

# **Forest Insect and Disease Activity on the Kaibab National Forest and Grand Canyon National Park, 1918-2006**

## **Report for the Kaibab N.F./Regional Analysis Team**

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## Summary

A century-long history of important forest insect and disease activity on the Kaibab N.F. and Grand Canyon N.P. 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 vegetation types on the Kaibab N.F. have incurred extensive damage by one or more agents, particularly during drought periods. The agents causing the most extensive damage have been piñon ips, *Ips* bark beetle species in ponderosa pine, western spruce budworm in mixed-conifer, and multiple biotic and abiotic agents in aspen. In recent years, the most extensive damage has been in the piñon-juniper, with almost 160,000 ac of damage in 2003.

Insect and pathogen populations have responded to changing forest character (especially to changing structure and species composition) and variability in climate. Contemporary insect outbreaks differ from pre-1950s regimes in that *Ips* bark beetle species are now of more significance than *Dendroctonus* species in ponderosa pine when the reverse was once the case; western spruce budworm causes widespread damage, though it was not a problem prior to the 1950s; and damage to white fir from fir engraver has increased. Only tip moth damage has decreased. Dwarf mistletoe incidence and infection severity have increased in ponderosa pine and Douglas-fir. The cumulative effects of several biotic and abiotic agents, which individually are seldom fatal, are also causing significant, widespread mortality and decline in aspen. Coniferous species are replacing aspen in extensive areas of aspen die-off and decline. Piñon-juniper woodlands are being becoming juniper woodlands or grasslands in extensive areas of drought- and pinyon ips-related piñon mortality. The potential for catastrophic insect outbreaks and pathogen-related mortality continues, especially during drought periods. Contemporary trends have enough differences from historic trends to anticipate altered ecosystem process 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 Kaibab N.F.

In this report we summarize historic and contemporary disturbance information of the major forest insects and diseases on the Kaibab National Forest (N.F.) and Grand Canyon National Park

(N.P.) for approximately the last century. 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 digital mapped annual aerial detection survey data that is compiled annually the U.S. Forest Service Region 3 Insect and Disease Annual Conditions Reports is used 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, such as Douglas-fir beetle and fir engraver, can occur in a mixed-conifer stand at the same time and yet are reported separately.

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 Park (Table 1), not a review of all insects and diseases that cause damage on the Forest and Park. 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, insect population dynamics, 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 Kaibab N.F. and Grand Canyon N.P. 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, forest insect and disease damage reported for the Kaibab N.F. is often combined with acreage for Grand Canyon N.P., or, less often, in combination with the Coconino N.F. Here we present data for the Kaibab N.F. and Grand Canyon N.P. combined, sometimes making a distinction between north of and south of the Grand Canyon. For convenience, areas of the Kaibab N.F. and Grand Canyon N.P. that are north of the Grand Canyon northern rim are referred to as “north of the rim”. North of the rim, unless we make specific reference to the Forest or the Park, we mean both.

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 sketchmapping process more than any other factor.

The aerial surveys are conducted during late summer for optimal detection of damage from insects that have historically been the worst pests 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 exception for this is 2003, where the magnitude of die-off in the piñon-juniper prompted a special survey to document it. 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, 1965-1970, and 1981.

## 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 in a GIS (ArcView 3.3). There was only one significant discrepancy in acreages reported by the available regional report and the GIS-determined acreages for 1976-2006 (see the section on bark beetles in ponderosa pine).

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 area 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 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 site visits are done after the aerial survey in order to confirm the damage agent, but not consistently. Ground-truth site visits are usually done for unusual damage, such as recent mortality in juniper.

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.

Only activity from the major damaging insect species (Table 1) is summarized here. No pathogens, other than as part of aspen or true fir complexes, are reported.

When summarizing historic reports, it is often necessary to make some judgment calls regarding the reported data. Though the data for the Kaibab N.F. is pretty consistent, some inconsistencies do occur. 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 vegetation types. 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 vegetation type. 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**

Insect activity 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 have incurred extensive damage by one or more agents. The transitory agents causing the most extensive damage have been pinyon ips in piñon-juniper, *Ips* bark beetle species in ponderosa pine, western spruce budworm

in mixed-conifer, and multiple biotic and abiotic agents in aspen; in recent years damage to each of these vegetation types has exceeded 100,000 ac. The most severe damage (the greatest amount of mortality) has been in piñon from pinyon ips, and in ponderosa pine from various *Ips* species. The most extensive and damaging persistent agent is southwestern dwarf mistletoe in ponderosa pine.

Each of the vegetation types shows two distinct periods of increased insect damage, one during the 1950s drought and another during recent droughts. As stated earlier, there would have been minor levels of insect activity in the intervening years, but if acreage was not reported it is not included in the data charts.

## **Ponderosa Pine**

### **Bark Beetles**

The Southwest, including the Kaibab N.F. and Grand Canyon N.P., 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 usually caused by 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), though there has been episodic bark beetle activity in ponderosa pine on the Kaibab N.F. and Grand Canyon N.P. during the historic period. Early reports of bark beetle activity north of the rim usually specified mountain pine beetle (known then as Black Hills beetle) as the most important

bark beetle in ponderosa pine. While mountain pine beetle was considered the primary agent during non-drought periods, other *Dendroctonus* and *Ips* worked to kill stressed ponderosa pine during droughts (Blackman 1931). Keen (1926) suggested that mountain pine beetle epidemics north of the rim generally occur at 20 year intervals, lasting approximately 5 years. Based on tree-ring analysis and the presence of pitch pockets left by unsuccessful beetle attacks, Blackman (1931) reported mountain pine beetle outbreaks north of the rim in 1837-1846, 1853-1864, 1878-1882, 1906-1910, and 1916-1926 (Fig. 1). Outbreaks in the late 1910s and 1970s were particularly severe, though data from Lang and Stewart (1910) indicate less than 3% mortality for the Kaibab Plateau. During the 1916-1926 outbreak approximately half a million trees were killed across 12% of the ponderosa pine type. The outbreak that began in 1972 (Flake 1973) killed approximately 10 trees per ac and 36% of the basal area on about 7,500 ac (Walters and Lessard 1978), with scattered mortality over 75,000 ac (Parker 1976).

There is a discrepancy in the data for the 1970s outbreak. The digitized maps indicate mountain pine beetle mortality on 2500, 2500, 2159, and 972 ac for 1973, 1974, 1975, and 1976, respectively. The 1974 Conditions Report (Parker and Acciavatti 1975) says that 4,750 individual ponderosa pines were killed within a 4,500-ac area south of Jacob's Lake, with infested tree frequency increasing from 1.9 to 4.5 trees per ac by September. Mortality "within" a 4,500 ac area is not inconsistent with the digitized acreage, which delineated the smaller areas within the 4,500 ac. However, the 1975 Conditions Report (USDA Forest Service 1976) indicated that the infestation continued to develop in 1975, with new attacks over about 8,000 ac, and Parker (1976) indicated that the outbreak covered more than 75,000 acres in a few years). Because the summarized digitized acreage for 1973 through 1976 is 8,131, we think that moderate to high levels of ponderosa pine mortality were caused by mountain beetle over about 10,000 ac during the early to mid-1970s (Fig. 2), with low level tree mortality over a much larger area of 75,000 acres.

Unlike other pine bark beetle species, especially *Ips* species, mountain pine beetle outbreaks can be associated with periods of abundant moisture rather than drought. Outbreaks begin after consecutive years of above average precipitation, in trees that are growing more rapidly than those not attacked (Blackman 1931), and often on better sites (Lessard 1978). In contrast, outbreaks of western pine beetle and *Ips* species are initiated primarily by drought. Furthermore, mountain pine beetle outbreaks collapse in part due to years of below-average precipitation, which causes the phloem and inner bark to dry out faster, reducing brood production (Blackman 1931). Mountain pine beetle prefers ponderosa pine at higher elevations because brood production is greater due to either cooler temperatures or more moisture (Blackman 1931).

