Mountain Pine Beetle Infestations and Sudden Aspen Decline in Colorado: Can the Forest Inventory and Analysis Annual Inventory System Address the Issues?

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Abstract.: *There are two events occurring in Colorado that are concerning forest managers in Colorado. There is severe and widespread mortality of lodgepole pine due to the mountain pine beetle and aspen forests in some areas of the state have experienced widespread, severe, and rapid crown deterioration leading to mortality. Implementation of the Forest Inventory and Analysis annual inventory coincided with the two mortality events, providing an opportunity to test the utility of the annual inventory system. Preliminary analysis suggests that annual inventory data can quantify status and trends.*

Keywords: forest inventory, FIA, conifer, mortality, bark beetles

In the mid-1990's, the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program began a transition from periodic to annual inventories (Gillisepie 1999). Under the periodic system, the entire sample grid of plots was measured in a given State over a period of 1 to several years. Subsequent periodic inventories occurred anywhere from 5 to 20 years. Users of FIA data and reports became concerned about the time lag between periodic inventories and suggested ways be explored to produce more timely information. In response, the FIA program began implementation of an annual inventory system that would provide inventory estimates on a yearly basis (Gillisepie 1999).

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The same systematic sample grid that was used for periodic inventories was also used for the annual inventory grid. The difference in an annual inventory is that each plot in a state is assigned to one 6000-acre hexagon. These hexagons are then systematically formed into groups that are referred to as panels. Panels are selected for measurement on an annual rotating basis, and measurement of all accessible plots in one panel is completed before measurement of plots in a subsequent panel is initiated (Reams and Van Deusen 1999). Therefore, theoretically, annual panels of data are free from geographic bias. In the western United States, one panel represents approximately one-tenth of all plots in a State with the objective being that all plots will be measured in ten years. The advantage of the annual inventory system is that data are available every year which provides researchers with more timely data across the landscape. This system results in data being collected and compiled every year, which allows for more flexible analysis options and provides opportunities to monitor forest change in ways that were not possible using periodic inventory data.

The Interior West FIA (IW-FIA) program operates in Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. The annual inventory system was implemented in Utah in 2000 and in most of the other IW-FIA states since then. The annual inventory began in Colorado in 2002, and as of 2007, six panels have been completed in the State. About the same time that annual inventories were implemented in the Interior West, forest managers began noticing significant increases in the incidence of insects and disease for certain tree species. Some of these incidents were attributed to drought that began in the late 1990's. Others are attributed to stand conditions, stand dynamics, and unusual weather patterns.

Two events, in particular, are considered significant issues in Colorado. There is severe and widespread mortality of lodgepole pine (*Pinus contorta*) due to mountain pine beetle (*Dendroctonus ponderosae*). The current mountain pine beetle epidemic is currently considered to be catastrophic and unprecedented. Aspen forests in some areas of Colorado and other regions have experienced widespread, severe, and rapid crown deterioration leading to mortality. This phenomenon is now being referred to as Sudden Aspen Decline (SAD). These two events can be considered an opportunistic test of the ability of the FIA annual inventory system for quantifying rapid change over a State. Analysis of the event may test some assumptions that have been made about the FIA annual inventory system.

This article describes mortality of lodgepole pine and aspen from the FIA annual inventory in Colorado, preliminary analysis of the results, and how the design of the annual inventory may influence the final analysis.

The FIA Annual Inventory Design

There are more analysis options for monitoring forest change under the annual inventory system than the periodic inventory system. One option is to simply compile the data as if it were a periodic inventory, ignoring the fact that some panels are several years older when compared to previous periodic inventories. This may be referred to as the traditional periodic option (Reams and Van Deusan 1999). Another analysis option considers the fact that the annual inventory is an interpenetrating design. This may be referred to as the independent panel option. Under this approach, each annual panel is analyzed independently and estimates are produced on a yearly basis. The independent panel option is a design where the n units (FIA sample plots) are divided into $k = 10$ panels, each panel containing $m = n/k$ units. Panel 1 plots are measured in year 1, panel 2 in year 2, etc., such that all plots have been visited by the end of year 10. The panel cycle is repeated into perpetuity (Reams and Van Deusan 1999).

