Forest Inventory and Analysis (FIA) Annual Inventory Answers the Question: What Is Happening to Pinyon-Juniper Woodlands?

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ABSTRACT

Widespread mortality in the pinyon-juniper forest type is associated with several years of drought in the southwestern United States. A complex of drought, insects, and disease is responsible for pinyon mortality rates approaching 100% in some areas, while other areas have experienced little or no mortality. Implementation of the Forest Inventory and Analysis (FIA) annual inventory in several states coincided with the onset of elevated mortality rates. Adjunct inventories provided supplemental data on damaging agents. Preliminary analysis reveals the status and trends of mortality in pinyon-juniper woodlands.

Keywords: forest inventory, FIA, pinyon pines, pinyon-juniper woodlands, drought, mortality, *Ips confusus*, bark beetles, southwestern United States

The Forest Inventory and Analysis (FIA) is a national USDA Forest Service program that conducts forest inventory across all land ownerships in the United States. FIA inventories are based on a systematic sample, establishing permanent sample plots on the ground at an intensity of approximately one plot per 6,000 forested acres. In the past, FIA conducted periodic inventories in which all plots in a given state were measured at once. In western states it commonly required several years to measure all the plots in a state. The planned periodic revisitation cycle in the western United States was 10 years, but actual cycle lengths sometimes approached 20 years. In response to user demand for more timely information, FIA began to test and implement an annual inventory system in 1996 (Gillespie 1999).

The annual inventory system uses the same systematic sample grid as was used for periodic inventories, but the plots are evenly divided into annual panels that are visited in a continuous cycle. In western states, one-tenth of the plots in a state is sampled per year, producing a 10-year inventory cycle. Plots are distributed throughout the state in each panel. Consequently, annual panels are theoretically free from geographic bias. This system provides a continuous flow of data, which allows for more flexible analysis options and provides opportunities to monitor forest change in ways that were not possible using periodic inventory data.

Pinyon-juniper woodland is the most common forest type in the American Southwest, covering over 36 million acres in 10 states and extending into Mexico. The type is defined by the presence of one or more pinyon species—usually common and singleleaf pinyon (*Pinus edulis* Engelm. and *Pinus monophylla* Torr.&Frem.)—and one or more juniper species (*Juniperus* spp.); pure stands of pinyon usually are not considered a separate type. Pinyon nuts were a staple food for Native Americans of the Southwest for thousands of years, and the harvest of this valuable resource continues today (Lanner 1981). There also are many traditional and modern uses for pinyon and juniper wood. The extensive range and volume of the resource has generated interest in intensive use, such as an energy-producing biomass crop. However, pinyon-juniper woodland is seen as a weedy invader of productive grasslands by some.

The Interior West FIA (IW-FIA) program operates in Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming, which includes most of the range of the pinyon-juniper type in the United States. Annual inventory was implemented in Utah in 2000 and in most of the other IW-FIA states since then. About the time that annual inventory was started in the IW, forest managers and researchers began to notice an increase in the incidence of insects and disease in several forest types, including pinyon-juniper. Much of the increase has been attributed to the drought that spread across the Southwest beginning in the late 1990s (Figure 1).

As of Jan. 2005, the drought was ongoing and significant drought-related mortality had occurred in the pinyon-juniper type