Mountain pine beetle is not an important bark beetle in ponderosa pine forests south of the Grand Canyon. Instead, other *Dendroctonus* and *Ips* become the primary tree-killing beetles. It should be kept in mind that separating ponderosa pine mortality caused by *Ips* and *Dendroctonus* beetles during aerial detection surveys can be difficult. During periods of drought we typically observe initial tree mortality 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. Western pine beetle activity was reported in late 1970's and early 1980's on the southern Kaibab. Ponderosa pine mortality over the last 5 years has been primarily attributed to *Ips* species; however, western pine

beetle and roundheaded pine beetle also contributed to mortality, particularly at the end of the outbreak (J. McMillin, personal observations).

The recent *Ips* outbreak, 2002-2004, appears to be unprecedented in the historic record, in both size and severity (Fig. 2). First, there seems to have been a shift in bark beetle activity over time, with pre-1950 outbreaks on the north rim dominated by mountain pine beetle, and *Ips* species playing a larger role since. There have been some contemporary outbreaks of mountain pine beetle north of the rim. But for the most part, across the Forest, contemporary outbreaks have been primarily *Ips* species (pine engraver beetle and Arizona fivespined ips) combined with western pine beetle and roundheaded pine beetle, and very little mountain pine beetle activity. This probably reflects the importance of regional drought events as well as the size and density of host trees made available as ponderosa pine forests transitioned from open stands with even diameter class distributions to denser stands dominated by pole-sized trees (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 (Furniss and Carolin 1977, Kolb *et al.* 2006). Early reports of *Ips* activity were typically associated with slash management issues and weather events such as windthrow and drought, and were localized rather than widespread. Pine engraver beetle, Arizona fivespined ips, western pine beetle, and roundheaded pine beetle outbreaks are all favored by drought conditions.

Second, the area damaged is far greater than any outbreak documented in the past for northern Arizona, with the 72,000 ac of damage reported in 2003 for the north rim, over 2 ½ times larger than in any previous year. The acreage of the 1890s mountain pine beetle outbreak is not known, but was “widespread”. The contemporary bark beetle outbreak is probably more severe than past outbreaks, in addition to being more extensive, especially south of the Grand Canyon. The recent event, 2002-2004, impacted more than 60,000 ac on the Kaibab N.F. Ponderosa pine mortality approached 100% in some stands (Gitlin *et al.* 2006), but averaged only 3.4% in a limited number of plots distributed across Williams Ranger District (R.D.) and Tusayan R.D. (Negrón *et al.*, unpublished data). Even though there is a long record of damaging mountain pine beetle outbreaks, reports during the early 20<sup>th</sup> century indicate that tip moths, not bark beetles, were the most serious insect problem in northern Arizona. This would not be the case if bark beetles were causing the amount of mortality as has occurred in the 2000s, though it also indicates that extensive amounts of mature timber had been harvested, and that bark beetle host resources were therefore diminished.

### **Defoliators and Other Insects**

On the Kaibab N.F. and Grand Canyon N.P. there are several insects that feed in or on ponderosa pine foliage: pandora moth, tiger moths, needleminers, sawflies, tip moths, and others (Furniss and Carolin 1977, Fairweather *et al.* 2006a). Pandora moth outbreaks occur where soils are loose enough for larvae to bury themselves prior to pupation, such as pumice soils found on the Kaibab Plateau (Carolin and Knopf 1968, Furniss and Carolin 1977). Outbreaks of this insect do not occur frequently in Arizona (Schmid and Mata 1996, Garcia-Gonzalez 2005) but can be spectacular due to the size of the insects (larvae can be 3 in. long and adults can have a 4 in. wing

span) and to the nearly complete defoliation of the host trees. An outbreak occurred near Jacob's Lake from 1978 to 1984 (Bennett and Andrews 1983, Schmid and Bennett 1988), causing moderate to severe defoliation on almost 30,000 ac by 1983, and light defoliation on several thousand additional acres. Many areas were defoliated more than once (Schmid and Bennett 1988). As is typical for this insect, tree growth was reduced by about 10% and mortality was minimal, less than 1% overall (Bennet *et al.* 1987). Mortality was greater in stands with heavy dwarf mistletoe infections (Bennet *et al.* 1987, Wagner and Mathiasen 1985). Pandora moth can be a nuisance when outbreaks occur near residential and recreation areas due to the large size and number of the caterpillars and moths and the appearance of defoliated stands (Schmid *et al.* 1988).

Elsewhere, pandora moth outbreaks occur approximately every 18-24 years (Furniss and Carolin 1977, Patterson 1929, Schmid and Mata 1996, Speer *et al.* 2001). On the north rim Garcia-Gonzalez *et al.* (2005) found dendrochronologic evidence of outbreaks beginning in 1712, 1753, 1775, 1844, 1879, and 1930, but could not definitively separate drought from pandora moth defoliation in the tree-ring record. Pandora moths pupate under open canopies where surface fuel loads are light (Schmid *et al.* 1981, Miller *et al.* 1984), so fire suppression may have a negative impact on pandora moth populations.

Southwestern pine tip moth and western pine shoot borer are the most common and damaging tip moths in northern Arizona, but other species occur as well (Long and Wagner 1992). These insects feed on terminal shoots of young trees, impairing height and radial growth and altering tree form (Lessard and Buffam 1976; Lessard and Jennings 1976; 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 1982). These insects continue to attack ponderosa pine and piñon in northern Arizona, but they are not considered to be major pests. During the early part of the last century, tip moths were considered to be the most serious insect pests in ponderosa pine in northern Arizona, rather than either *Ips* or *Dendroctonus* bark beetles. In part this is due to the understandably short temporal perspective of the time. However it also reflects the extensive areas of suitable tip moth host material that was present at that time – large stands of planted and naturally regenerated ponderosa pine that established after extensive timber harvesting and large fires.

## **Piñon-Juniper Woodlands**

### **Bark Beetles**

Both localized and widespread mortality events have occurred over time in the piñon-juniper woodlands on the Kaibab N.F. and Grand Canyon N.P. These events have typically been pinyon ips outbreaks associated with drought, such as in the late 1950's, and more recently in 2001-2003. Localized outbreaks resulted from range improvement projects that generated large amounts of fresh piñon slash (Buffam 1970, Furniss and Carolin 1977, Negrón and Wilson 2003, Yasinski and Pierce 1962, Pierce 1961, McMillin personal observations). Although pinyon ips outbreaks

can be severe with piñon mortality approaching 100% within a given stand, they are generally short lived (1-2 years). An outbreak on the South Rim during the late 1950s killed small scattered groups of trees, an outbreak thought to be ended by a cold event during the autumn of 1961 (Pierce 1961). High levels of piñon mortality were detected by aerial survey during 2001 through 2003 with approximately 2,000,000 acres impacted Region-wide and almost 160,000 acres on the Kaibab N.F. and Grand Canyon N.P. (Fig. 3). The cause of mortality was attributed to pinyon ips attacking drought-stressed piñon. Twig beetles (*Pityophthorus* spp.) were also observed killing smaller piñon in 2003.

