Drought-Related Mortality in Pinyon-Juniper Woodlands: A Test Case for the FIA Annual Inventory System

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Abstract.—Several years of drought in the Southwest United States are associated with widespread mortality in the pinyon-juniper forest type. A complex of drought, insects, and disease is responsible for pinyon mortality rates approaching 100 percent in some areas, while other areas have experienced little or no mortality. Implementation of the Forest Inventory and Analysis annual inventory approximately coincided with the beginning of the mortality event, providing an opportunity to use the event as a test case for the annual inventory system. Preliminary analysis suggests that annual inventory data can quantify status and trends. Some findings will be verified using aerial imagery and independent ground inventory data.

In the mid-1990s, the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program began a shift from a periodic to an annual inventory system (Gillespie 1999). Under the periodic system, plots were measured over the entire sample grid in a given State over a period of 1 to several years. The planned revisitation cycle in the Western United States was 10 years, but actual cycle lengths sometimes approached 20 years. FIA data and reports produced by periodic inventories became increasingly outdated. In response to user demand for more timely information, the FIA program began to test and implement an annual inventory system in 1996 (Gillespie 1999).

The annual inventory system uses essentially the same systematic sample grid that was used for periodic inventories, with 1/10th of the plots in a State sampled in any given year. Plots are distributed throughout the State in each annual panel—i.e., the entire grid is used each year, and the plots are shifted on the grid from year-to-year. As a result, annual panels are theoretically free from geographic bias. Under this system, data are available every year, and reporting is intended to occur after 50 percent of the plots (five annual panels) in a State have been sampled.

The Interior West FIA (IWFIA) program—which is responsible for Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming—implemented the annual inventory system in 2000 in Utah and has added most other States since then (table 1). About the same time that annual inventory was started in the Interior West, forest managers and researchers began to notice an increase in the incidence of insects and disease in some forest types. Some of these effects were attributed to the drought that spread across the Southwest beginning in the late 1990s.

Table 1.—*Year of last periodic inventory and implementation of annual inventory for IWFIA States.*

State	Last periodic	First annual	State	Last periodic	First annual
Arizona	1999	2001	New Mexico	2000	tbd[b]
Colorado	1983	2002	Montana	1989	2003
Idaho	1991	2004	Utah	1994	2000
Nevada	1989	2004[a]	Wyoming	1983	tbd

[a] Research pilot inventory approximating an annual panel.
[b] tbd = year of first annual inventory to be determined.

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At the writing of this article, the drought is ongoing, and significant drought-related mortality has been observed in several forest types across the Southwest. Among the most seriously affected are the ponderosa pine and pinyon-juniper types. Widespread and locally severe mortality in these types has led to several efforts to quantify the effects of drought, insects, and disease over the past 5 years. Most of these efforts have been ad hoc or local in nature and lack the geographic and temporal ranges covered by the FIA program. Therefore, the current mortality event can be considered an opportunistic test of the utility of the FIA annual inventory system for quantifying rapid change over a large geographic area. Analysis of the event may also test some assumptions that have been made or concerns that have been expressed about the FIA annual inventory system.

This article describes the geographic distribution of FIA data obtained before and during the mortality event, preliminary analysis of the results, and how the design of the annual inventory system may affect the final analysis.

Drought and Effects on Forests

Onset of the drought currently experienced across the Southwest occurred about 1998 (McPhee *et al.* 2004), but the exact time of onset varies by location and interpretation of climatic data. In the spring of 2003 a "Drought Summit" was held in Flagstaff, AZ, bringing together a wide variety of experts from across the Southwest. At that time, some suggestions were made that the drought could become a 1-in 500-year, or even an unprecedented, event. But it now appears that the current drought is comparable in magnitude to the early 1900s drought, the 1950s drought, and many other dry periods that have been documented by tree-ring-based reconstructions of the past 800 years (Cole *et al.* 2004, McPhee *et al.* 2004). As of December 2004, it appears that some areas affected by drought since the late 1990s are experiencing some 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). Local reports noted up to 100 percent mortality in ponderosa pine and pinyon-juniper forest types, such as in the Horsethief Basin and San Francisco Peaks areas of Arizona. A rapid increase in the extent of high-mortality areas was recorded by aerial surveys between the fall of 2002 and the fall of 2003 (Anhold and McMillin 2003). Estimates of 90-percent or greater mortality over large areas continue to be reported (e.g., Society of American Foresters 2004), but the exact extent of high-mortality areas has not yet been completely documented.