When FIA began implementation of annual inventories in the mid 1990's, questions immediately arose regarding the inventory design. The most fundamental question was, are there enough plots in one annual panel to detect the progression of events such as tree mortality due to natural disturbance? A systematic grid of plots serves as the base for annual inventories where one field plot represents approximately 6000 acres. Therefore, under the annual inventory in the Interior West, one plot in an annual panel represents about 60,000 acres ($1/10^{th}$ of the periodic grid). Table 1 illustrates the number of plots that sample forest land in Colorado by measurement year and panel number. An average of about 394 plots is scheduled to be visited in any given year in Colorado.

Since each panel represents about $1/10^{th}$ of all plots in Colorado, the smaller number of plots results in a higher variance around the individual panel estimate. Mortality estimates, in particular, are subject to high variances since tree mortality is relatively infrequent. Tree mortality does not always occur on every plot. For situations like insect and disease outbreaks where mortality may be spatially spotty, the signature of the event may not be adequately captured with a limited sample size. Caution must also be exercised when screening data for single panels by certain attributes such as forest type or analyzing data for very small domains since the small number of plots may result in an unacceptably high variance. Therefore, there is a tradeoff between variance and temporal currency. Does having current inventory estimates with a high level of statistical variance outweigh having more dated data with lower variance?

Estimating Tree Mortality

The IWFIA program defines a mortality tree as one determined to have died within 5 years of the plot measurement date (USDA 2007). Therefore, field crews make a distinction between trees that have recently died and long-standing dead trees on all plots that sample forest land. For this analysis, population estimates of the number of all formerly live lodgepole pine and aspen trees with a minimum diameter at breast height of 5.0 inches that qualify as mortality on forest land are used for comparisons. All trees that qualify as mortality on FIA plots are assigned a cause of death code that estimates the primary agent that caused the tree’s death. Only lodgepole pines that were assigned a cause of death of insects were used in mortality estimates. All aspen trees, regardless of cause of death, were used in mortality estimates. The annual number of mortality trees is the number of mortality trees expanded to a population level averaged over a 5-year period and reported as an average annual number. For example, the mortality tree estimate for the year 2002 represents the average number of trees that died each year during the period 1998-2002. This period is termed mortality period in this paper (Table 1). The reason behind this mortality estimation procedure in Colorado, along with several other IW regions, is the inventory data was limited to initial plot measurements. Complete remeasurement data for the State, where the status of the plot and all trees on the plot are known at two points in time, will not be available in Colorado until all ten panels of data are completed and remeasurement begins in the eleventh year.

Table 1: Number of Inventory Plots That Sampled Forest Land in Colorado by Mortality Period, Measurement Year, and Panel Number.

Measurement Year	Mortality Period	Panel Number	Number of Plots
2002	1997-2002	1	362
2003	1998-2003	2	387
2004	1999-2004	3	409
2005	2000-2005	4	407
2006	2001-2006	5	391
2007	2002-2007	6	411

The Mountain Pine Beetle Epidemic

The USDA Forest Service Region 2 Forest Health Management Group began statewide aerial surveys of mountain pine beetle infestations in 1996. This monitoring effort has recorded significant increases in the area of lodgepole pine forests affected by the mountain pine beetle since 1996 and as of 2007, the epidemic is believed to be catastrophic and unprecedented. Mountain pine beetle outbreaks are occurring at greater intensity and at locations where they have not previously occurred (Logan and Powell 2001, Caroll et al. 2004). These epidemics are not unique to Colorado—much of western North American and Canadian lodgepole pine forests are also suffering from mountain pine beetle infestations.

The mountain pine beetle is a native insect to western pine forests in North America and innocuous populations are almost always present in forests. Transition to epidemic populations is a function of the beetle's capacity to locate, colonize and reproduce within suitable host trees in a weather pattern conducive to overwintering survival, emergence, and dispersal (Caroll et al. 2004). The current epidemic in Colorado is of major concern because lodgepole pine, the primary host of the insect in the state, is an important tree for timber production, recreation, and wildlife.

Sudden Aspen Decline

Rapid mortality of trembling aspen has been reported from multiple locales in southwestern Colorado by varied observers since 2004 (Worrel et. al. 2008). The suddenness of the phenomenon is in striking contrast to the stand-level mortality processes typically observed in aspen stands. Adding to the concern, there appears to be a lack of regeneration occurring in stands were the overstory mortality is unusually high.