At least for the historic period, the size and severity of the recent drought- and pinyon ips-related die-off is unprecedented for northern Arizona, especially the north rim (Allen 2007, Mueller *et al.* 2005). The contemporary piñon die-off is 100X as large (two orders of magnitude) as any previously recorded acreage for piñon ips damage in northern Arizona. Piñon damage associated with the 1950s drought on the Kaibab N.F. and Grand Canyon N.P. was less than 4,000 ac, compared to almost 150,000 ac in 2003 (Fig. 3). Two studies found that piñon mortality averaged 37 and 41% since 1996 across the Kaibab N.F. (Gitlin *et al.* 2006, Negron *et al.*, in preparation). Mortality was most severe on southern aspects, on shallow cinder soils, at low elevations, and in stands with greater stand density (Gitlin *et al.* 2006, Negron *et al.*, in preparation). These findings are similar to patterns seen in the mid-1990's east of Flagstaff (Negrón and Wilson 2003). That study also found that pinyon ips-caused mortality was correlated with the severity of dwarf mistletoe infection. Factors that may have contributed to the size and severity of the recent outbreak include higher tree densities with larger tree diameter, drought, and altered temperature regimes (especially drought combined with warmer temperatures) (Allen 2007).

It should be reiterated that the piñon-juniper woodlands are not flown during the annual insect and disease detection survey unless they are close to ponderosa pine stands. Therefore, minor, local outbreaks of pinyon ips would not have been included in the Conditions Reports data unless they were close to stands of ponderosa pine or highly valued sites. However, since pinyon ips-related mortality was noted in the 1950s, followed by a complete lack of reported damage until 1997, it can be concluded that there were no large or severely damaging events in the intervening 40 years.

Juniper species are more drought tolerant than piñon (Mueller *et al.* 2005 and references cited therein), but juniper mortality from wood borers and *Phloeosinus* beetles has occurred in areas of poor site quality (i.e., cinder cones; shallow, well-drained soils) during the recent drought (Mueller *et al.* 2005; USDA Forest Service 2002, 2003). Juniper mortality averaged 3.3% within an 80 km radius of Flagstaff, with greater mortality on grassland vs. non-grassland sites (Gitlin *et al.* 2006).

## **Defoliators and Other Insects**

In Arizona, ponderosa pine and piñon both fairly frequently incur damage from several persistent insects. Though the biology and damage modes of these insects vary widely, they are all persistent pests. Though populations may increase at times, they are always present at damaging levels in the same locations, often persisting on the same trees. There are several species of

*Neodiprion* and *Zadiprion* sawflies that feed on needles, repeatedly defoliating the same ponderosa pine and piñon trees, or groups of trees (Dunbar and Wagner 1990, Fairweather *et al.* 2006a, Furniss and Carolin 1977). Prescott scale on ponderosa pine twigs, pine needle scale on ponderosa pine needles, and pinyon needle scale on piñon needles, feed by sucking sap from the host trees.

Pine-feeding needleminers, *Coleotechnites ponderosae* on ponderosa pine and *C. edulicola* on piñon, feed inside the needles of the host trees, reducing tree growth and vigor, and increasing tree susceptibility to bark beetle attack. Ponderosa pine needleminer defoliated almost 4,000 ac in 1983 (which was not referred to in the annual Conditions Report (Linnane 1984)), and about 30,000 ac in 1997-2000 (USDA Forest Service 1998, 1999, 2000, 2001). The latter outbreak was widespread, damaging almost 60,000 ac in northern Arizona (USDA Forest Service 2000). Ponderosa pine needleminer defoliates ponderosa pine by mining inside the needles. It 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).

## **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). On the Kaibab N.F. and Grand Canyon N.P., the insects that cause the most significant damage in mixed-conifer are western spruce budworm, Douglas-fir beetle, and fir engraver.

## **Western Spruce Budworm**

Western spruce budworm is a native insect that defoliates Douglas-fir and white fir, and to a lesser degree Engelmann spruce, Colorado blue spruce, and corkbark fir, usually when those species are mixed with white fir and Douglas-fir. Populations erupt episodically in many stands over large areas, and outbreaks continue for several years to several decades (Fellin *et al.* 1983; Furniss and Carolin 1977; Swetnam and Lynch 1989, 1993). Repeated defoliation causes growth reduction, top-kill, and increased susceptibility to bark beetle attack. Severe, continued defoliation eventually kills trees, and extensive mortality occurred in Region 2 and parts of northern New Mexico during the 1980s outbreaks.

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). Increased presence of white fir and Douglas-fir in mixed-conifer and ponderosa pine stands due to fire exclusion has probably created conditions favoring western spruce budworm outbreaks in northern Arizona, where the species used to be innocuous. The onset of western spruce budworm outbreaks in northern Arizona coincides with increased synchronicity, extensiveness, and possibly severity of outbreaks across the Southwest (Swetnam and Lynch 1989, 1993; Ryerson *et al.* 2003). This is thought to be caused by past management practices and fire exclusion that altered the character of mixed-conifer forests, favoring multi-storied canopies

with greater proportions of shade-tolerant, budworm-host, species such as white fir and Douglas-fir (Fellin *et al.* 1983; Linnane 1986; Swetnam and Lynch 1993).

Western spruce budworm outbreaks in the Southwest are associated with periods of increased moisture (Swetnam and Lynch 1993, Swetnam and Betancourt 1998, Ryerson *et al.* 2003). Current lack of western spruce budworm activity may be due to drought conditions over the last decade.

Within the historic period western spruce budworm was not a problem on the Kaibab N.F. and Grand Canyon N.P. prior to the 1950s, but two widespread outbreaks have occurred since, one in the 1950s and one beginning in the mid-1970s and ending in the late 1980s (Fig. 4, Lessard 1975). Outbreaks of this insect occurred through the historic period in northern New Mexico (Lessard 1975, Swetnam and Lynch 1993) but severity increased beginning with the 1950s outbreak (Linnane 1986). Dendrochronologic reconstructions of western spruce budworm damage show that this insect has had outbreaks in the southern Rocky Mountains and northern New Mexico for several centuries (Swetnam & Lynch 1989, 1993, Fellin *et al.* 1983). However, western spruce budworm does not show up as a damage agent in Kaibab N.F. and Grand Canyon N.P. until 1950 (Fig. 4, Lindh 1950).

Both reported outbreaks on the Kaibab N.F. and Grand Canyon N.P. were extensive, affecting approximately 200,000 ac (Fig. 4). These outbreaks affected most of the host type, damaging Douglas-fir and white fir, as well as Engelmann spruce where it occurred with those species. Western spruce budworm is a native insect that defoliates Douglas-fir and white fir, and to a lesser degree Engelmann spruce, Colorado blue spruce, and corkbark fir, usually when those species are mixed with white fir and Douglas-fir. Populations erupt episodically in many stands over large areas, and outbreaks continue for several years to several decades (Fellin *et al.* 1983; Furniss and Carolin 1977; Swetnam and Lynch 1989, 1993). Repeated defoliation causes growth reduction, top-kill, and increased susceptibility to bark beetle attack. Severe, continued defoliation eventually kills trees, and extensive mortality occurred in Region 2 and parts of northern New Mexico during the 1980s outbreaks.

### **Douglas-fir Beetle**

Douglas-fir beetle occasionally damages Douglas-fir on the Kaibab N.F. and Grand Canyon N.P., attacking damaged trees and trees weakened by dwarf mistletoe infection and root disease. As with western spruce budworm, Douglas-fir beetle damage increased markedly in the 1950s, damaging almost 24,000 ac. The 1950s Douglas-fir beetle outbreaks are unique in the historic period for the Kaibab, Apache-Sitgreaves, and Prescott National Forests in that they were much larger than any other outbreak before or after (Fig. 5; Lynch 2008b, c). The Conditions Reports do not actually include any reference to Douglas-fir beetle prior to the 1950s for the Kaibab N.F., Grand Canyon N.P., or the Coconino N.F., but it presumably killed individual trees, as described earlier. At least part of the 1950s outbreak coincided with western spruce budworm defoliation, and the Conditions Reports indicate that Douglas-fir beetle activity was associated with both western spruce budworm damage and drought conditions.