The primary agents responsible for tree mortality in the Southwest were the western pine beetle (*Dendroctonus brevicomis* LeConte) in ponderosa pine, and the pinyon ips beetle (*Ips confusus* LeConte) in pinyon pine. A variety of other insects and diseases also affected these and other tree species, and a comprehensive list of possible agents has yet to be completed. Hereafter in this article, mortality will refer to that caused by a complex of drought, insects, and disease, excluding fire and other causes.

In early 2003, the USDA Forest Service Interior West Forest Health Monitoring (FHM) Regional Program Manager requested a preliminary analysis of FIA annual inventory data as a supplement to ongoing FHM assessments. The preliminary assessment focused on Arizona and Utah, for which 2 and 3 years of annual inventory data were available, respectively. The data suggested a modest increase in mortality of pinyon and juniper species in 2002, but the percentage of total basal area affected was still relatively small. At that point, in part due to the fact that estimated mortality (based on annual data only) was near zero in 2000 and 2001, whether the apparent increase was signal or noise was not clear. The prospect of using data from annual FIA panels as time series data raised several important questions, some of which had been discussed in detail when the move from a periodic to annual inventory system was considered, and some of which are still subjects of active research. The nature of the mortality event—widespread, patchy, and increasing over time—and the questions raised by attempts to quantify it using annual FIA data suggested that the event could be used as an ideal test of the FIA annual inventory system.

Questions About FIA Inventory Design and Reporting

The first set of questions relates to FIA inventory design, in terms of the number and design of plots. First and most fundamentally, are there enough plots in one annual panel to detect the progression of the mortality event? FIA periodic inventories are sampled on a grid, with one potential field plot for approximately every 6,000 acres (known as phase 2). Under annual inventory, approximately 9,500 phase 2 plots are in Utah, about 3,700 of which are expected to occur in forest conditions. This means that approximately 370 plots (1/10th of the forested phase 2 plots) across the State are scheduled to be visited in any given year. Pinyon-juniper is the most common forest type in most of the States in which it occurs. Of the 370 plots to be visited annually in Utah, 160 to 180 are expected to sample the pinyon-juniper type. The proportions given for Utah are comparable to other States with significant acreage of the pinyon-juniper type (Arizona, Colorado, New Mexico, and Nevada).

Stand densities commonly found in the pinyon-juniper type span the low end of stocking that meets the definition of forest for the purpose of FIA inventory. The most recent periodic inventories and all annual inventories use the new mapped-plot design, which consists of a cluster of four 1/24-acre subplots (Scott and Bechtold 1995). Given the sparse nature of the pinyon-juniper type, asking whether enough trees are tallied on plots in very sparse stands to adequately represent the site is a reasonable question. In addition, mortality may be quite patchy within stands, raising the possibility that only green trees may be sampled in a landscape that is clearly experiencing significant mortality.

Potential users of FIA data who are interested in the causes of mortality often raise questions about identification of causal agents. Although FIA maintains an extensive quality control program, the nature of the mortality event is such that primary causes may be obscured. Drought-related mortality has been characterized as a complex of drought, insects, and disease, and two or more agents are likely to be present on the plot (although drought is assumed to be ubiquitous at present, ground crews do not measured it). In addition, the mortality trees are defined as those judged to have died in the 5 years before the current inventory. The possible lag between time of death and measurement allows for the loss of evidence of the primary agents or invasion of secondary agents factors. This may lead to the recording of "unknown" as the cause of death by the field crew because the cause is not discernible or several likely causal agents exist.

Questions related to analysis and reporting are also of concern. FIA statisticians are currently researching the implications of several methods of compiling annual data, such as methods of combining panels to reduce variance (Patterson and Reams, 2005). Under normal circumstances, the combination of multiple annual panels may not be a significant issue. In the event of catastrophic change—fire and hurricanes being commonly cited examples—the catastrophe has relatively identifiable boundaries, and affected plots can be stratified to reduce variance. By all accounts, however, drought-related mortality in the pinyon-juniper type is a population-scale phenomenon. Although locally concentrated in some cases, mortality appears to occur patchily across the landscape. These two characteristics may make stratification of affected and unaffected plots difficult or impossible.