Evidence to date suggests that it is a decline disease incited by acute, warm drought. Predisposing factors include low elevation, south and southwest aspects, droughty soils, open stands, and physiological maturity. Contributing factors, which kill the stressed trees, include Cytospora canker, two bark beetle species, poplar borer, and bronze poplar borer.

What is happening to aspen in Colorado? Unlike mountain pine beetle infestations, an event that has been extensively researched, there is no recorded precedent for this phenomenon and the aspen mortality appears to be function of several agents. Aspen forests are dynamic and have always changed in response to climate, frequency and intensity of disturbance, and natural succession. There is no conclusive evidence to date that indicates that this event will continue into the future nor what the eventual impact on the aspen resource will be.

What the Data Show

Annual inventory data indicate an upward progression of lodgepole pine mortality caused by bark beetles in Colorado. The average annual number of lodgepole pine trees killed by insects in the 2002-2007 mortality period is over 10 times that recorded in the 1997-2002 mortality period (Figure 1). The annual average of lodgepole pine mortality indicated an increase with each successive mortality period over the six years of measurement with the largest increase occurring after the 2000-2005 mortality period. Average annual mortality rates of beetle-killed lodgepole pine progressed upward from .22 percent during the 1997-2002 mortality period to 2.6 percent in the 2002-2007 mortality period.

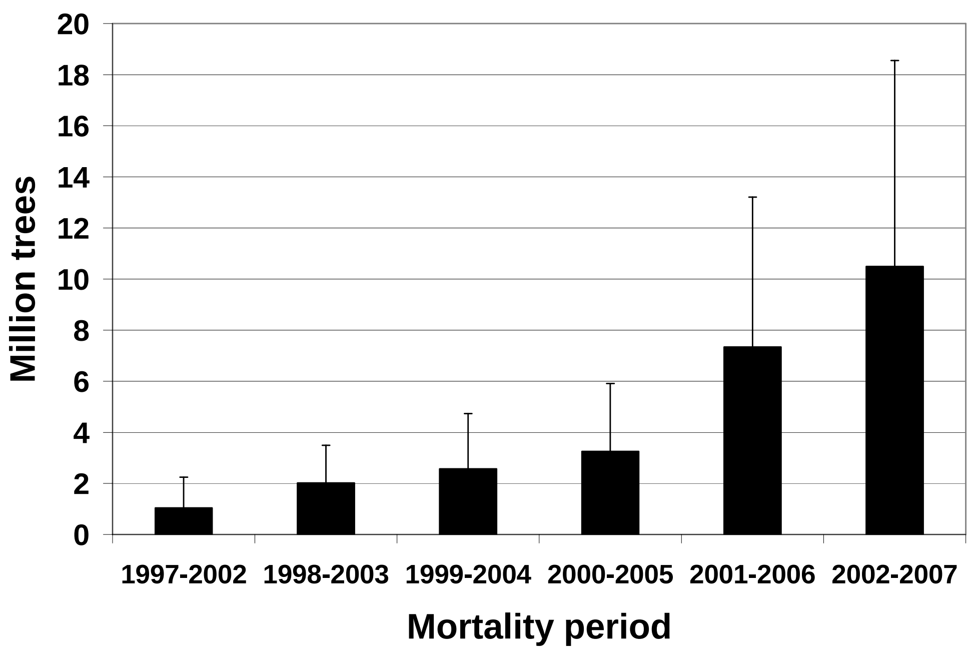

Figure 1: Average annual number of lodgepole pine trees killed by insects by mortality period in Colorado. Error bars represent 95% confidence interval.

Statistical analysis of the mortality data was performed in two steps. First, an analysis of variance was done to detect mortality period effect using the ANOVA procedure version 8.02, of the SAS system for Windows Version 5.0.2195 (SAS, 2001). The difference in the mean number of lodgepole pine mortality trees per acre among mortality periods panels was significant (P=0.0130). Second, all combinations of mortality periods were tested against each other using the Bonferroni correction factor for multiple tests. Comparisons among panels identified two combinations of mortality periods significant at the 0.05 level; 1997-2002 compared to 2002-2007, and 1998-2003 compared to 2002-2007.