Localized Douglas-fir mortality in the mid-1960's and early 1980's was caused by a complex of Douglas-fir beetle, dwarf mistletoe, and root disease (McMillin 2005, Wood 1983), and perhaps by trees being predisposed to bark beetle attack by earlier western spruce budworm defoliation (Fig. 5) (Bennett 1983, Lindh 1950).

Recently, in 2002 through 2006, individual and small groups of trees have been killed on over 2,500 ac. The recent outbreak has been primarily driven by drought conditions. Because Douglas-fir beetle has only one generation per year, its populations typically do not respond to weather factors as do *Ips* bark beetle populations in pine that have 2 or more generations per year. This pattern can be seen in the most recent drought in which the largest pine bark beetle impacts occurred in 2001 – 2003, and Douglas-fir beetle impacts were greatest later in 2003 – 2005 (Fig. 5 and Fig. 2).

Douglas-fir mortality on the Kaibab N.F. has been limited in scope compared with pine types due to the limited amount of host type, but has increased throughout the Southwestern Region during the past few years. 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 by this insect on the Kaibab N.F. and Grand Canyon N.P. is small with respect to the extensive mortality in ponderosa pine and piñon-juniper, 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.

### **Insects on White Fir**

Damage from true fir beetles, especially fir engraver in white fir, has increased in recent years on the Kaibab N.F. and Grand Canyon N.P. (Fig.5). Though the area affected is small, less than 5,000 ac each year, a similar pattern is seen on the Coconino N.F., with over 10,000 ac of damage (Lynch *et al.* 2008a). There is no record of significant bark beetle damage in white fir prior to the 1980s on the Kaibab N.F., Coconino N.F., or Grand Canyon N.P., indicating not only that there was little damage but probably also reflecting the lack of value placed on white fir as a timber species. As the host population has increased, so have its herbivore populations. Increased amounts of damage reported on true firs in the mixed-conifer vegetation type reflects both an increase in white fir representation and changing resource values.

Fir engraver attacks white fir trees stressed by drought, defoliation, root disease, or competition (Ferrell *et al.* 1994, Yarger and Leatherman 1975). White fir mortality from fir engraver in the early 1990s on the North Kaibab R.D. was in areas previously defoliated by white fir needleminer in the late 1980s (Schmeckpeper 1994). White fir needleminer 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. It is considered to be a minor pest species, but can cause heavy defoliation and branch mortality, as well as predisposing trees to fir engraver attack (Furniss and Carolin 1977, McGregor and Washburn 1968, Washburn and McGregor 1974). Approximately 2,000 ac were damaged on the Kaibab N.F. by white fir needleminer in the late 1980s (the area is too small to be very visible in Fig. 4). High levels of white fir mortality associated with fir engraver from the late 1990's through 2006 have been in drought-stressed trees, particularly on the north side of Bill Williams Mountain (J. McMillin, personal observations).

## **Spruce-fir Forest**

Disturbance regimes in spruce–fir forests have been less affected by fire exclusion than have other forest types in the Southwest (Dahms and Geils 1997). Furthermore, because of the limited spruce habitat on the Kaibab N.F., the potential for large-scale outbreaks is low compared with other forest types.

When spruce beetle populations are at endemic levels, they attack individual stressed, diseased or damaged spruce. When extensive outbreaks occur, their impacts can be significant and can convert spruce-fir forests to fir-dominated stands (Schmid and Hinds 1974, Schmid and Frye 1977).

Though minor spruce beetle outbreaks may occur frequently (perhaps one every 2 to 4 decades), extensive, severe, outbreaks occur infrequently because it prefers areas dominated by dense stands of large-diameter spruce (Furniss and Carolin 1977, Schmid and Frye 1976, Schmid and Mata 1996, Veblen *et al.* 1994), a condition that must be renewed before the next outbreak can occur. Spruce beetle outbreaks are typically associated with disturbance events such as windthrow, logging slash, and stand conditions conducive to supporting outbreaks (large numbers of large trees) (Schmid and Frye 1977), and with warm temperatures during the growing season (Barber *et al.* 2000; Werner and Holsten 1985; Werner *et al.* 2006).

Reliable estimates of spruce beetle activity is difficult to ascertain on the Kaibab N.F. and Grand Canyon N.P., as aerial detection surveys generally underestimate current spruce mortality due to the short period of time in which spruce trees have fading needles. There is a history of minor spruce beetle activity on the Kaibab N.F., and a small amount of activity was reported in the 1990s (Fig. 6). Spruce beetle infestations occurred in 1967 on the north rim in 2,000 acres of scattered blowdown and 4,000 ac of logging slash, but there was no subsequent spruce beetle activity in standing spruce in either area (Lessard 1976b). Another extensive blowdown occurred in 1972 in mixed-conifer on the north rim in Grand Canyon N.P., but a potential outbreak was prevented by sanitation efforts. No large scale, seriously damaging spruce beetle outbreaks have occurred on the Kaibab N.F. or Grand Canyon N.P. during the period of record.

Both western balsam bark beetle and fir engraver attack both corkbark fir and white fir, though western balsam bark beetle is predominantly found in corkbark fir and fir engraver in white fir. Corkbark fir is a major component of the spruce-fir vegetation type, and a minor component of the mixed-conifer forest; white fir is not found in Southwestern spruce-fir forests. Until very recently, activity of both insects was combined in aerial detection surveys and reported as “true fir

beetles”. Therefore, it is difficult to speculate on historic population trends of the individual species. In other geographic locations, outbreaks of western balsam bark beetle have been associated with disturbance events, such as windthrow, and in stands with high stand density index, conditions 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). Endemic populations are typically restricted to root disease-infected corkbark and subalpine fir (Doidge 1981). No large scale, seriously damaging western balsam bark beetle outbreaks have occurred on the Kaibab N.F. or Grand Canyon N.P. during the period of record.

Because spruce beetle and western balsam bark beetle outbreaks are 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). 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). Given the limited extent of spruce and corkbark fir on the Kaibab N.F. and Grand Canyon N.P., there is not a great potential for extensive bark beetle-caused mortality in this forest type.

Spruce aphid is an exotic insect that is found on the Coronado N.F., Coconino N.F., Apache-Sitgreaves N.F., and Fort Apache Indian Reservation. It established on the San Francisco Peaks in 1999, but has not yet been reported on the Kaibab N.F. or Grand Canyon N.P. This exotic insect damages Engelmann spruce of all size classes, and is capable of killing 25-40% of severely damaged trees after a single defoliation episode (Lynch 2004). In the Southwest, it has autumn outbreaks that may persist into spring.

## **Aspen Forest**

Aspen communities throughout the Southwest have been declining for decades, a phenomenon thought to be the result of: 1) altered fire regimes since European settlement which promoted succession to conifer forests (USDA Forest Service 1994, Dahms and Geils 1997, Cocks *et al.* 2005) and 2) heavy browsing by large ungulates, especially Rocky Mountain elk, which prevent successful regeneration of aspen in burned or harvested forests (Shepperd and Fairweather 1994, Rolf 2001). Aspen decline has been a problem on the Williams R.D. Recent accelerated mortality, due to weather, defoliation and fire events, coupled with the inability of aspen regeneration to survive browsing (Bailey and Whitham 2002, Fairweather *et al.* 2006b) is resulting in conversion of aspen forest to conifer forest, and the loss of the aspen component in mixed-species stands (Bailey and Whitham 2002, 2003; Fairweather *et al.* 2006b).