In addition to the variance issue, a concern exists over lag and smoothing effects created by combining panels. Patterson and Reams (2005) describe two methods of combining panels that may be used in FIA analyses—moving averages and temporally indifferent combination. Both methods can produce a time lag bias when the variable of interest exhibits unidirectional change over time. The magnitude of the bias depends on the length of time over which panels are combined and the rate of change over time. For some variables, lag and smoothing effects may be minor and offset by the reduction in variance produced by combining panels. Patterson and Reams (2005), however, note that "in the presence of a widespread catastrophic event, lag bias cannot be ignored."

Analysis of annual inventory data may have some limitations due to the reduction in sample size caused by dividing the phase 2 grid by the number of annual panels. The combination of plots over space, as well as combining panels over time, will tend to reduce variance. In this case, the tradeoff is between geographic extent and variance as opposed to temporal currency and variance. This tradeoff raises questions regarding the appropriate scale at which estimates can be made with reasonable confidence. Because of the limitations in the data, these scales may or may not be satisfactory from some users' perspectives.

Addressing the Questions

As a naturally occurring experiment, the drought-related mortality event provides an opportunity for addressing some of the questions that surround the FIA annual inventory system. The widespread nature of the event has drawn interest from a broad group of managers and researchers, some of whom have experience with the FIA program. In response to increasing mortality across the Southwest, non-FIA entities inside and outside the USDA Forest Service implemented short-term inventory and monitoring projects. Two organizations in the Forest Service—the Forest Health Technology Enterprise Team (FHTET) and Region 4 Forest Health Protection (FHP)—approached the IWFIA program requesting data on pinyon-juniper forests for use in designing their own studies. Based on the planned design of the studies, closer coordination could benefit all organizations involved. From the FIA perspective, the primary benefit would be to produce data that could be used to address some of the questions stated above, thereby testing the annual inventory system. As a result, cooperative agreements were established, and both studies were implemented as adjunct inventories using FIA phase 2 plot locations.

The FHTET study involved acquisition of high-resolution, digital color infrared imagery over plots in the pinyon-juniper type in late 2003. Plot locations were selected using a random sample of plots from the 2003 annual panel that were classified as pinyon-juniper. For each selected plot, the nearest neighbors that were measured in 2002, or planned for field visits in 2004, 2005, and 2006, were selected to form five-plot clusters. The study was designed such that at least 30 five-plot clusters were available for sampling in each of the Four Corner States. The aerial image database will provide data in three ways: (1) each image taken over plots in the 2003 panel will provide a synoptic view (approximately 92 acres) of the vicinity of the FIA plot, enabling comparison of plot data with virtual plots of varying size (including whole image); (2) plots from other panels can be used as an ad hoc sample intensification of some geographic areas for 2003, enabling comparison of estimates based on different sampling intensities (table 2); and (3) time series up to 4 years in length, with one end of the series established by imagery and the other established by ground-based measurement, will be available for analysis on completion of the 2006 panel (table 2). The utility of data obtained in the third case will depend on the degree of agreement, in terms of variables such as stand density and mortality, that can be obtained between images and plots taken in the same year.

The FHP study, limited to Utah and Nevada, is focused on detailed identification and documentation of agents and the progression of mortality over time. Plot locations were stratified by ecoregion section (Cleland *et al.* 2004) in the two-State area, with at least 10 plots available for sampling in each of nine ecoregion sections. Under the FHP study plan, the selected plots will be visited every year for at least 5 years. Damaging agents and their effects are recorded in more detail than is currently being done during FIA plot visits; FIA currently records up to three damaging

Table 2.—*Matrix of annual and adjunct inventory schedules.*

Year measured[b]	Year assigned to plot for FIA annual inventory[a]				
	2002	2003	2004	2005	2006
2002	FIA				
2003	FHTET	FIA, FHTET	FHTET	FHTET	FHTET
2004	FHP	FHP	FIA, FHP	FHP	FHP
2005	FHP	FHP	FHP	FIA, FHP	FHP
2006	FHP	FHP	FHP	FHP	FIA, FHP

FIA = IWFIA annual inventory; FHTET = FHTET aerial image acquisition; FHP = Region 4 FHP ground-based survey.
[a] Columns represent plots measured repeatedly over time.
[b] Rows represent intensification of the sample in a given measurement year—i.e., measurement of plots not scheduled for FIA annual inventory in that year.

