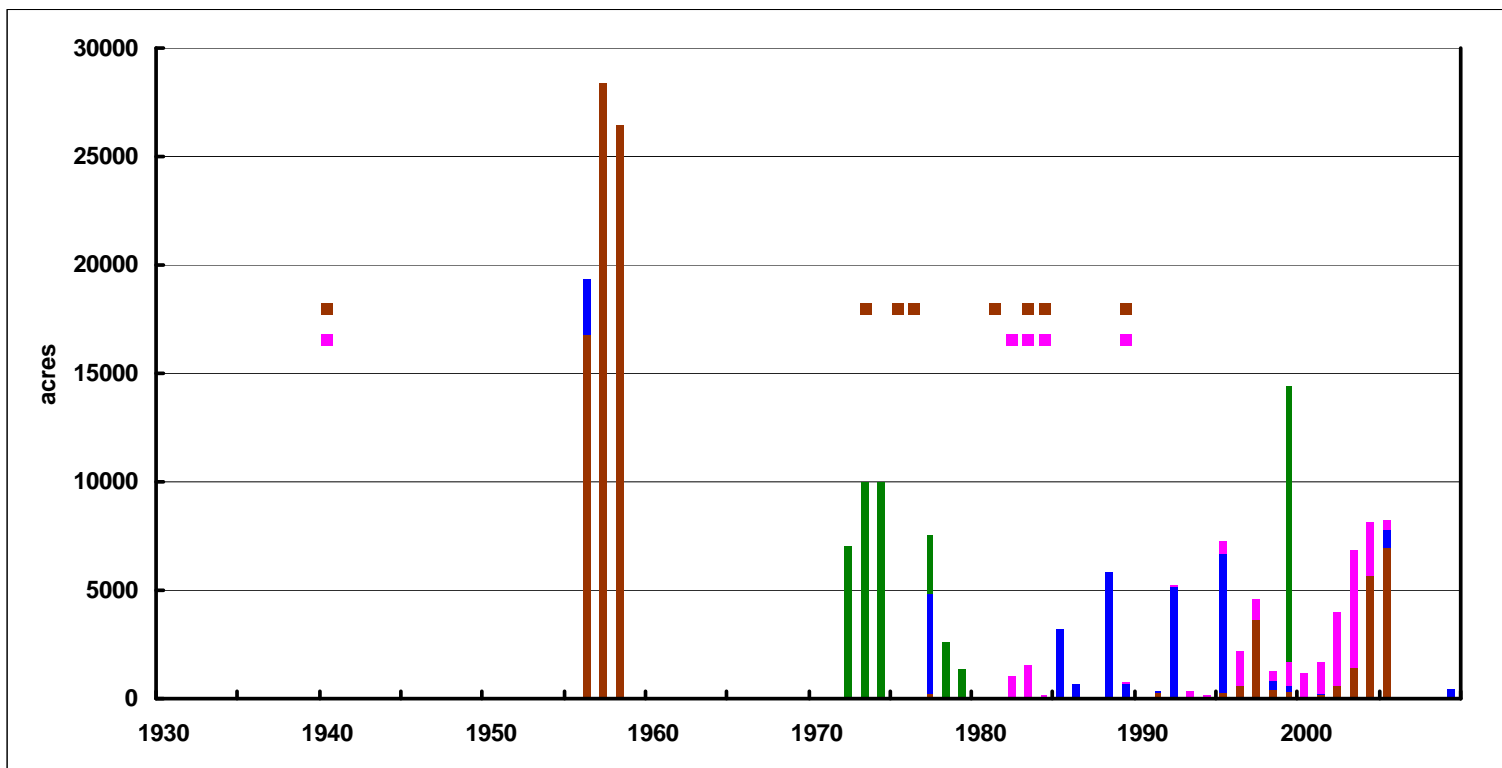


Fig. 5: Area (bars) of spruce-fir in the White Mountains damaged by spruce beetle (blue), *Nepytia janetae* (red), and spruce aphid (magenta). Years for which insect activity was reported without reference to the size of the area damaged are shown as dots, as inferred from text references. Data are missing for the Southwester Region for 1959-1963 and 1965-1970.