Aspen on the Kaibab N.F. and Grand Canyon N.P. are occasionally damaged by western tent caterpillar, large aspen tortrix, melampsora rust, and black leaf spot, with damage reported since the 1940s (Fig. 7). Though extensive, these defoliation events seldom cause significant mortality. Western tent caterpillar and large aspen tortrix are early-season defoliators, allowing aspen to re-

leaf later in the summer. 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), as well as making it difficult to detect from the air. Defoliation on the Kaibab N.F. and Grand Canyon N.P. from 1975 through the late 1990s included by all four agents. Significant defoliation by western tent caterpillar and/or large aspen tortrix has occurred every decade since the 1940s (Fig. 7), with the outbreak in the 1970s being the largest - 130,000 ac of defoliation in 1977 (Fig. 7). 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). More recently, western tent caterpillar and large aspen tortrix defoliated almost 50,000 ac in 1998. Specific causal agents are difficult to identify from the air and ground truthing is limited, so defoliation is now mapped and reported as a complex rather than by individual insects and diseases.

The cumulative effects of several abiotic and biotic agents have accelerated dieback and mortality of aspen across northern Arizona, particularly on the Kaibab N.F. (Fig. 7) (Fairweather *et al.* 2006b). In addition to recent major outbreaks of insect and fungal defoliators, a severe frost damaged almost 115,000 ac in June 1999. The frost event caused defoliation and some branch mortality and topkill in aspen clones that were in the process of leaf development and most vulnerable to damage. Noticeable mortality occurred following additional drought stress in 2002-2003. Western tent caterpillar activity increased again in 2004, continuing through 2006. These recent weather events have accelerated dieback and mortality of aspen across northern Arizona, particularly on the Kaibab N.F. (Fairweather *et al.* 2006b). Fig. 7 mostly depicts annual defoliation, and does not adequately depict a dramatic reduction in health of the aspen forest, with large areas now suffering decline (severe branch dieback and mortality) (Fairweather *et al.* 2006b).

Based on data collected from other forests that experienced similar weather patterns, mortality in affected aspen sites at 7,500-8,500 feet is probably 50% in the last 5 years, and 25% above 8,500 feet (Fairweather *et al.*, *in preparation*). Gitlin *et al.* (2006) found approximately 15% mortality associated with the 2002-2003 drought in a random sample of affected and non-affected aspen stands near Flagstaff above 7500 ft.

Ungulate browsing has impacted aspen regeneration on the Williams R.D. 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. 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 different species altogether (Heffelfinger *et al.* 2002).

Elk feed heavily on new sprouts and introduce decay fungi in saplings by antler rubbing. Stem decay fungi contribute to stem instability as the trees grow (DeByle 1985). For these reasons, permanent exclusion fences are required to regenerate and maintain aspen on Williams R.D. (Fairweather *et al.* 2006b, Rolf 2001, Shepperd and Fairweather 1994), except on steeper slope on Kendrick Peak following the Pumpkin fire.

The cumulative effects of several 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 across the entire Kaibab N.F., aspen on the southside of the forest is in crisis due to the inability to regenerate.

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. Dwarf mistletoes have narrow host specificity, often with only one preferred tree host species. On the Kaibab N.F. and Grand Canyon N.P., southwestern dwarf mistletoe infects ponderosa pine, Douglas-fir dwarf mistletoe infects Douglas-fir and, rarely, 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. Annual growth loss for ponderosa pine from the 1980s was estimated at 20–30 MMBF annually for the Kaibab N.F. (Hessburg and Beatty 1985).

Survival of host trees is influenced by the severity of dwarf mistletoe infection and site factors. Hawksworth and Geils (1990) found in Grand Canyon N.P. that more than 90% of uninfected and lightly infected trees survived over a 32-year period, but that only 5% of the heavily infected trees over 9 in. dbh, and none of the 4- to 9 in. dbh trees survived. Heavily infected trees are frequently attacked by secondary bark beetles. During the 2002-2003 bark beetle outbreak on the Kaibab N.F., ponderosa pine mortality within dwarf mistletoe-infested stands was greater in severely infected trees (Kenaley *et al.* 2006).

Spread and intensification of dwarf mistletoe within a stand are functions of stand density, age, and site index, and averages one or two feet a year. Spread is most efficient and rapid from an infected overstory to an understory and slowest through a dense even-aged stand. 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, but may be beneficial for many species of birds and mammals (Bennetts *et al.* 1996, Garnett *et al.* 2004). 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).

Although southwestern dwarf mistletoe is found throughout the Kaibab N.F. and Grand Canyon N.P., incidence is higher on the North Kaibab R.D. where nearly 46% of the commercial ponderosa pine type was infected in the 1980s, compared to 25-38% on the Williams R.D. (25% on what was the Chalender R.D. and 38% on what was the Williams R.D. before the two were merged) (Hessburg and Beatty 1985). Only about 5% of the surveyed area was infected on the Tusayan R.D., and this was at the north end of the District, near the rim of the Grand Canyon.

After roadside surveys in the 1980s showed serious problems with southwestern dwarf mistletoe, silvicultural prescriptions were applied in the mid- to late-1980s to reduce dwarf mistletoe infections on the Kaibab N.F. More aggressive prescriptions were applied on the North Kaibab R.D., than on the south side of the Forest. On the North Kaibab R.D., all age classes of infected ponderosa pines were targeted for removal, while on the south side typically just the infected overstory was targeted for removal. The prescriptions on the north side led to reduced dwarf mistletoe infection frequency in regeneration that is developing beneath scattered lightly to moderately infected overstory trees (Fairweather 2004).

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. Prescribed fire 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).

Southwestern dwarf mistletoe incidence and infection severity have increased on the Kaibab N.F. In the mid-1980s, Hessburg and Beatty (1985) estimated that 34% of the commercial acres of ponderosa pine on the Kaibab N.F. were infected with southwestern dwarf mistletoe, an increase from 30% found in a similar survey 30 years earlier (Andrew and Daniels 1960). Based on present understanding of mistletoe ecology (Parmeter 1978, Hawksworth and Weins 1996), increases in host abundance over the past 150 years, decreases in fire frequency, and evidence of previous forest conditions and fire regimes, it can be inferred that Southwestern dwarf mistletoe abundance was likely lower in the historic period (Dahms and Geils 1997), and that current conditions are likely similar to the 1980s estimate. When dwarf mistletoe has been targeted during forest management, silviculture prescriptions have typically tried to reduce infection levels, not eliminate dwarf mistletoe from sites. Some large crown fires have reduced the size of the infected area by eliminating both the host and its dwarf mistletoe, but dwarf mistletoe has continued to spread into uninfected areas on the Forest.

The incidence of Douglas-fir dwarf mistletoe in the Southwest is believed to be even more widespread on Douglas-fir than southwestern dwarf mistletoe is on 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. As with southwestern dwarf mistletoe, heavily infected trees are frequently attacked by bark beetles, killing them.

## 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. Unfortunately, the North Kaibab R.D. was not included in his survey. 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.

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). On the Kaibab

N.F. and Grand Canyon N.P., root disease incidence is increasing as a result of increased logging activities (Hagle and Goheen 1988).

- Defoliation by native defoliating agents, such as western tent caterpillar and black leaf spot on aspen, pandora moth in ponderosa pine, and sawflies in ponderosa pine and piñon, 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 on the Kaibab N.F. and Grand Canyon N.P. include:

- In ponderosa pine, pre-1950 outbreaks were mostly comprised of mountain pine beetle, and the 1950s and recent outbreak have been comprised mostly of *Ips* species (pine engraver beetle and Arizona fivespined ips) followed by drought responsive *Dendroctonus* species such as western pine beetle and roundheaded pine beetle.
- The size and severity of recent drought- and pinyon ips-related piñon die-off is 100 times

In the piñon-juniper type, 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 increasingly 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, so will the prevalent pest problems. Many insects and pathogens attack trees of specific species and ages, 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 it was in the early 1900s due to 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.
- 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 are likely to establish and become problems. White pine blister rust is an exotic pathogen that kills white pines. This disease alternates between white pines and *Ribes*, Indian paint brush, and lousewort, all of which are present on the Kaibab N.F. and Grand Canyon N.P. The pathogen has yet to be detected in Arizona but has been found on the Gila, Lincoln, and Santa Fe National Forests, and establishment in Arizona forests seems inevitable. Once established, damage to limber pine and bristlecone pine will likely be severe over several decades. Spruce aphid has been damaging Engelmann spruce on the San Francisco Peaks since 1999, and establishment of this insect on the Kaibab N.F. and Grand Canyon N.P. also seems inevitable, leading to diminished

- representation of Engelmann spruce. Other exotics are likely to establish, with unknown but potentially catastrophic consequences.
- 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 in other Southwestern forest. 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). Kaibab N.F. forests will continue to change with time and in response to changing environmental conditions, these and other new problems may emerge.

