
Rapid Forest Change in the Interior West Presents Analysis Opportunities and Challenges

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Abstract.—A recent drought has caused compositional and structural changes in Interior West forests. Recent periodic and annual inventory data provide an opportunity to analyze forest changes on a grand scale. This “natural experiment” also provides opportunities to test the effectiveness of Forest Inventory and Analysis (FIA) methodologies. It also presents some analysis challenges, because analysts must evaluate the relative contributions of data obtained on phase 2 and phase 3 (i.e., Forest Health Monitoring) plots. In the case of the latter, some variables may reveal less-than-catastrophic changes. Evaluation of available data may allow FIA analysts to answer several longstanding, fundamental questions.

Introduction

Early in 2003, scientists and managers from universities and government agencies approached the Interior West Forest Inventory and Analysis (IW-FIA) program with questions about a widespread episode of drought-related mortality they were observing in pinyon-juniper woodlands (primarily common pinyon [*Pinus edulis* Engelm.] or singleleaf pinyon [*P. monophylla* Torr. & Frem.] in combination with any of several *Juniperus* spp.). In response, IW-FIA analysts began to follow the progression of mortality in States where annual inventory had recently started (Shaw 2005, Shaw *et al.* 2005). FIA annual data revealed an ecosystem-wide mortality episode that varied regionally in its intensity. In addition, FIA data showed that population-wide mortality, which ranged between 3 and 14

percent of pinyon basal area at the State scale, was considerably lower than suggested by anecdotal reports and ad-hoc surveys, some of which suggested 40 to 100 percent mortality of pinyon basal area.

The IW-FIA experience with this “natural experiment” revealed some important facts, perhaps the most important being that the annual inventory system can provide important information about forest change not obtainable from traditional, periodic inventories. At the same time, the event raised questions as to whether the same analysis could be repeated for other types of disturbances and other forest types (Shaw 2005). These questions relate not only to events that result in considerable mortality, but also events that produce widespread nonlethal effects—for example, crown dieback. A more general approach to these questions might be “How sensitive to forest change is the FIA sample for a given forest type (or species) and type of disturbance?” or, to state the issue another way, “We know it’s happening, but can FIA see it?”

These concerns are not unique to IW-FIA, but apply to the FIA program in a broad way. In his introductory talk at this symposium, Reams raised three relevant points: (1) FIA is in the business of quantifying trends, (2) FIA analysis and reporting have an increasingly ecological emphasis, and (3) it has been difficult for FIA to anticipate the “next big issue” in forest management. To that list, Guldin added the point that consumers of FIA data were not only interested in what is happening to the forest, but also where it is happening. In this paper, selected data from 16 western species (table 1) are explored with the intent of developing an approach for a priori sensitivity analysis of FIA data.

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Table 1.—*Selected species and distribution by State in the Interior West.*

FIA Code	Species name	Range in Interior West*
15	white fir (<i>Abies concolor</i> (Gord. & Glend.) Lindl. ex Hildebr.)	AZ, CO, ID, NV, NM, UT
19	subalpine fir (<i>A. lasiocarpa</i> (Hook.) Nutt.)	All IW-FIA States
63	alligator juniper (<i>Juniperus deppeana</i> Steud.)	AZ, NM
65	Utah juniper (<i>J. osteosperma</i> (Torr.) Little)	All IW-FIA States
66	Rocky mountain juniper (<i>J. scopulorum</i> Sarg.)	All IW-FIA States
69	oneseed juniper (<i>J. monosperma</i> (Engelm.) Sarg.)	AZ, CO, NM
93	Engelmann spruce (<i>Picea engelmannii</i> Parry ex Engelm.)	All IW-FIA States
106	common pinyon (<i>Pinus edulis</i> Engelm.)	AZ, CO, ID, NV, NM, UT, WY
108	lodgepole pine (<i>P. contorta</i> Dougl. ex. Loud.)	CO, ID, MT, NV, UT, WY
113	limber pine (<i>P. flexilis</i> James)	All IW-FIA States
122	ponderosa pine (<i>P. ponderosa</i> Dougl. ex Laws.)	All IW-FIA States
202	Douglas-fir (<i>Pseudotsuga menziesii</i> (Mirb.) Franco)	All IW-FIA States
321	Rocky Mountain maple (<i>Acer glabrum</i> Torr.)	All IW-FIA States
322	bigtooth maple (<i>A. grandidentatum</i> Nutt.)	AZ, CO, ID, NM, UT, WY
746	aspen (<i>Populus tremuloides</i> Michx.)	All IW-FIA States
814	Gambel oak (<i>Quercus gambellii</i> Nutt.)	AZ, CO, NV, NM, UT, WY

IW-FIA = Interior West-Forest Inventory and Analysis.