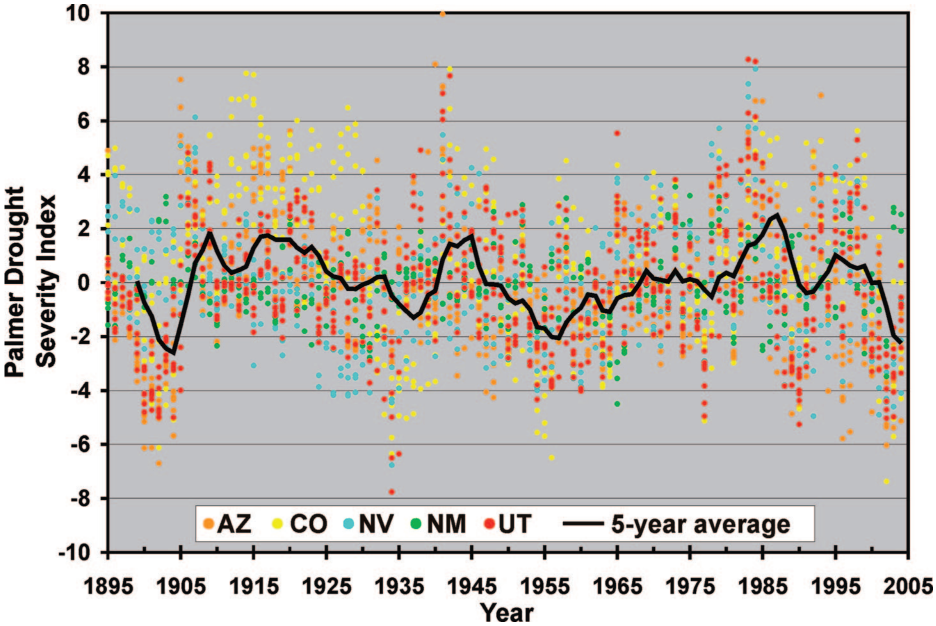

Figure 1. Climate record from 1895 to 2004 for five southwestern states as recorded in the Palmer Drought Severity Index (PDSI). Data points represent the mean annual PDSI for National Oceanic and Atmospheric Administration (NOAA) Climate Divisions within each state (National Climatic Data Center 1994).

Figure 2. Landscape-scale pinyon mortality in pinyon-juniper woodland in southeastern Utah. (Photo by B. Steed.)

(Figure 2). Widespread and locally severe mortality has inspired efforts to quantify the effects of drought, insects, and disease over the past 5 years. Some of these efforts have been local in nature and lack the geographic and temporal ranges covered by the FIA program. Other efforts provided wider coverage but were focused on areas where mortality was known to occur. Because the FIA sample is unbiased with respect to plot location and covers a wide area and extended time period, it provides a unique view of pinyon-juniper woodlands. The systematic sample also reduces the likelihood of producing erroneous conclusions that may come from surveys conducted only in known areas of mortality. Therefore, the current mortality episode has provided an opportunity to test the usefulness of the FIA annual inventory system for quantifying rapid change in pinyon-juniper woodlands over a large geographic area (Shaw in press).

Because of the high degree of interest in the amount of mortality and causal agents, we established an adjunct inventory on a subset of FIA inventory plots to document damaging agents in detail. Here, we describe the extent and severity of mortality in the pinyon-juniper forest type and highlight some of the contributing mortality agents.

Drought and Effects on Forests

The current Southwest drought began about 1998 (McPhee et al. 2004), but the exact time of onset varies by location and interpretation of climatic data. Although locally severe, the current drought appears comparable in magnitude to droughts in the early 1900s, in the 1950s, and during many other dry periods that have been documented using tree-ring–based reconstructions of the past 800 years (Cole et al. 2004, McPhee et al. 2004; Figure 1). In recent months, it appears that some areas affected by drought since the late 1990s are experiencing a degree of relief (Society of American Foresters 2004).

Anecdotal reports of drought-related effects on Southwest forests began in 2000, but a dramatic increase in tree mortality occurred in 2002 (Anhold and McMillin 2003). There were local reports of up to 100% mortality of the pinyon component in pinyon-juniper woodland. A rapid expansion of high-mortality areas was recorded during aerial surveys between the fall of 2002 and the fall of 2003 (Anhold and McMillin 2003). Although locally severe, little of the observed mortality has been attributed to drought alone. The cause of mortality may be best described as a complex of drought, insects, and disease.

Mortality Status and Trends

Data from IW-FIA periodic and annual inventories offer some insight into the progression of drought-related mortality across the Southwest. Periodic inventories from Arizona, New Mexico, and Utah quantified predrought conditions of pinyon-juniper forests and more recent annual inventory data from Arizona, Colorado, Nevada, and Utah captured the current drought-related mortality episode. Although junipers and other species have suffered mortality in some areas, FIA plot data suggest that, to date, they are largely unaffected in the pinyon-juniper type. For the sake of simplicity, the figures and trends presented here represent only the pinyon component of the pinyon-juniper type.

