

WHITE ASH (*FRAXINUS AMERICANA*) HEALTH IN THE ALLEGHENY PLATEAU REGION, PENNSYLVANIA: EVALUATING THE RELATIONSHIP BETWEEN FIA PHASE 3 CROWN VARIABLES AND A CATEGORICAL RATING SYSTEM

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ABSTRACT

Following the detection of white ash (*Fraxinus americana*) decline in the Allegheny National Forest (ANF) of Pennsylvania, we established an intensified white ash monitoring network throughout the ANF. We rated crowns using both a categorical system as well as Forest Inventory and Analyses (FIA) Phase 3 measures of uncompact live crown ratio, density, dieback, and transparency. Across our plots, ash averaged 17.33 trees/acre and made up 19 percent of the total stand basal area. We found that trees on lower slopes were healthier than those on upper slopes. Categorical ratings correlated well with density and dieback and allowed us to develop and test conversion formulas to predict dieback and density using categorical scores. Our formulas proved robust in predicting density and dieback on an independent ash tree dataset. Erroneous predictions were generally linked to differences in what either measure defined as dieback. We suggest categorical assessments may provide a suitable alternative for rapid crown evaluations.

INTRODUCTION

Ash (*Fraxinus* spp.) is an important component of eastern deciduous forests and a valued timber species; an estimated 1.25 billion trees (≥ 5 inches DBH) grow throughout the 24 state region of the Upper Midwest and northeastern United States inventoried by the USDA Northern Research Station (USDA Forest Service 2010). Throughout much of this area, ash species, and in particular white ash (*Fraxinus americana*), have suffered from episodic periods of decline and dieback since at least the 1920s with more recent escalations in dieback and mortality heightening interest

in this problem (Hibben and Silverborg 1978, Sinclair and others 1990). Even more recently, the current and projected decimation of existing ash populations by the exotic emerald ash borer (*Agrilus planipennis*; EAB) beetle has focused attention on the current status and risk of ash regionally (Cappaert and others 2005). Indeed, baseline measures of ash health and decline status may be critical because susceptibility risk and mortality rates from EAB may be greater in stressed trees than in healthy trees during the early stages of EAB invasion (McCullough and others 2009).

While drought, fungal pathogens, and phytoplasmas all contribute to regional declines in ash health (Hibben and Silverborg 1978, Woodcock and others 1993), several lines of evidence suggest nutrient deficiencies may play a role in predisposing ash trees to decline. First, several studies indicate white ash is a base cation (e.g., Ca^{2+} , Mg^{2+}) demanding species that is consistently associated with soils with higher pH and greater base cation availability (Bigelow and Canham 2002, Finzi and others 1998, van Breemen and others 1997). Second, researchers have found strong relationships between exchangeable base cation availability and regional declines of sugar maple (*Acer saccharum*), another hardwood species with high cation requirements (Horsley and others 2000, Long and others 2009). Finally, Morin and colleagues (2006) found ash decline was primarily responsible for an observed 60 percent decrease in ash live basal area/acre in the 1990s in an intensified FIA/FHM monitoring plot network established in the Allegheny National Forest (ANF) and suggested mortality was concentrated on ridgetops and upper slopes. This latter finding is critical because within the unglaciated portion of the ANF, concentrations of exchangeable calcium and

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magnesium are often greater on lower slopes than on upper slopes, often by as much as an order of magnitude (Bailey and others 2004).

Despite this provocative detection of ash decline on upper slope positions, the robustness of this finding is problematic because ash is greatly underrepresented with just 60 live trees distributed across 16 percent of the intensified FIA/FHM monitoring plots throughout the ANF. Furthermore, existing individuals are distributed unevenly across physiographic or topographic positions (e.g., 1 individual on dry, upper ridgetops vs. 40 in rolling uplands), making a well replicated analysis impossible. Given the small sample sizes and the highly unbalanced representation of ash, a definitive assessment of current white ash health status and its variability across topographic gradients (i.e., soil nutrition) requires enhancement of existing data and greater ash canopy sampling. Furthermore, given the impending invasion of emerald ash borer to the ANF, knowing what landscape positions are likely to contain stressed ash trees may lead to better risk models and mitigation strategies.

The objectives of this study were to assess white ash health status in the Allegheny Plateau region by establishing an expanded network of ash health monitoring plots throughout the ANF to complement existing FHM/FIA data. This enhanced sampling will allow us to explore, in detail, how topographic position and site characteristics (e.g., soil pH and nutrition) are related to ash decline and mortality patterns across the landscape. Additionally, we created a formula to relate FIA Phase 3 (P3) crown ratings (dieback, density, etc) to a user friendly categorical rating system. Finally, we tested the predicted FIA P3 crown ratings derived from our conversion formula on an independent dataset of ash crown health from Ohio.