agents and their severity, whereas the FHP study attempts to list all damaging agents present on the plot. Only FIA tree variables related to damage and mortality are recorded; variables such as height and diameter are not remeasured, in part because of low growth rates and to minimize impacts to the plot. The FHP study will also sample seedlings over a larger area than is measured in the FIA plot design, and seedling status will be followed over time. The FHP study will produce data in the following ways: (1) "expert" evaluation and a comprehensive listing of agents provides a database of damaging agents that can be compared to agents recorded by FIA crews; (2) a series of annual visits will allow comparison of agents present before, during, and after mortality occurs; and (3) as with the FHTET study, a local sample intensification and the creation of time series that can be used to supplement annual FIA panel data will occur (table 2).

What the Data Show

Preliminary analysis of the FHTET and FHP studies is beyond the scope of this article, but data from FIA periodic and annual inventories offer some interesting insight into the progression of drought-related mortality across the Southwest and how annual panel data might be analyzed to improve the quality of mortality estimates. Annual data from Arizona, Colorado, and Utah are available for preliminary analysis. In addition, recent periodic inventories from Arizona, New Mexico, and Utah quantified predrought conditions of pinyon-juniper forests. For the sake of simplicity, the figures and trends presented here represent only the pinyon component of the pinyon-juniper type. Although junipers and other species have suffered mortality in some areas, they are, to date, largely unaffected in the pinyon-juniper type.

The IWFIA program defines a mortality tree as one judged to have died within 5 years of the measurement date. For reporting purposes, measured mortality is converted to an annual figure. Periodic inventory data suggest that background mortality is relatively low for species that occur in the pinyon-juniper type (table 3). One possible explanation for low annual mortality may be the low growth rates that are typical of the type and stand dynamics that are somewhat different from other forest types. Following disturbance, pinyon and juniper species are more likely to gradually accumulate on the site as opposed to regenerating in large numbers and self-thinning over time. This process is most evident where the forest is encroaching on grasslands or sagebrush. This means that background mortality due to competition is less common in the pinyon-juniper type than, e.g., in ponderosa pine, which is listed in table 3 for comparison.

Annual inventory data show that drought-related mortality has occurred widely across the Southwest, although large numbers of plots remain unaffected (fig. 1). In the early stages of drought (2000–01), nearly all the mortality occurring at the county scale was located in one or two plots (fig. 1a). As the event progressed, mortality was recorded on many more plots, but considerable variation still existed within counties (fig. 1b). In the case of counties in which 10 or more plots were measured annually, however, mortality trends appear to be consistent with trends in adjacent counties also containing moderate numbers of plots.

Table 3.—*Annual mortality for selected species based on most recent periodic inventory, by State.*

	Mortality as a percent of volume[a]		
Species	**Arizona (1999) (%)**	**New Mexico (2000) (%)**	**Utah (1995) (%)**
Common pinyon	0.163	0.079	0.231
Singleleaf pinyon	—	—	0.145
Ponderosa pine	0.212	0.365	0.479
Alligator juniper	0.205	0.061	—
Oneseed juniper	0.011	0.009	—
Rocky Mountain juniper	0.003	0.082	0.047
Utah juniper	0.009	0.072	0.016

[a] Includes all causes of mortality, including fire. Mortality data are based on O'Brien (2002) for Arizona, O'Brien (2003) for New Mexico, and O'Brien (1999) for Utah.

Figure 1.—*Plots in the pinyon-juniper type showing plot-level and county-level mortality of pinyon species.*