* Ranges based on Little (1971, 1976); IW-FIA States include Arizona (AZ), Colorado (CO), Idaho (ID), Montana (MT), Nevada (NV), New Mexico (NM), Utah (UT), and Wyoming (WY).

Analysis Approach

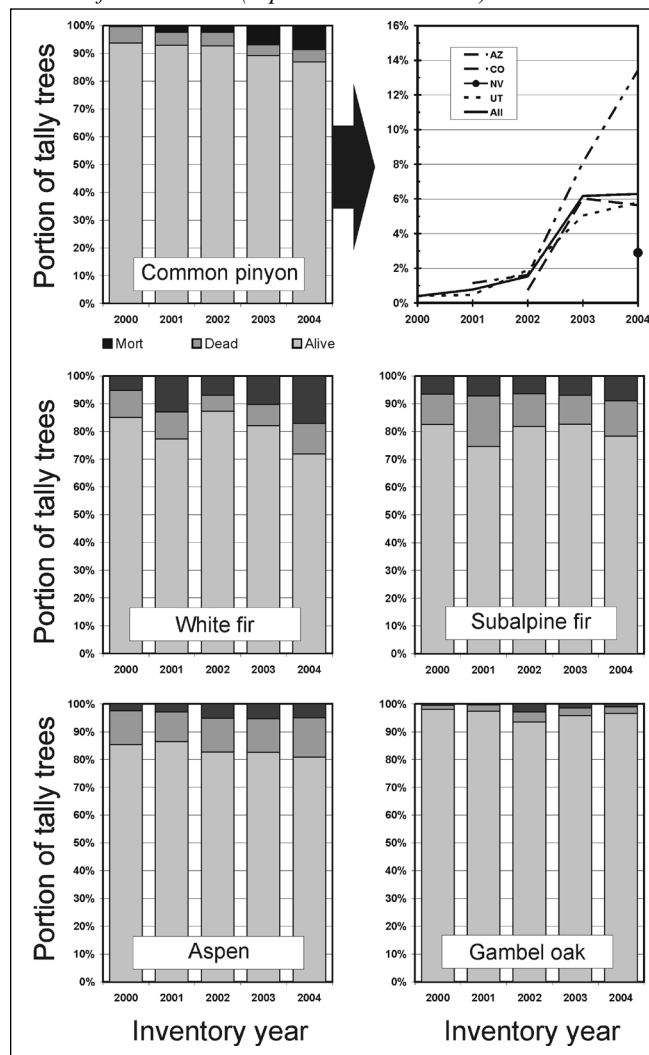
Detailed description of disturbances that affect western forests is beyond the scope of this article, but we know that landscape-scale phenomena occur in many forest types—for example, bark beetle outbreaks occur in pinyon pines, lodgepole pine, and Engelmann spruce, and aspen has been declining due to a wide variety of factors. These events are commonly related to drought and other stressors. Because the recent drought is thought to have caused mortality in forest types other than pinyon-juniper, FIA data are analyzed here under the assumption that the recent period of drought has caused at least some change in other forest types in the past 5 years. Qualitative comparisons are made here using the response of pinyon-juniper woodlands as a reference (fig. 1).

Several key characteristics of the pinyon-juniper mortality event affect our expectations for other species. Most importantly, pinyon-juniper woodlands are the most common type in the Southwest, comprising approximately 50 percent of FIA plots in the States of Arizona, Colorado, Nevada, New Mexico, and Utah. This suggests that, in terms of sample size, pinyon-

juniper may provide the best-case scenario with respect to the possibility of detecting forest change. FIA has long recognized limitations to analysis of rare types because of low sample size; all types that remain are “in betweeners” for which the adequacy of the samples remain to be assessed.