The IW-FIA program defines a mortality tree as one determined to have died within 5 years of the plot measurement date. Therefore, a distinction between long-standing dead trees and recently killed trees is made in the field. In the case of periodic inventories, this distinction was necessary for the purpose of estimating annual mortality because data were limited to initial plot measurements. In reports based on periodic data, observed mortality is averaged over the 5-year period and reported as annual mortality in the year before inventory. Therefore, using this method it is assumed that 5-year average mortality is representative of the reported year. Periodic inventory data suggest that annual mortality is relatively low for pinyon and juniper species. Based on recent periodic inventory data from Arizona (O'Brien 2002), New Mexico (O'Brien 2003) and Utah (O'Brien 1999), annual mortality, on a volume basis, was estimated at 0.08–0.23% for common pinyon, 0.14% for singleleaf pinyon, 0.01% for oneseed juniper (*Juniperus monosperma* (Engelm.) Sarg.), 0.01–0.08% for Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), and 0.01–0.07% for Utah juniper (*Juniperus osteosperma* (Torr.) Little). In contrast, e.g., estimates of annual mortality for ponderosa pine (*Pinus ponderosa* Laws.) ranged from 0.21 to 0.48% in the same inventories. Because these estimates were computed from periodic inventories conducted in relatively normal years (i.e., not excessively droughty), they may be representative of approximate "background" mortality rates. These estimates also include mortality due to fire, so background mortality rates excluding fire are actually somewhat lower.

Basing mortality estimates on a 5-year average can be advantageous when it is desirable to smooth year-to-year variation and represent a "typical" year. However, the method also may mask trends that are of interest or produce biased estimates. For example, consider a periodic inventory that immediately followed a severe fire season. If mortality data were attributed only to the previous year, the mortality estimate would be relatively accurate for that year but would drastically overestimate mortality for a typical year. On the other hand, the 5-year average would be closer to the true background mortality rate but still overestimates typical mortality because of the inclusion of a severe fire year. In addition, it is impossible to discern trends based on a single periodic inventory.