METHODS

Throughout May – August 2009, we systematically surveyed areas across the entire ANF to establish new white ash monitoring plots (Figure 1). We superimposed a grid over the ANF ownership and, using existing stand information on ash basal area and landform classifications of both bottom/foot slope positions and shoulder/plateau top positions, we searched each 700 ha block to locate pairs of ash plots where one plot in the pair was established on a lower slope position and the other on an upper slope position. Because topographic position itself is not always a reliable indicator of site nutrition on the unglaciated portion of the ANF, we also conducted herbaceous plant surveys at each potential plot to detect species known to be reliable indicators of high base cation nutrition (Horsley and others 2008). At each plot, a focal ash tree was defined as plot center and the surrounding tree community was inventoried

in a variable radius plot using a 10 factor prism. Within each pair of upper and lower slope positions, care was taken to choose focal trees that were similar in diameter and crown class. Trees with two trunks were counted as separate trees if they divided below breast height (4.5 ft).

In summer 2009, we assessed the crown health status of all ash trees in the plots using a categorical rating system developed for managers for assessing ash decline due to emerald ash borer infestation; this rating system is itself a modification of protocols developed for bronze birch borer (Ball and Simmons 1980, Smith 2006). The rating scale is defined as follows:

1. Ash tree with a full, healthy canopy
2. Ash tree with a thinning canopy but no dieback
3. Ash tree with dieback, defined as dead twigs or branches near the top of the tree, exposed to sunlight. Dead branches that are low and shaded were not rated and considered a normal part of branch senescence
4. Ash tree with less than 50 percent of a full canopy, which could occur through a combination of dieback and thinning
5. Ash tree with a dead canopy, defined as no foliage in the canopy portion of the tree (The canopy is counted as dead even if live epicormic sprouts low on the trunk or stump sprouts are present.)

In summer 2010 we revisited each plot and assessed crown health using both the categorical measures and FIA P3 measures of uncompact live crown ratio (UCLR), crown density, dieback, and transparency. UCLR is estimated as the percentage of the actual tree length made up of live crown. Crown density estimates the amount of crown branches, foliage, and reproductive structures that block light visibility through the crown. Crown dieback is the percentage of the live crown area that exhibits signs of recent dieback, excluding snag branches and gaps in the canopy. Finally, transparency is calculated by estimating the percentage of skylight visible through the live, normally foliated portion of the crown (USDA Forest Service 2007).

We tested for differences in these canopy condition response variables using mixed model analysis of variance (PROC MIXED; SAS Institute Inc. 2005). Topographic position (upper/lower) was modeled as a fixed factor, and each 700 ha block was modeled as a random factor. We used Spearman rank correlations to examine the relationship between our categorical rating system and each of the FIA P3 crown measures and to identify the P3 measures that exhibited the strongest relationship. We then used linear and nonlinear regression analyses to derive the most parsimonious formula that best (e.g., high r^2 value) related our categorical measure with P3 metrics.

Finally, we tested the predictive ability of our Pennsylvania derived formulas on an independent dataset of ash canopy conditions from Ohio. This dataset contained 494 individuals of various native ash species (e.g., green ash, white ash) located throughout seven stands that varied in the severity of emerald ash borer infestation (Knight, unpub. data). We assessed the robustness of the predicted values by rounding the predicted value to the nearest 5 percent class and allowing a ± 10 percent tolerance (2 classes) as indicated in the FIA Phase 3 Field Guide (USDA Forest Service 2007).

RESULTS

Overall, we established 192 plots and assessed 538 white ash trees throughout the ANF. Ash basal area relative abundance, which is biased toward plots where ash was present, averaged 19.03 ± 1.1 percent of the basal area and ranged from 4.5 to 75 percent. Mean ash stem density was 17.33 ± 1.2 trees per acre and ranged from 2 to 111 trees per acre. Neither measure of ash abundance differed significantly between topographic positions:

Basal Area : $\bar{X}_{lower} = 17.9 \pm 1.4$ and $\bar{X}_{upper} = 20.8 \pm 1.6, P = 0.2$

Stem Density : $\bar{X}_{lower} = 16.3 \pm 1.6$ and $\bar{X}_{upper} = 19.1 \pm 1.8, P = 0.3$

Crown health assessments determined by the categorical method and FIA P3 variables of density, dieback, and transparency all indicated crowns were healthier on lower slope positions than on upper slopes (Figure 2). The P3 variable of uncompact live crown ratio did not differ significantly between topographic positions

($x = 31.6 \pm 0.7$ and $x = 31.2 \pm 0.7, P = 0.73$).

Correlation analyses revealed that all three FIA P3 ratings were significantly correlated with our categorical measure (Table 1); however only density and dieback exhibited moderately strong correlations (r values > 0.7 or < -0.7). We therefore further explored the relationship between the categorical rating and these two measures.