Another key aspect of the pinyon-juniper type is that background mortality is known to be relatively low for species that occur in the type, based on results of periodic inventories. For example, annual mortality, on a volume basis, was estimated at 0.08 to 0.23 percent for common pinyon and 0.14 percent for singleleaf pinyon, and even lower (< 0.10 percent) for juniper species. In contrast, for example, estimates of annual mortality for ponderosa pine ranged from 0.21 to 0.48 percent in the same inventories (Shaw 2005). At least some of the differences among species are likely to be because stand density tends to be an accretion process in pinyon-juniper stands, whereas stands of most other forest types tend to become established with an overabundance of seedlings (or sprouts) and undergo self thinning over most of the life in the stand. Therefore, capturing episodic mortality becomes an issue of separation of “unusual” mortality from background mortality.

Figure 1.—Samples from 2000–04, showing relative number of live, dead, and mortality trees. Graph shows resulting pinyon mortality estimate over time. Species selected for comparison show increasing mortality trends (white fir and subalpine fir) or lack of clear trends (aspen and Gambel oak).



Because FIA now uses a single fixed-plot design for all forest types and pinyon-juniper woodlands tend to have relatively low stem density, plots in most other forest types are expected to have more tally trees per plot than plots in the pinyon-juniper type. This may mitigate the fact that fewer plots are likely to be located in other types than in the pinyon-juniper type. The actual effect, however, may depend on the nature of the disturbance (for example, whether trees are affected singly or in patches). On a related note, the typical number of tally trees found on an FIA plot is expected to vary according to the range

of mixtures in which a species may be found. For example, in the last periodic inventory of Nevada, which is dominated by pinyon-juniper woodland, 590 plots had only one tree species present (usually singleleaf pinyon) and 920 plots had two tree species present. Only 138 plots included three or more tree species. In contrast, aspen has more than 70 associated tree species in the West, 45 of which are relatively common and many of which occur together. Hence, the abundance of any given species on a plot can range from a small fraction of basal area to 100 percent. These contrasts suggest that sensitivity to forest change may be different for species that occur in mixed stands compared with species that are most common in monotypic stands.

Finally, species-specific responses to type and severity of disturbance may affect the ability to detect change with FIA inventories. Although not yet confirmed by remeasurement data, it is thought that many of the pinyon trees on which drought symptoms (e.g., faded foliage and branch dieback) were observed in the past 5 years eventually succumbed. Some damage responses are relatively rare in the data because the time span between when a tree appears healthy and when it can be reasonably judged as dead can be relatively short compared with the 5-year window for being considered “recent” mortality. As a result, the probability of recording drought-related damage on live trees may be relatively low. In effect, this produces a binary response—live or dead—for most of the individuals that are measured. In contrast, it is common for juniper species, which are typically multistemmed, to suffer dieback in a few stems, thereby reducing live crown volume. Dead stems persist for some time, increasing the probability that a live juniper is observed with damage while it is still alive. Hypothetically, at least, this situation suggests that junipers may be more likely to exhibit a wider range of responses to drought than pinyons.

For other species, the drought response may resemble that of the pinyons, with mortality being the primary detectable response in most drought-affected trees and little damage evident on survivors, or it may resemble the response of the junipers, where mortality is low but damage is common. For any given species, the expected response will depend on the species’ ecology and the type and severity of disturbance.