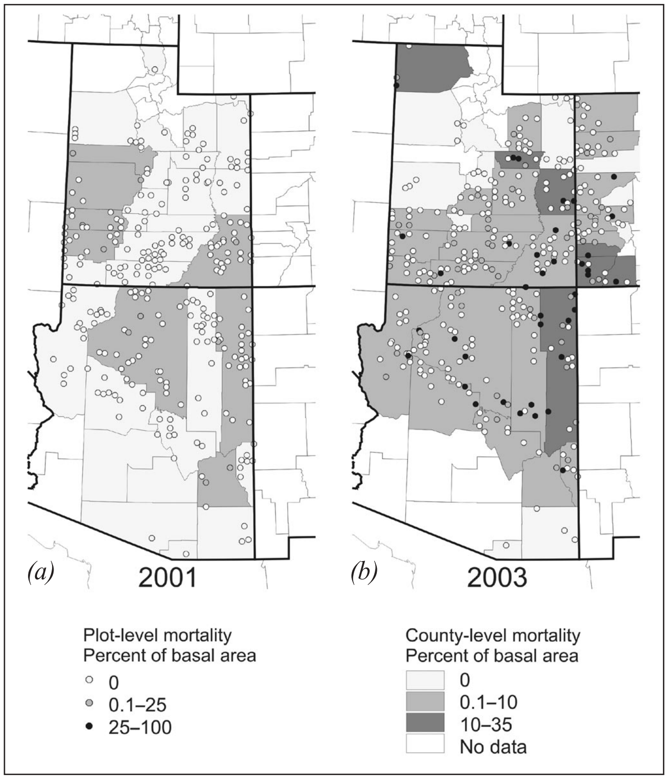
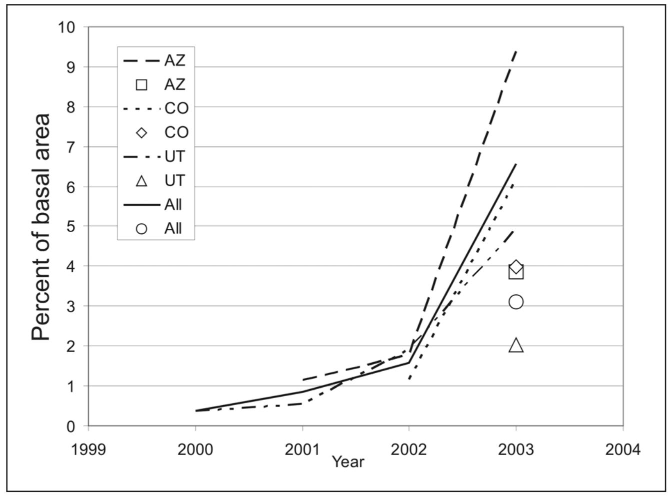


Figure 2.—*Mortality trends in Arizona, Colorado, and Utah. Lines are based on individual annual panels and symbols are based on combining all available panels within a State. Symbols are shown in 2003 for clarity, but each represents the midpoint of the record for each respective State.*



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 (fig. 2). Two aspects of figure 2 are worth noting. First, the trends shown by each statewide curve are similar, even though the record lengths are different. This lends to confidence in the results, even before confidence intervals have been computed. They also agree with anecdotal accounts of the progression of the event to date. Second, the point estimates created by combining all available panels give some indication as to the degree of lag bias that can occur in the event of rapid onset, accelerating changes. For example, the combined estimate for Utah is less than half that estimated by the 2003 data alone. In addition, estimates for different States cannot be combined using all available panels because of the differing record lengths. Note that the combined estimate for Arizona, which has just over 9 percent mortality according to the 2003 panel alone, is about equal to the combined estimate for Colorado, in which just over 6 percent of the basal area has died. This result is due to the fact that regional mortality was low in 2001, the extra year in the Arizona record. This illustrates that regional combinations are limited to the lowest common denominator in terms of the number of concurrent panels in the area of interest.

What Can Annual Inventory Tell Us?

Based on early results, the potential usefulness of annual panels as independent samples and time series data appears promising. Annual inventory 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 can probably be estimated with a reasonable degree of confidence at larger scales. Some reduction in variance may be possible using strata that are not commonly used in FIA reporting, such as ecoregional units or discrete population segments. Drawing some conclusions at medium geographic scales, such as county or national forest, may be possible, but this ability is largely dependent on the distribution of the forest type of interest in the geographic area.

For widespread, rapid onset phenomena such as drought-related mortality, combining panels may produce an unacceptable degree of lag bias. To produce results that accurately reflect current conditions and trends in the field, earlier panels must be brought forward using methods that account for rapid change, or annual panels must be used independently. In cases where panels are combined, the methodology must account for different lengths of time series that exist in different States.

The ongoing mortality event presents an opportunity to evaluate the efficacy of the FIA annual inventory system. The pinyon-juniper type was featured here; however, drought-related mortality has occurred to some degree in several other common forest types. Although the preliminary results look promising, acceptance of final results can only occur following the application of rigorous statistical evaluation. In addition, data obtained from adjunct studies such as those conducted by FHTET and FHP should be used to evaluate results based on FIA data alone.

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