Regression analyses indicated our categorical rating was linearly related to Crown Density (adjusted $r^2 = 0.65$; Figure 3) and yielded the following formula:

$Y_{Density} = -10.59x + 59.114$; where $x = \text{Categorical Rating (1 - 5)}$

The best relationship between our categorical rating and Crown Dieback was obtained using an exponential model (adjusted $r^2 = 0.91$; Figure 4):

$Y_{Dieback} = 0.2626 \times e^{-1.18x}$; where $x = \text{Categorical Rating (1 - 5)}$

Predictions of crown density derived from the categorical ratings were accurate in 81.6 percent of the cases including

all trees and dropped to 71.2 percent excluding dead trees. The failure rates (i.e., predicted value fell outside actual value by > 10 percent) were 32, 20, 42, and 7 percent for condition classes 1, 2, 3, and 4, respectively. Crown dieback predictions derived from the categorical ratings were accurate in 96.8 percent of the cases including all trees and 92.8 percent excluding the dead trees. The prediction failure rate for classes 1 – 3 was negligible (< 1 percent). For condition class 4, the formula routinely overestimated dieback, resulting in a 92 percent failure rate.

DISCUSSION

LANDSCAPE LEVEL PATTERNS OF ASH HEALTH ON THE ALLEGHENY NATIONAL FOREST

We found that white ash was distributed throughout the ANF on both upper and lower slope positions. Nevertheless, we documented stark differences in crown health as measured by both a categorical condition class rating system and by the more quantitative FIA P3 measures of density, dieback, and transparency. White ash individuals located on upper slope positions throughout the ANF were generally rated more poorly, had less dense crowns, exhibited greater dieback, and appeared more transparent than similarly sized individuals at nearby lower slope positions. Although all four measures differed statistically between slope positions, we suggest that only the categorical condition rating and the FIA P3 measure of dieback differed enough (~ 1 condition class or 10 percent dieback) to operationally evaluate differences in crown health throughout the plateau.

We hypothesize that these stark differences in canopy health may be related to known site quality differences across topographic positions, and more specifically, the low concentrations of extractable pools of calcium and magnesium. Although we do not directly confirm differences in soil nutrition between our slope positions (e.g., soil analyses) several lines of evidence suggest these differences exist. First, research in the region has consistently documented that the highly weathered parent materials available to tree roots on the plateau and shoulder slopes in the unglaciated Allegheny Plateau region contain low concentrations of these ions. In contrast, lower slope positions tend to have higher concentrations due to delivery of these ions via water flow paths that percolate through deeper, mineral containing layers and enrich the soil as the water flows back out to the soil, sometimes in the form of seeps (Bailey and others 1999, 2004). Second, 50 percent of our selected lower slope plots had ≥ 1 herbaceous plant species known to be robust indicators of soils rich in base cations, and several other sites were characterized by the presence of seeps, which often transport cation supply to the soil complex (Horsley and others 2008). In contrast, only 7 percent of upper slope positions contained any of these indicator species. Finally, foliar nutrition analyses

from a subset of our focal trees found that both calcium and magnesium foliar concentrations were 39 and 29 percent greater, respectively, on trees found on lower slopes than on trees sampled on upper slopes (Royo, unpub. data).

ON THE UTILITY OF AN EASY CATEGORICAL SYSTEM

Categorical rating systems have a rich history in forest ecology and management as a method to rapidly assess tree health and position (Ball and Simmons 1980, Fajvan and Wood 1996, Gottschalk and MacFarlane 1993, Mader and Thompson 1969, Millers and others 1991). These protocols generally divide a relevant continuous variable into a few categories that are simple to recognize, biologically relevant, and easy to assess. Often, such protocols can be reliably used in the field by new users after just a few days of practice (e.g., Meadows and others 2001). Such rating systems allow forest managers to improve stand management via rapid assessments of current stand conditions. The FIA Phase 3 measures, in contrast, offer a far richer and detailed assessment of crown conditions, but are concurrently more complex involving as many as 14 categories in 5 percent classes and may require a week long training session to competently assess these in a reliable and repeatable manner. Finally, the rapid assessments possible using the categorical system may allow repeated sampling of an intensified plot network to monitor the rapid canopy decline and mortality that occur when outbreaking or invasive pests invade an area (e.g., EAB); at existing FIA implementation rates of 5 to 10 years (Bechtold and others 2008), regional or state level monitoring may miss the decline and only capture the end result.