Looking for Consistency and Trends

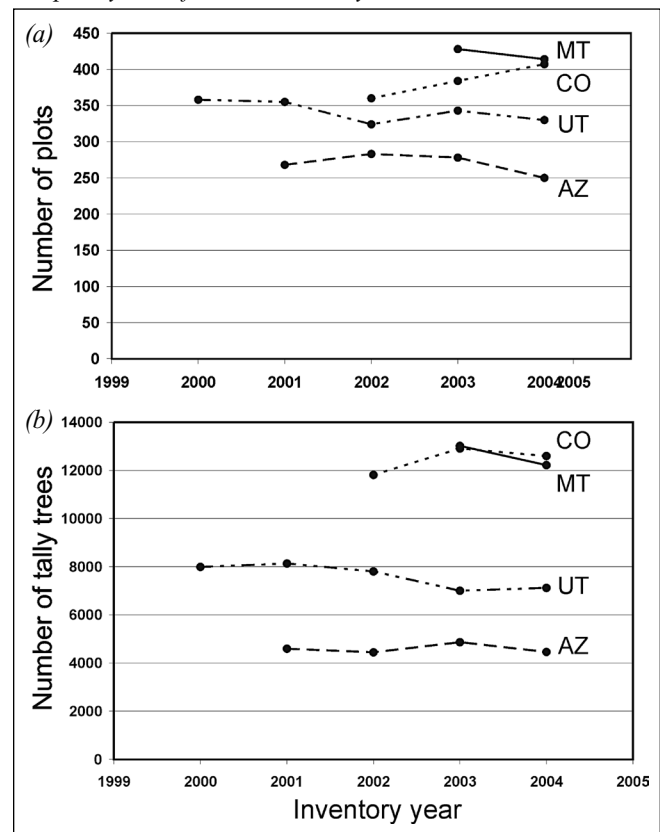
In a first attempt to assess the sensitivity of FIA data to mortality and damage, 16 species (table 1) were selected for comparison and contrast in terms of their relative abundance on the landscape and the distribution of values recorded for selected variables. Ranges of the selected species vary from limited local or regional distributions to common occurrence throughout the IW-FIA States. Plot data used in this analysis come from a combination of annual and periodic inventories conducted from 2000 to 2004. Annual inventory was implemented in most of the IW-FIA states during this period (table 2), resulting in uneven (although generally increasing) geographic coverage in any given year. For this reason, the analysis presented here is primarily qualitative.

If FIA data are expected to reveal trends with annual resolution, there should be annual consistency in basic characteristics of the inventory, such as number of plots visited per year or number of plots occurring annually in a given forest type. Similarly, the sample should include relatively consistent distributions of trees by species and size over time. Consistency of the sample is important in light of the fact that nonoverlapping sets of plots are measured in successive annual panels. Some annual variation in the sample is inevitable, so the issue is primarily a matter of how much noise is introduced by sample size variation as compared with the magnitude of the signal caused by forest changes.

It is currently impossible to evaluate consistency of sample size for all eight IW-FIA States because annual inventory has not

yet been implemented in all States and in some of those only one annual panel has been completed. For the four States with 2 or more complete years of annual data, annual variation in the number of plots and number of trees differs by State (fig. 2). Annual variation in number of plots is usually within 5 percent of the 5-year State average (fig. 2a), and variation in the number

Figure 2.—Annual variation in number of plots and number of tally trees for Interior West-FIA States with two or more complete years of annual inventory data.



AZ = Arizona; CO = Colorado; MT = Montana; UT = Utah.

Table 2.—Type, year, and location of FIA surveys used in this study.

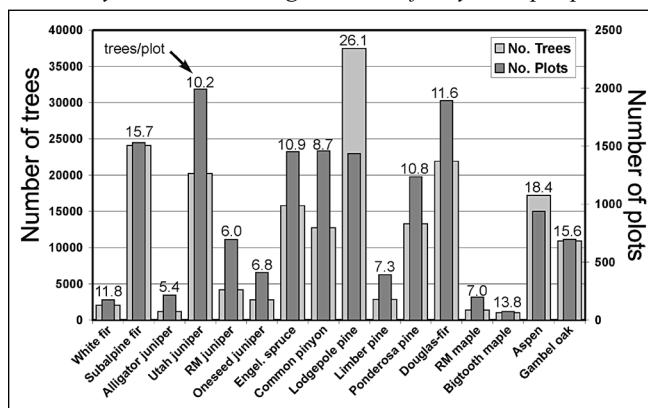
State	Inventory year				
	2000	2001	2002	2003	2004
AZ	none	annual (10%)	annual (10%)	annual (10%)	annual (10%)
CO	none	none	annual (10%)	annual (10%)	annual (10%)
ID	periodic	periodic	periodic	annual (10%)	annual (10%)
MT	none	none	none	annual (10%)	annual (10%)
NV	none	none	none	none	annual (10%)
NM	periodic	none	none	none	none
UT	annual (10%)	annual (10%)	annual (10%)	annual (10%)	annual (10%)
WY	periodic	periodic	periodic	none	none

AZ = Arizona; CO = Colorado; ID = Idaho; MT = Montana; NV = Nevada; NM = New Mexico; UT = Utah; WY = Wyoming.

of tally trees is usually within 7 percent of average (fig. 2b). This includes plots found to be inaccessible, plots to which access has been denied, and plots missed due to fire, weather, or other logistical limitations. Some of the annual variation may be expected to decrease over time once annual inventory is fully implemented and logistical issues are resolved. The remainder of variation, partly due to annual panel shift of the phase 2 grid and partly due to other causes, is likely to exist after full implementation.