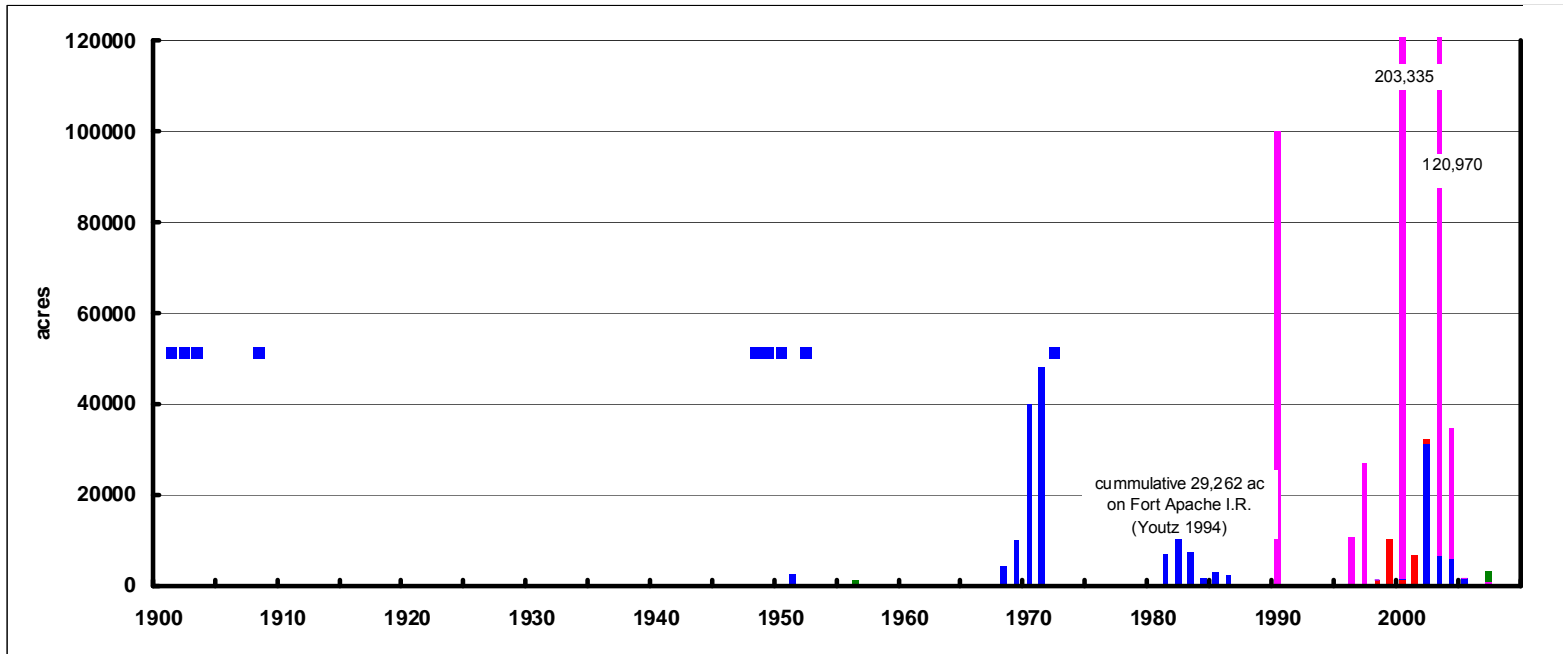


Fig. 6: Area of aspen in the White Mountains damaged by insects (green), pathogens (blue), multiple insects & pathogens (black), and drought (red), and the cumulative area in 2009 affected by decline (purple). Data are missing for the Southwest Region for 1959-1963 and 1965-1970.