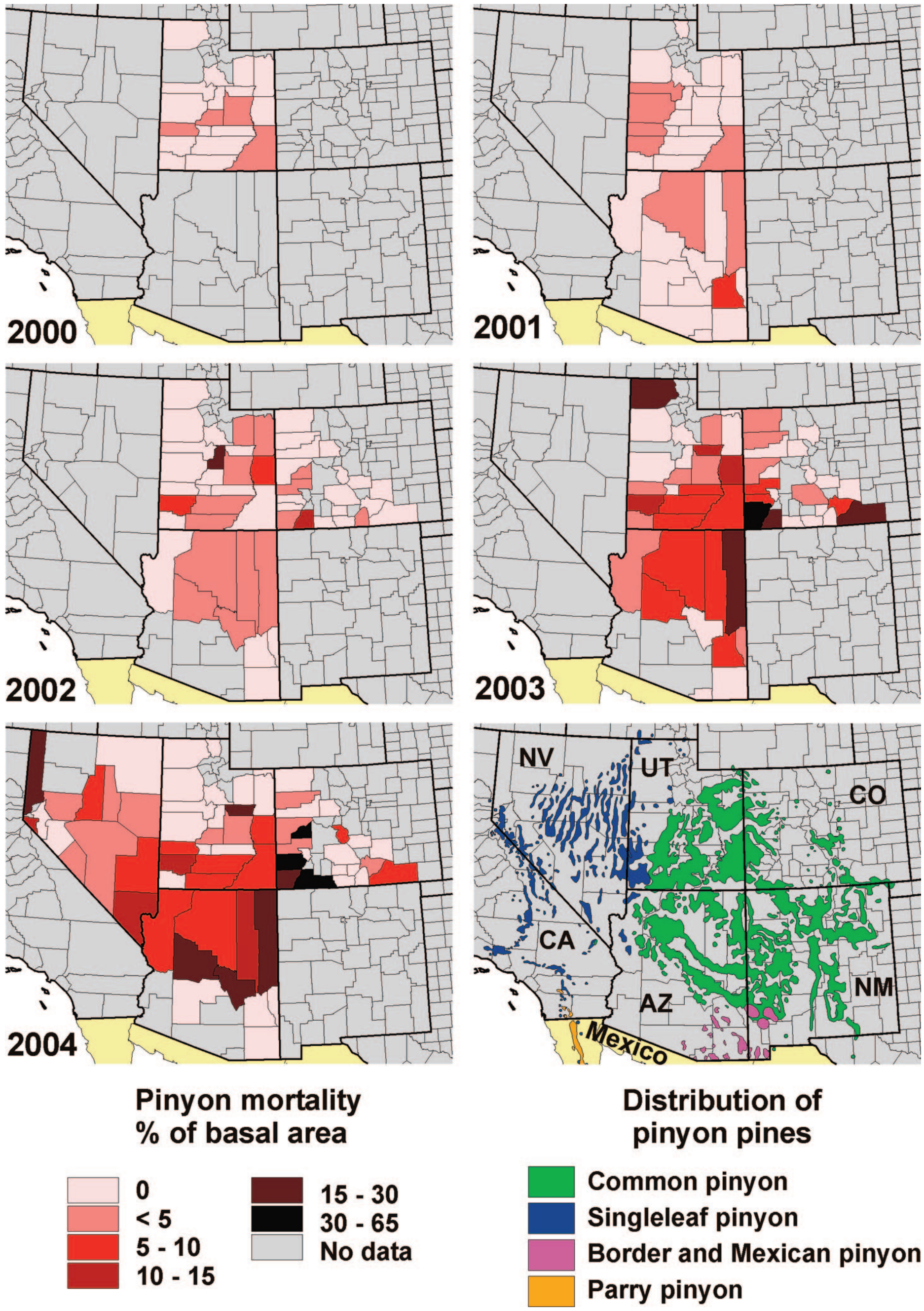

Figure 3. County-level estimates of pinyon mortality 2000–2004. Mortality values represent the percentage of mortality of all pinyon trees 5.0 in. DBH and greater (live and mortality), on a basal area basis and on plots classified as the pinyon-juniper woodland type and excludes mortality attributable to fire and logging. Annual inventory was implemented in Utah in 2000, Arizona in 2001, and Colorado in 2002. Data for Nevada are from a pilot inventory conducted in 2004. Annual inventory still has not been implemented in New Mexico. The range of pinyon-juniper woodlands, based on the ranges of common, singleleaf, border, Mexican, and Parry (*Pinus quadrifolia* Parl.) pinyons, is shown for reference. Ranges modified using FIA data from digitized maps (USGS 2005).

In the case of insect and disease outbreaks, short-term temporal trends are of significant interest. Annual data provide finer-scale temporal resolution that may reveal short-term trends. Preliminary analysis suggests that the progression of drought-related

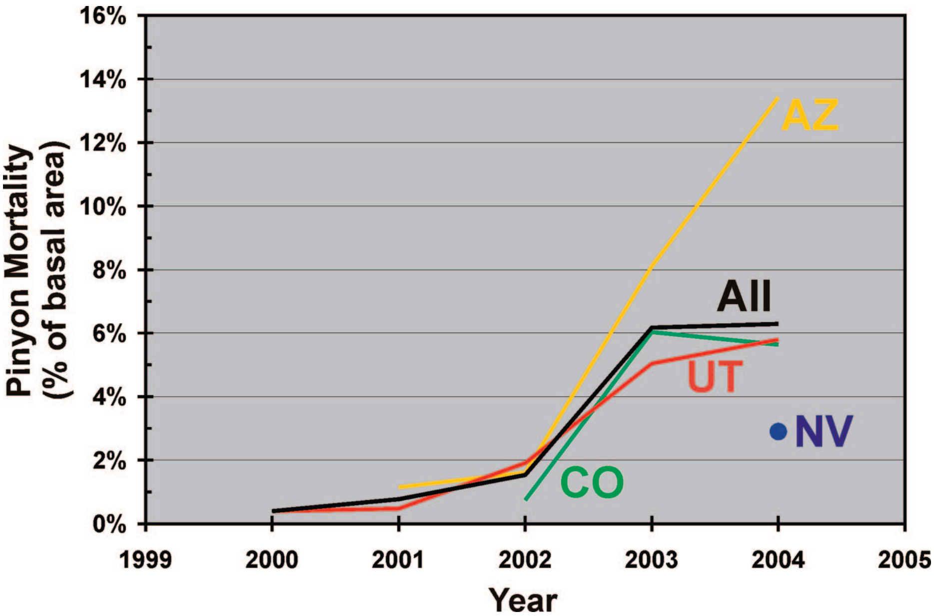

Figure 4. Statewide mortality trends in Arizona, Colorado, Nevada, and Utah. Pinyon mortality is defined as in Figure 3. Nevada is represented only by 2004 pilot inventory data. Line labeled as "all" represents the combination of all states in which annual data were collected in a given year.

mortality has been captured by annual data collected in southwestern states over the past 5 years.