Species varied widely in the number of plots on which they occurred and the average number of individuals found on a plot (fig. 3). As expected, timber species were usually represented by more trees per plot than woodland species. Among timber species, shade intolerant species known to regenerate in high numbers, such as aspen and lodgepole pine, tended to have higher numbers of trees per plot than late successional species such as subalpine fir and Engelmann spruce. Interestingly, of the 16 species examined, 6 were found on a number of plots comparable to or greater than the number on which common pinyon was found. These species were relatively common in the northern IW-FIA states, where pinyon-juniper woodlands do not occur. While sample sizes are not exactly comparable due to the mixture of annual and periodic plots, it appears that rangewide sample sizes of at least some species are comparable to that of pinyon-juniper and should be adequate to determine rangewide trends.

Figure 3.— *Select tree species showing number of plots on which they occur and average number of tally trees per plot.*



RM = Rocky Mountain.

Detecting Nonlethal Effects

Preliminary analysis of drought-related effects in pinyon-juniper woodland showed that there was relatively little mortality in the juniper component (Shaw *et al.* 2005). It is possible, however, that the drought caused sublethal damage to juniper species—e.g., death of some stems in multitemmed trees. As a result, it is reasonable to expect that there is a “drought signature” in live junipers and, perhaps, for other species in which relatively little mortality was observed. Two phase 3 indicator variables, crown density and crown dieback, were examined for possible trends over the time that most of the mortality was observed. It was expected that at least some of the species should have experienced changes in crown volume during the drought period, and that the changes should be reflected as decreases in mean crown density or increases on crown dieback over time.

The number of trees with crown density and dieback observations (i.e., trees located on phase 3 plots) was relatively small compared to the number of tally trees on phase 2 plots over the same time period. This difference is expected because there are approximately one-sixteenth the number of phase 3 plots as phase 2 plots. In 2003 and 2004, the years during which the highest number of phase 3 plots was measured, the number of crown observations ranged from less than 20 to just more than 300 for most species. The small number of trees with crown measurements suggests that it may be difficult to generalize about rangewide trends for some species, especially considering the large geographic ranges that are typical of Western species.

Mean crown density ranged between 30 and 60 percent, and in any year it was usually within 5 percentage points of the 5-year mean for most species (fig. 4a). There appeared to be a slight downward trend in mean crown density for many species over the 5-year period, although year-to-year variation was high compared to the magnitude of the overall trend. Interestingly, the rank of mean crown density among species appeared as might be expected from general knowledge of crown characteristics. The junipers, firs, and spruces tended to be in

the upper ranges of density, whereas aspen and Gambel oak usually ranked lowest.

Mean crown dieback values tended to be low (< 8 percent), in part because no dieback was recorded on many trees in the sample (fig. 4b). Interannual variation in mean dieback values tended to be approximately 2 percentage points, but variation was much higher for some species. Variation appears to mask any existing trends, with the exception of Gambel oak, which appears to have suffered increasing dieback between 2001 and 2004. Although changes in mean values are highly variable,

distributions of responses appear more informative. In all years, the vast majority of dieback observations are in the 0 and 5 percent categories for all species, with very few observations of dieback > 15 percent (fig. 5a). The few observations of high dieback tend to occur in 2002 or later, suggesting that there may be a “drought signature” in the data. Gambel oak is the only species that clearly shows the expected pattern, which is not only an increasing mean dieback value, but a shifting distribution of values over time (fig. 5b). Similar patterns might be observable in other species given larger samples.

Figure 4.—Mean responses for crown variables by species, 2000–04. Trends of selected species are highlighted.