Trends in number of aspen mortality trees do not indicate the same distinctive upward trend as lodgepole pine beetle-killed mortality over the same period in Colorado (Figure 2). The highest level of aspen mortality occurred in the 2002-2007 period where the average annual number of trees was nearly 15 million trees. A test for mortality period effect indicated no significant difference (P=0.5387).

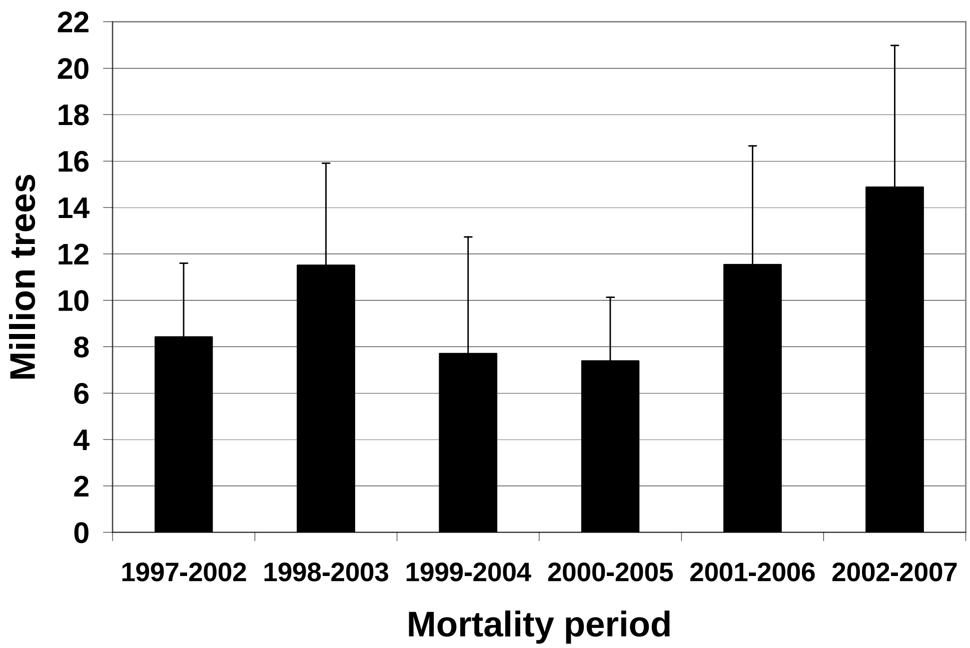

Figure 2: Average annual number of aspen trees classified as mortality by mortality period in Colorado. Error bars represent 95% confidence interval.

Discussion

The current high rate of lodgepole pine mortality due to the mountain pine beetle event has forest managers very concerned about the future of this species in Colorado. There is concern that the high rate of mortality will continue and could possibly deplete the supply of large-diameter trees in as little as five years. Trends revealed by annual data of other forest estimates agree with the progression of lodgepole pine mortality. For example, examination of the percentage of live lodgepole pine trees damaged by bark beetles by individual year indicates similar trends (Figure 3). Bark beetle damage rates jumped from 4 percent in 2005 to over 12 percent in 2006 and continued upward to 15 percent in 2007. If the 2007 mortality and damage rates continue to increase, assuming that most of the damaged trees will die in the near future, the impact of the remaining living lodgepole pines in Colorado could be dramatic.