## 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 co-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 pine and mixed-conifer forests, 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 significant climatic and 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 introduction and effects of exotic insect and pathogen species, 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.**

Name	Scientific Name
<b>Insects</b>	
Arizona fivespined ips	<i>Ips lecontei</i>
Douglas-fir beetle	<i>Dendroctonus pseudotsugae</i>
fir engraver	<i>Scolytus ventralis</i>
large aspen tortrix	<i>Choristoneura conflictana</i>
Mountain girdle	<i>Enypia griseata</i>
mountain pine beetle	<i>Dendroctonus ponderosae</i>
Pandora moth	<i>Coloradia pandora</i>
Phloeosinus beetles	<i>Phloeosinus</i> spp.
pine engraver	<i>Ips pini</i>
pine needle scale	<i>Chionaspis pinifoliae</i>
pinyon ips	<i>Ips confusus</i>
pinyon needle scale	<i>Matsucoccus acalyptus</i>
Prescott scale	<i>Matsucoccus vexillorum</i>
roundheaded pine beetle	<i>Dendroctonus adjunctus</i>
sawflies	<i>Neodiprion</i> spp., <i>Zadiprion</i> spp.
southern pine beetle	<i>Dendroctonus frontalis</i>
Southwestern pine tip moth	<i>Rhyacionia neomexicana</i>
spruce aphid	<i>Elatobium abietinum</i>
spruce beetle	<i>Dendroctonus rufipennis</i>
tiger moths	<i>Lophocampa ingens</i> and others
tip moths	<i>Rhyacionia</i> spp.
true fir beetles	bark beetles attacking white fir & corkbark fir, usually fir engraver &/or western balsam bark beetle
western balsam bark beetle	<i>Dryocoetes confusus</i>
twig beetles (in piñon)	<i>Pityophthorus</i> spp.
western pine beetle	<i>Dendroctonus brevicomis</i>
western pine shoot borer	<i>Eucosma sonomana</i>
western spruce budworm	<i>Choristoneura occidentalis</i>
western tent caterpillar	<i>Malacosoma californicum</i>
white fir needleminer	<i>Epinotia meritana</i>
<b>Pathogens</b>	
Annosus root rot	
Armillaria root rot (shoestring root rot)	<i>Armillaria</i> spp.
black leaf spot	<i>Marssonina populi</i>
Douglas-fir dwarf mistletoe	<i>Arceuthobium douglasii</i>
pinyon dwarf mistletoe	<i>Arceuthobium divaricatum</i>
Schweinitzii root and butt rot	<i>Phaeolus schweinitzii</i>
Southwestern dwarf mistletoe	<i>Arceuthobium vaginatum</i> subsp. <i>Cryptopodum</i>
Tomentosus root disease	<i>Inonotus tomentosus</i>
western spruce dwarf mistletoe	<i>Arceuthobium microcarpum</i>
white pine blister rust	<i>Cronartium ribicola</i>



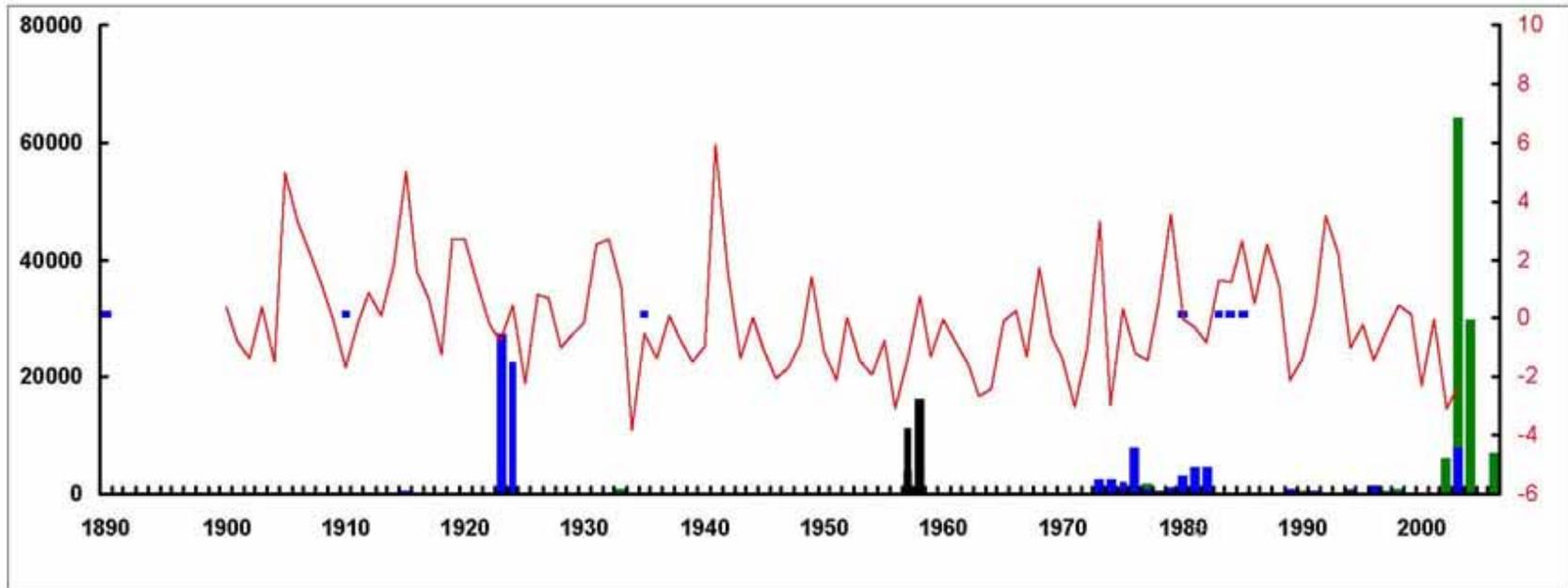


Figure 2. Area (bars) of ponderosa pine damaged by *Ips* (green) and *Dendroctonus* (blue) bark beetles on the Kaibab N.F. and Grand Canyon N.P., in acres. Years for which bark beetle activity was reported without reference to the size of the area damaged are shown as dots. Areas and years for which *Ips* and *Dendroctonus* were not distinguished are shown in black. Instrumental Palmer Drought Severity Index for Arizona and New Mexico (NCDC 2006) is shown in red. See the text for a description of a data discrepancy for mountain pine beetle damage in the mid-1970s.