Annual inventory data show that drought-related mortality has occurred widely across the Southwest. Figure 3 shows mortality estimates at the county scale, which is a common FIA reporting unit (USDA Forest Service 2005). In the early stages of drought (2000–2001), nearly all the mortality occurring at the county scale was located in one or two plots in the county. As the event progressed, mortality was recorded on many more plots, but considerable variation in the amount of mortality still occurred among plots within counties.

When all plots are combined at state or regional scales, it is evident that the annual inventory has captured the rapid increase in drought-related mortality across the Southwest (Figure 4). There are several aspects of Figure 4 worth noting. The first is that the annual mortality estimates (as well as the county-level estimates in Figure 3) are actually 5-year cumulative mortality values. Given the previous explanation of how annual mortality is calculated, it would appear that the data overestimate mortality in a given year. However, because data from earlier panels show far less mortality than later panels, it is possible to infer that the mortality detected in later years, or at least most of it, occurred just before the time it was observed. Thus, the actual "new" mortality for a given year could be estimated by subtracting the cumulative mortality from the previous year. Compilation methods that can produce such estimates are under investigation.

The similarities and differences in mortality rates among states also may be informative. The fact that the trends shown by each of the statewide curves are similar from 2000 to 2003 lends to confidence in the results. However, the differences among states revealed by the 2004 data raise a number of questions, perhaps the most important being: why? Our preliminary attempts at modeling mortality risk in the pinyon-juniper type suggest that mortality may be predicted by a combination of edaphic factors and stand structural traits. This may allow prediction of trends in New Mexico, e.g., where annual inventory still has not been started but recent periodic inventory data are available.

Finally, trends revealed by annual data agree with anecdotal accounts of the progression of mortality. Reports from the field indicated that new insect and disease-caused mortality declined during 2004 and mortality, while still increasing, was doing so at a decreased rate. Inventory data from Utah and Colorado appear to confirm field observations, and data from Arizona suggest a slight decrease in the rate of increase. No inference of trend is possible for Nevada, which is represented by only a single panel of annual data. However, the Nevada statewide estimate of 2.9% mortality probably is five to 10 times the expected background mortality, based on pinyon mortality rates in other states (O'Brien 1999, O'Brien 2002, O'Brien 2003).

Mortality Agents

Although mortality has been attributed to drought alone in some cases, the death of a tree is commonly attributable to multiple factors. In conjunction with stress caused by drought, a number of insects and diseases can affect the health of pinyons. These agents may work singly, killing the tree directly, or in concert, with each agent causing cumulative damage or stress that eventually overcomes the tree. Agents of particular importance include pinyon ips (*Ips confusus* (LeConte)), twig beetles (*Pityophthorus* spp. and *Pityogenes* spp.), pitch moths (families Pyralidae (especially *Dioryctria* spp.) and Sesiidae), black stain root disease (*Leptographium wageneri* (Kendrick) Wingfield), and pinyon dwarf mistletoe (*Arceuthobium divaricatum* Engelm.).

The pinyon ips (Figure 5, A and B) is the most important insect mortality agent, causing the majority of the pinyon mortality in the Intermountain West (Rogers 1993). However, ips beetles tend to be only moderately aggressive, attacking and killing trees stressed by other agents (Hagle et al. 2003). Outbreaks of this native bark beetle are known to occur during periods of drought (Furniss and Carolin 1977), but also may be associated with root disease, heavy dwarf mistletoe infection, previous defoliation, dense stand conditions, or poor soil conditions (McCambridge 1974, Hessburg et al. 1995, Negron and Wilson 2003, Skelly and Christopherson 2003). When beetle populations build, outbreaks may continue for a year or two even if stressful conditions, such as drought, are removed. Pinyon ips can have two to four generations per season, which has resulted in rapid progression of mortality in some areas.

Other species of bark beetle may attack the smaller branches of pinyon pines. These "twig beetles" are largely from the genera *Pityophthorus* and *Pityogenes* and are considered secondary beetles that make use of trees that are already stressed (Rogers 1993, Cain et al. 1995, Skelly and Christopherson 2003). Some beetles from these genera may attack larger branches and trunks (Cain et al. 1995, Skelly and Christopherson 2003). Al-