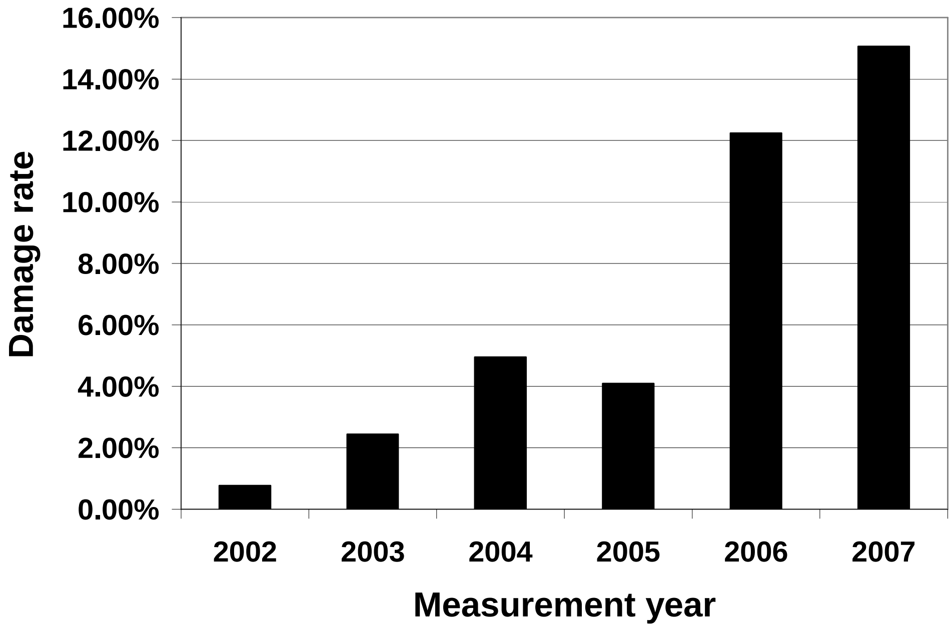

Figure 3: Percentage of live lodgepole pines damaged by bark beetles by measurement year in Colorado.

Unlike lodgepole pine, trends in aspen mortality over the annual inventory period do not indicate an immediate serious threat to the statewide inventory of aspen. There are several reasons why SAD is not reflected in Colorado's annual inventory. First, the rapid mortality associated with this phenomenon is relatively recent—it was first observed by researchers in 2004 (Worrel et. al. 2008). Second, it may be more of a localized event that will impact aspen in domains too small to be adequately captured in a broad-scale inventory. Third, the diverse factors associated with the decline make it difficult to assess cause of death and damaging agents that are specific to SAD. Fourth, aspen stand dynamics are complex. It is a relatively short lived species susceptible to a host of pathological organisms. Aspen is also a clonal tree species showing a variety of characteristics between individual clones.

Is there additional data from the annual inventory that might shed light on aspen decline? Figure 4 illustrates the percentage of live aspen trees that had evidence of damage. Disease was identified as predominate damaging agent of this species in Colorado and the highest disease damage rate of nearly 11 percent was recorded in 2007. As the annual inventory progresses in Colorado, and more temporal data is collected, the eventual impact that Sudden Aspen Decline may have on the aspen resource can be assessed with more confidence.

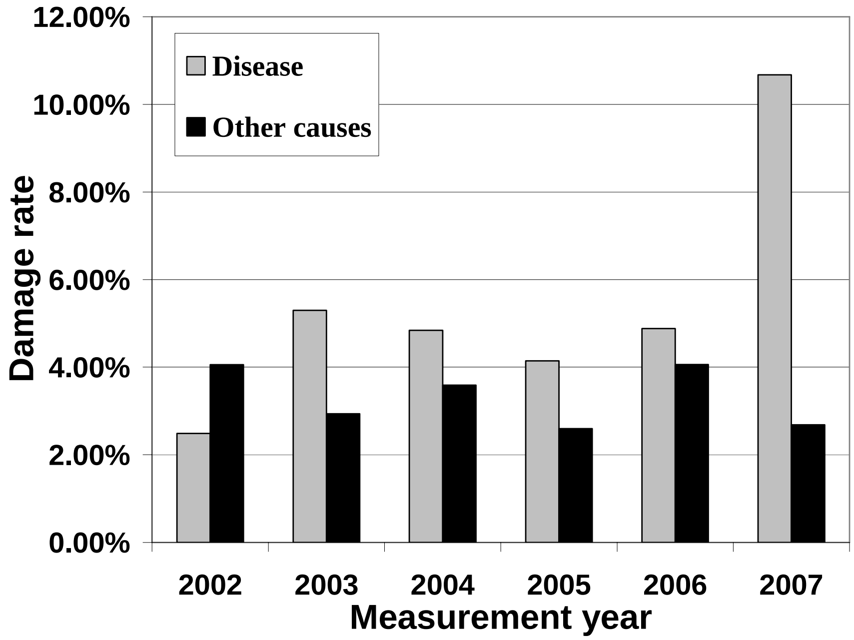

Figure 4: Percentage of live aspen trees that have evidence of damage by cause and measurement year in Colorado.

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