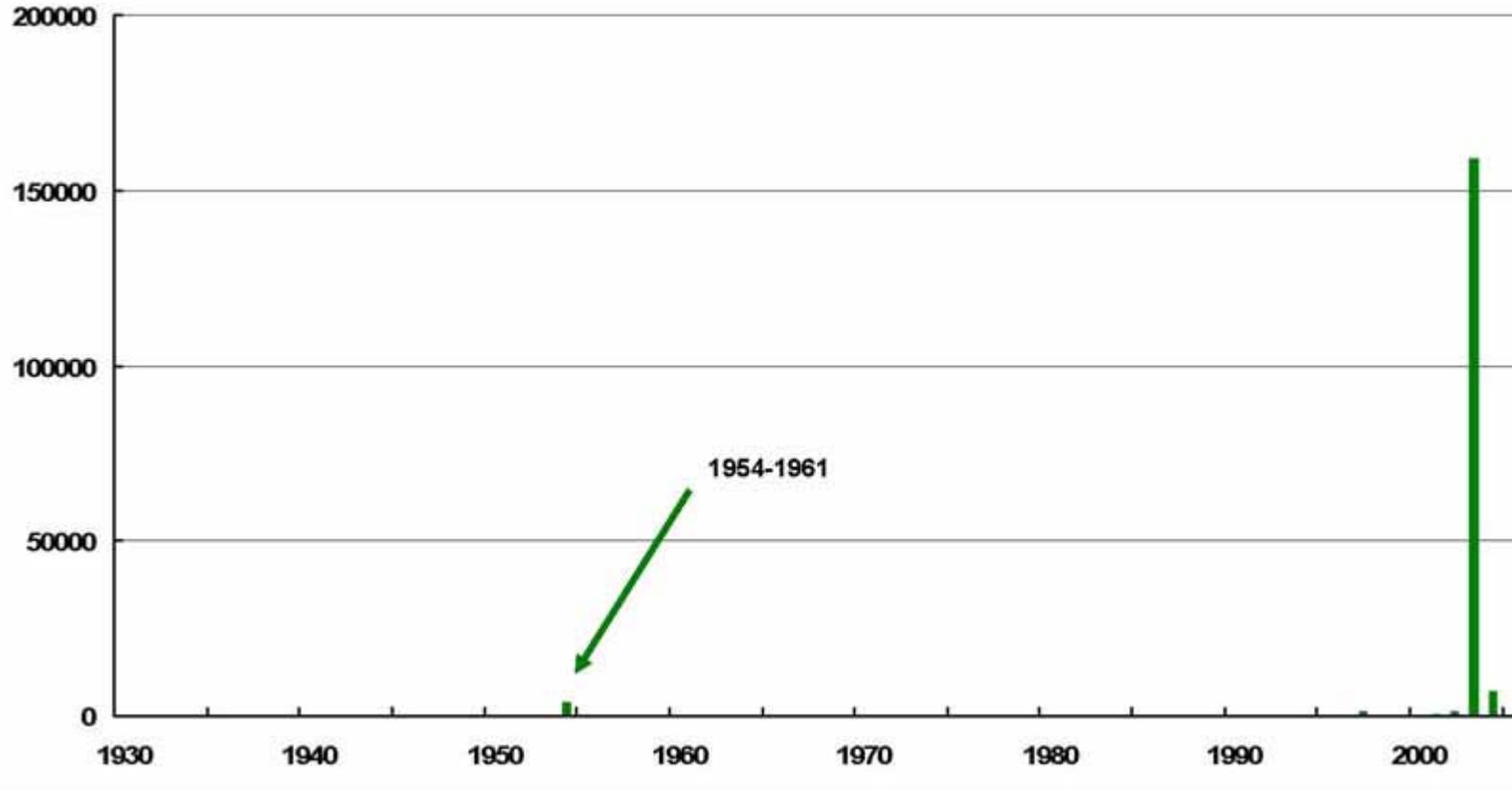


Figure 3. Area (ac) damaged by piñon ips on the Kaibab N.F. and Grand Canyon N.P.

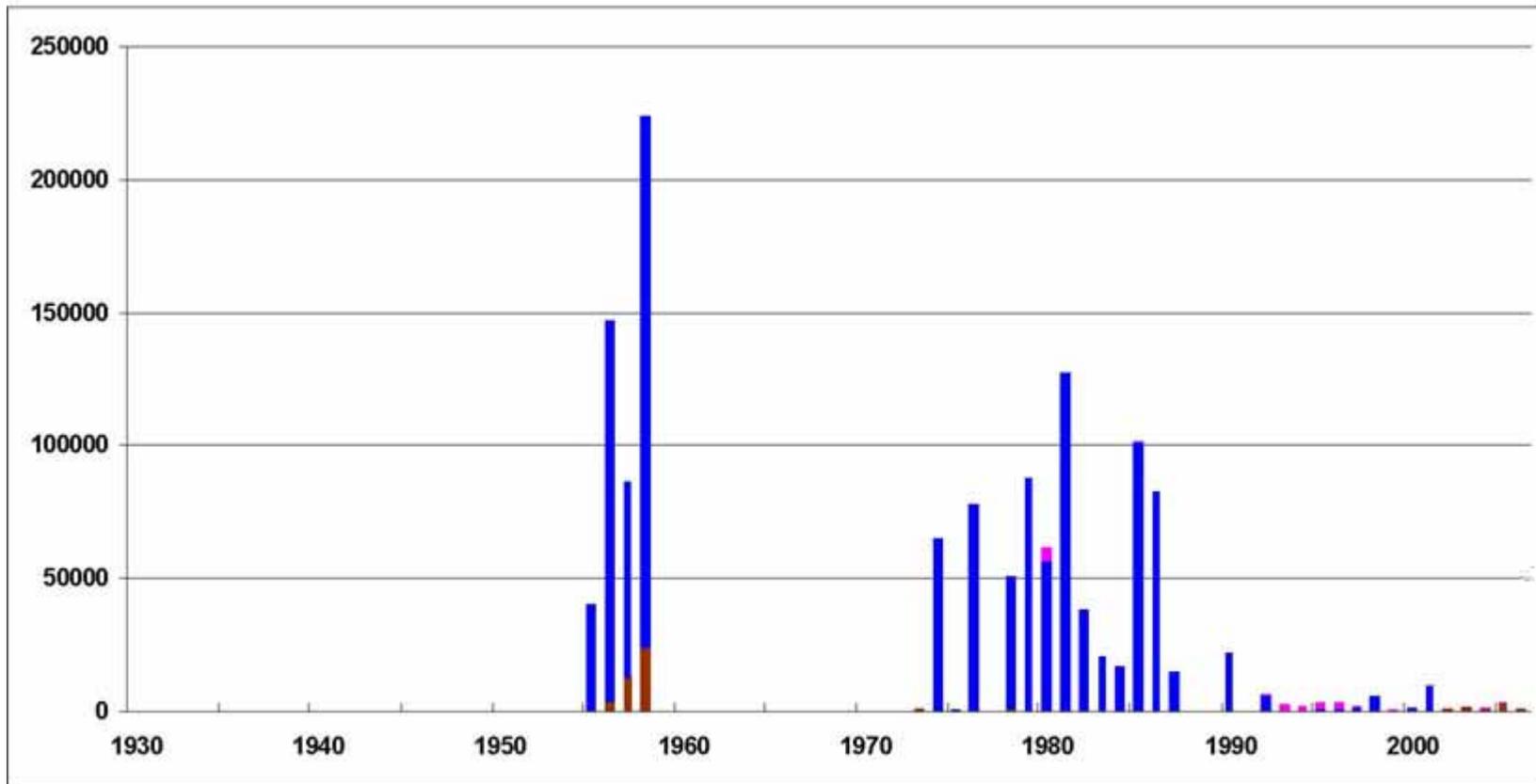
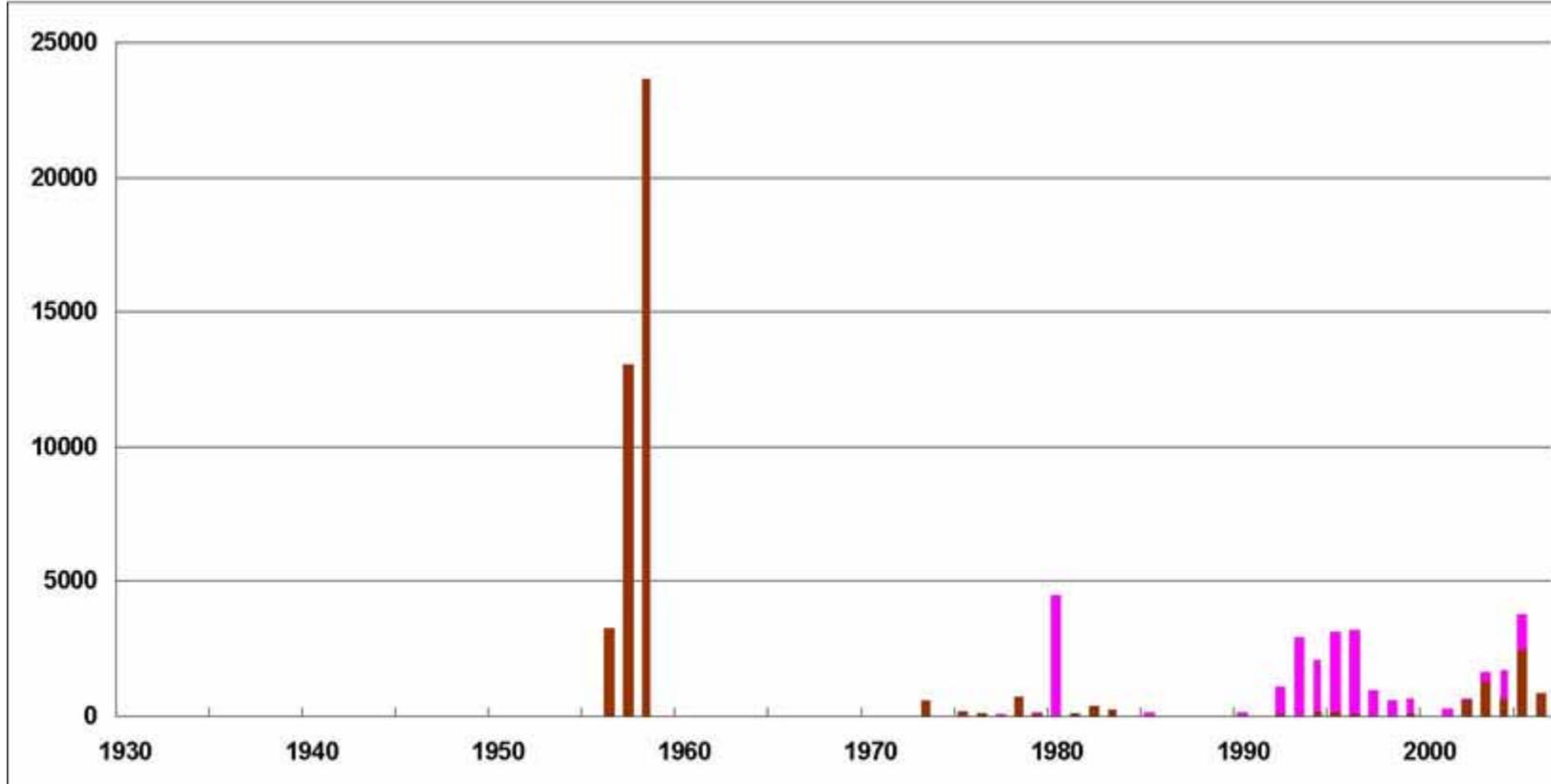