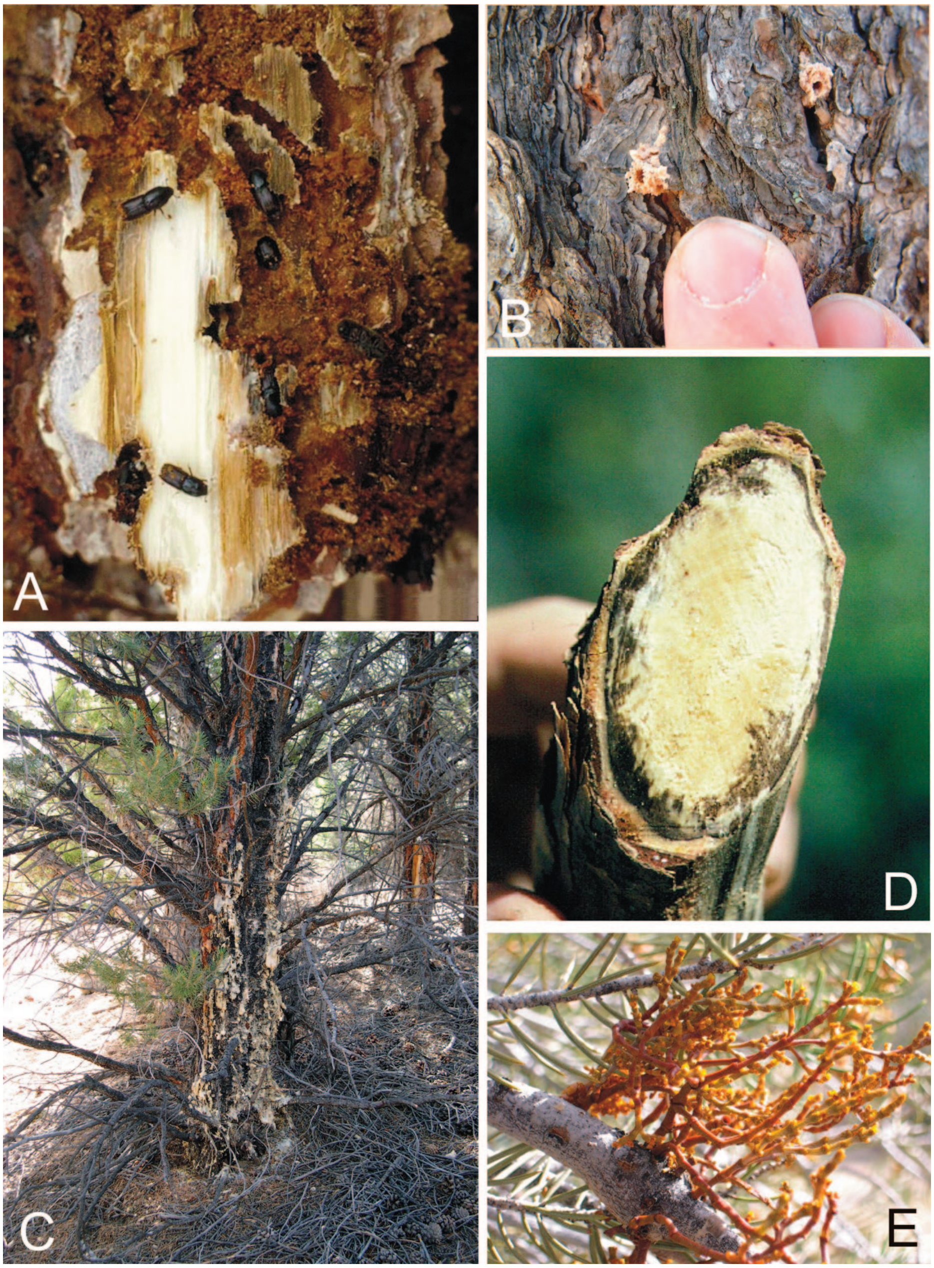

Figure 5. Agents associated with mortality of pinyons in drought-affected areas: (A) pinyon ips beetle, (B) entrance hole and frass from pinyon ips, (C) pitch flow caused by pitch moth, (D) black stain root disease, and (E) pinyon dwarf mistletoe. (Photos by: panel A, T. Eager; panel B, University of Arizona; panels C and E, B. Steed; and panel D, W. R. Jacobi.)

though they usually have little effect on tree health, these beetles can kill small trees or branches of larger trees during periods of drought (Cain et al. 1995) and have been associated with occasionally heavy, localized mortality. Most twig beetle species produce two to four generations a year depending on weather and location.