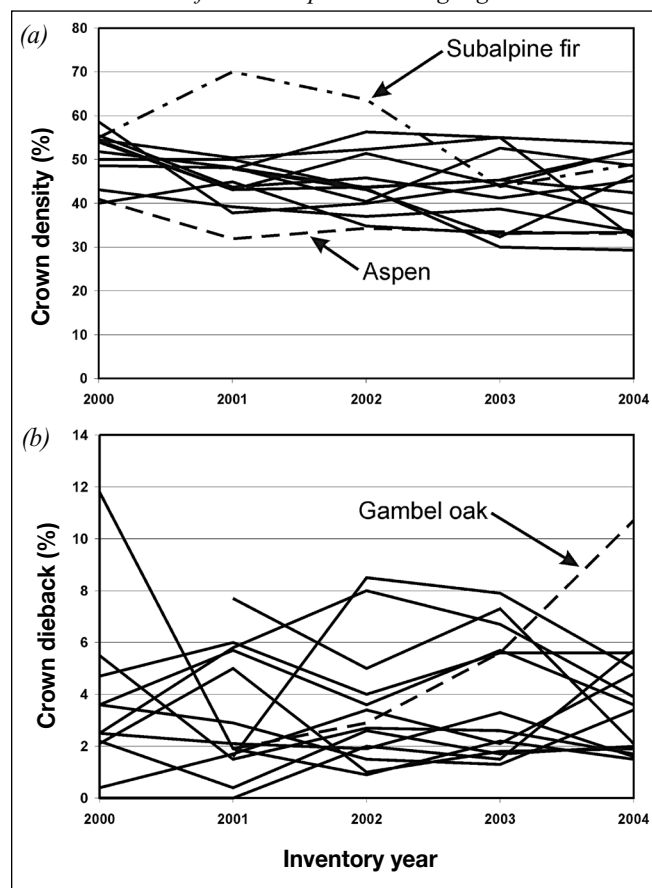
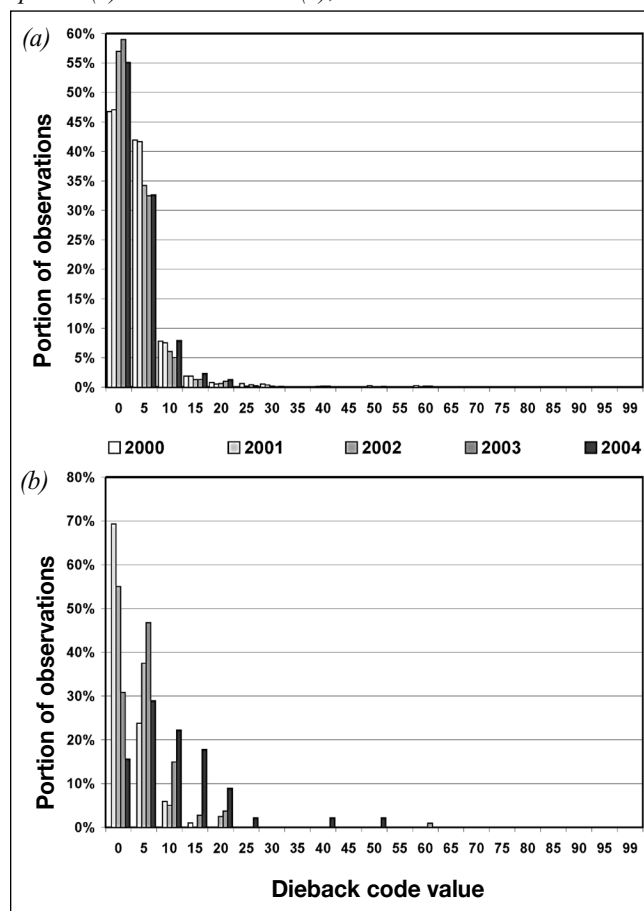


Figure 5.—Distribution of crown dieback observations for all species (a) and Gambel oak (b), 2000–04.



Conclusions

The IW-FIA experience with drought-related mortality in pinyon-juniper woodlands suggests a need to produce similar analyses for other species and forest types. Opportunities to track trends by species or forest types will depend on the magnitude and type of forest change, as well as the effects on individual trees (mortality vs. damage) and the representation of the species in the sample. Currently, complete sensitivity analysis is challenging because plot coverage in the Interior West is uneven in time and space. Analysis opportunities should improve with time, however, as annual inventory is implemented in all states.

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