Figure 4. Mixed-conifer area (ac) affected by defoliators (blue), Douglas-fir beetle (brown), and true fir beetles (magenta) on the Kaibab N.F. and Grand Canyon N.P. Data is shown only for years with acreage reported.



**Figure 5. Mixed-conifer area (ac) affected by Douglas-fir beetle (brown) and true fir beetles (magenta) on the Kaibab N.F. and Grand Canyon N.P. Data is shown only for years with acreage reported, excluding years where defoliation occurred, but not acreage was reported.**



**Figure 6. Area (ac) of spruce-fir on the Kaibab N.F. and Grand Canyon N.P. damaged by western balsam bark beetle (green) and spruce beetle (blue).**

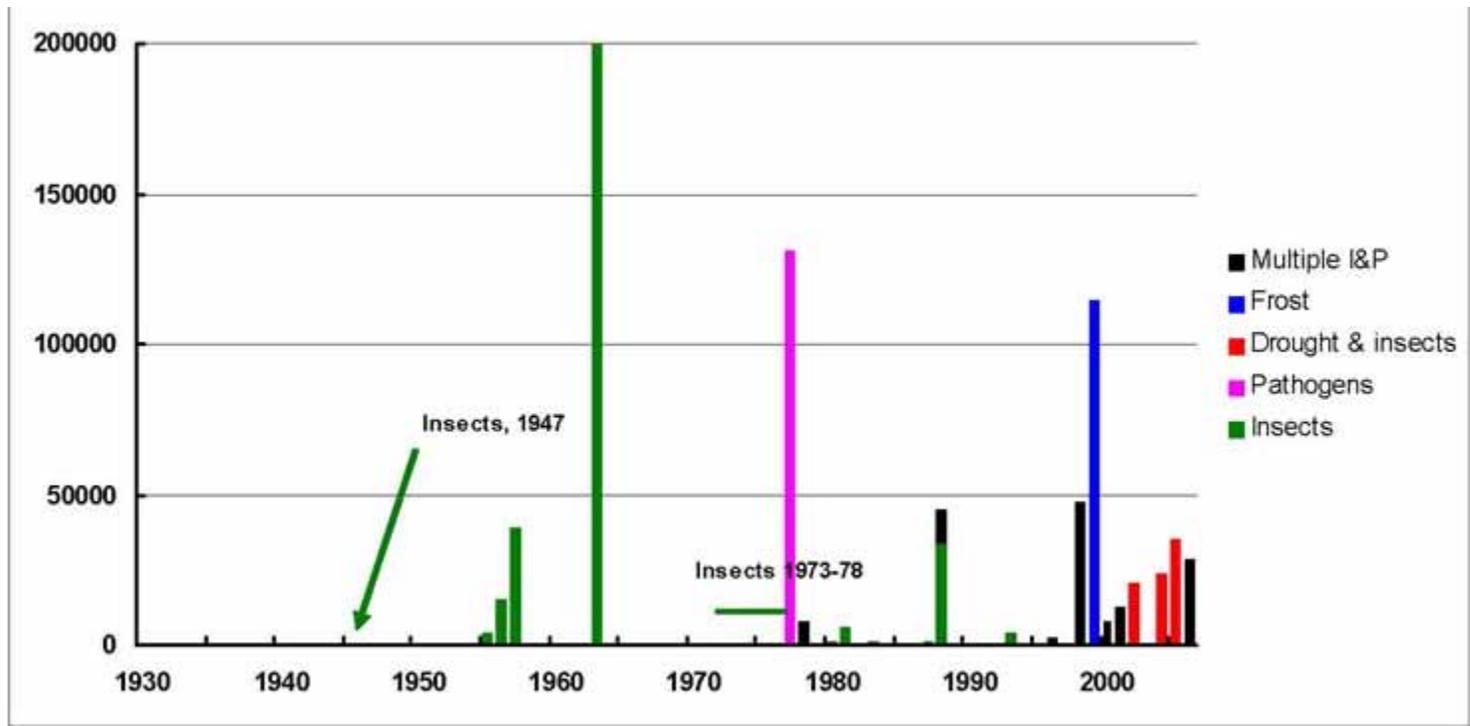


Figure 7. Area (ac) of aspen on the Kaibab N.F. and Grand Canyon N.P. damaged by various biotic and abiotic agents.