Large masses or streamers of pitch (Figure 5C) are indicative of pitch moth activity. The taxonomy and biology of many of these species appear to be poorly understood (Swift 2004), resulting in difficulty defining the organism(s) responsible for pitch mass-causing activity on pinyons. Potential agents include pyralid moth larva (Pyralidae), including several *Dioryctria* species, and clearwing moth larvae (Sesiidae) (Cain et al. 1995, Skelly and Christopherson 2003, Swift 2004). Injuries inflicted by these species weaken the host tree, making it susceptible to attacks by other insects (Skelly and Christopherson 2003). If sufficient numbers of larvae feed on a tree, the tree may be killed.

Recent research indicates that the black stain root disease variant *L. wageneri* var. *wagneri* is specific to pinyon species. Black stain fungi colonize the water-conducting tissues of the roots and lower stem, preventing movement of water to the foliage. Black-colored bands in the sapwood of roots, the root collar, or lower bole of dying trees (or no more than 6 months dead) indicate infection (Figure 5D). Root-feeding beetles and weevils may spread the fungi as they move to feed and breed. However, the most important method of infection is likely through root contact with adjacent infected trees (Skelly and Christopherson 2003). Infected trees may fade over time but often are killed early by other agents such as pinyon ips (Hessburg et al. 1995, Skelly and Christopherson 2003). The disease does not appear to be widespread (Skelly and Christopherson 2003), although it has been identified in the Four Corners area of southwestern Colorado and southeastern Utah and is implicated in the death of many trees in that area (Dr. Bill Jacobi, Colorado State University, personal communication, 2005).

The pinyon dwarf mistletoe (Figure 5E) is a parasitic plant that robs its host tree of water and nutrients. It frequently infects both common and singleleaf pinyons and can appear on other pinyon species within the mistletoe's distribution (Hawksworth and Wiens 1996, Mathiasen et al. 2002). Infection reduces tree growth and vigor, predisposing it to attack by other agents. Several studies (e.g., Negron and Wilson [2003]) suggest that dwarf mistletoe-infected trees are more susceptible to, and perhaps preferred by, pinyon ips. However, dwarf mistletoe alone can kill trees, especially seedlings and saplings. The length of time it takes to kill a tree depends on the level of infection and the age and health of the tree (Hawksworth and Wiens 1996, Mathiasen et al. 2002).

Several other insects and diseases can have strong visual effects on pinyon trees but generally are not important mortality agents. Some areas thought to be mortality locations during windshield or aerial surveys were, in fact, defoliated by nonlethal agents and found to have greened up during subsequent surveys. However, some of these organisms may predispose trees to attack by other agents. Some of the insects and diseases that can be found on pinyons still may not be identified. However, the onset of drought-related mortality has generated new interest in the ecology of the pinyon-juniper woodlands and the taxonomy and general biology of many associated organisms.

The Value of Annual Inventory

The annualized FIA inventory (Gillespie 1999) was implemented with an associated complement of assumptions and unanswered questions. The onset of widespread drought-related mortality in the Southwest is providing an opportunity to test some of the assumptions and answer some important questions (Shaw in press). In addition, some characteristics of this mortality episode have led us to consider alternative methods of compilation and analysis of FIA data. For example, the geographic distribution of mortality suggests that geographic delineations not commonly used in FIA reporting, such as ecoregional units or discrete population segments, may better capture regional variation and reduce variance in statistical analyses.

Based on early results, the potential for using annual panels as independent samples and time series data appears promising. The IW-FIA annual inventory system appears able to detect trend and magnitude of short-term change during a widespread, patchy event such as drought-related mortality. It also appears that relatively low levels of change can be detected, at least in cases where the variable of interest (in this case, background mortality) is typically at low levels and relatively constant over time and space. Status and trends probably can be estimated with confidence at larger scales. It may be possible to draw some conclusions at medium geographic scales, such as the county or national forest, but this ability is largely dependent on the distribution of the forest type of interest within the geographic area. For example, in less common forest types such as limber pine (*Pinus flexilis* James) or bristlecone pine (*Pinus aristata* Engelm.) it may be difficult to detect trends because of the relatively small numbers of FIA plots that occur in those types.

The FIA annual inventory system is providing the intended benefits of shorter reporting cycles and fine-resolution temporal trends in the states where it has been implemented. It is also providing a valuable record of change during an ecosystemwide phenomenon. With full implementation (i.e., all states under annual inventory) and the addition of new data every year, the resulting information will become increasingly valuable with time and will continue to be an important resource for managers and researchers.

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