Overall, our conversion formula proved fairly robust in correctly predicting crown density within tolerance in nearly three quarters of the cases in which it was tested. This finding is remarkable given that the conversion formula was generated on only white ash trees, 89 percent of which were in dominant or codominant crown positions, in an area without any signs of EAB. In contrast, the Ohio data contained five species of ash, 68 percent of which were in dominant or codominant crown positions, in stands spanning the full range of EAB infestation. Our dieback formula was highly reliable for classes 1 – 3, but had virtually no power in predicting crown dieback when trees were rated as a category 4. We believe the primary explanation for this inconsistency lies in the characterization of what is measured as dieback. Phase 3 dieback refers only to the severity of “recent stresses on a tree” on the upper and outer branches with fine twigs of the live crown and excludes snag branches (USDA Forest Service 2007). In contrast, our

categorical ratings were developed to assess the progressive decline and dieback of trees, and thus a categorical value of 4 includes any tree crown that contains 50 percent or greater dieback, including snag branches. Thus, trees may rate a 4 under scenarios of high recent dieback detected only in twigs or the cumulative dieback over a longer period of time that is evidenced by presence of dead twigs and snag branches. Indeed, examination of the range of dieback values of our trees in either Pennsylvania or Ohio reveals that P3 dieback assessments in our category 4 rating range from 1 to 80 percent. Additionally, our category 4 rating may encompass too great a range of conditions because any tree that is not completely dead but has >50 percent dieback is placed in category 4. Dividing this category into two distinct categories (e.g., 50 to 74 percent dieback and > 75 percent dieback to dead) may improve model reliability without complicating the rating system excessively. Indeed, other crown health and vigor rating systems often employ slightly more partitioned rating systems where dead trees are a sixth category (e.g., Fajvan and Wood 1996, Mader and Thompson 1969).

In summary, our survey of white ash throughout the ANF confirms Morin and colleague’s (2006) reports that white ash decline appears most prevalent on upper slope positions. Furthermore, we provided evidence that a simple, categorical rating system correlates well with FIA P3 crown measures of density and dieback. The advantage of this system is that it can readily and rapidly be assessed by managers and practicing foresters. With the use of our conversion formulas, these categorical ratings can estimate FIA P3 density and dieback with a fair amount of confidence. Finally, the establishment and assessment of ash monitoring plots in stands varying in ash abundance and crown health conditions may now be used as the basis of an EAB risk assessment and monitoring network.

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Table 1—Spearman rank correlation matrix among FIA Phase 3 crown condition variables of uncompact crown live ratio (UCLR), crown density, dieback, and transparency, and a user friendly categorical rating of health conditions where 1=healthy, 5=dead, and 2 through 4 represent increasing stages of crown decline and dieback

	Condition	Density	Dieback	Transparency
Condition	1			
UCLR	-0.223 <0.0001			
Density	-0.723 <0.0001	1		
Dieback	0.719 <0.0001	-0.551 <0.0001	1	
Transparency	0.562 <0.0001	-0.539 <0.0001	0.434 <0.0001	1

For each cell, the upper value is the Spearman correlation coefficient (ρ) and the lower value is the significance (P value) of relationship.

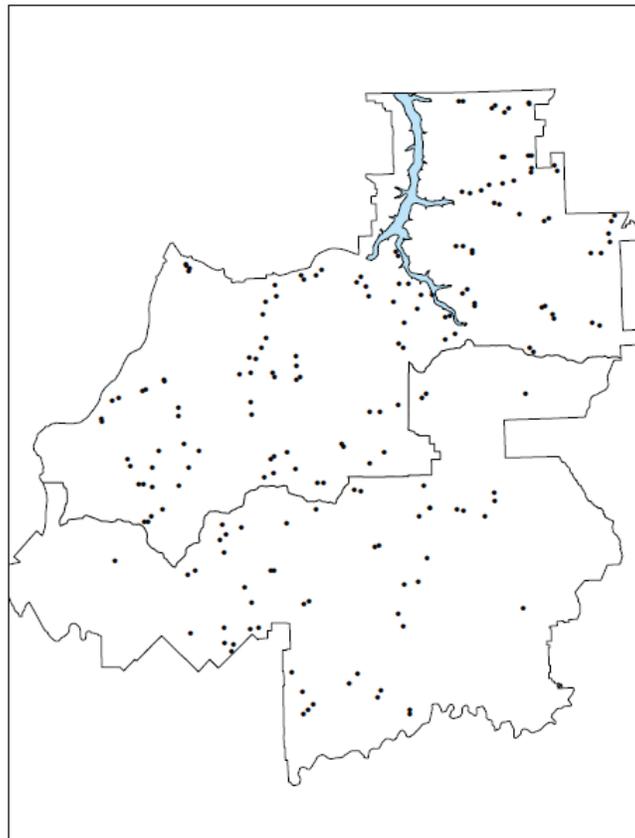


Figure 1—Approximate locations of the expanded network of ash health monitoring plots throughout the Allegheny National Forest proclamation boundary.

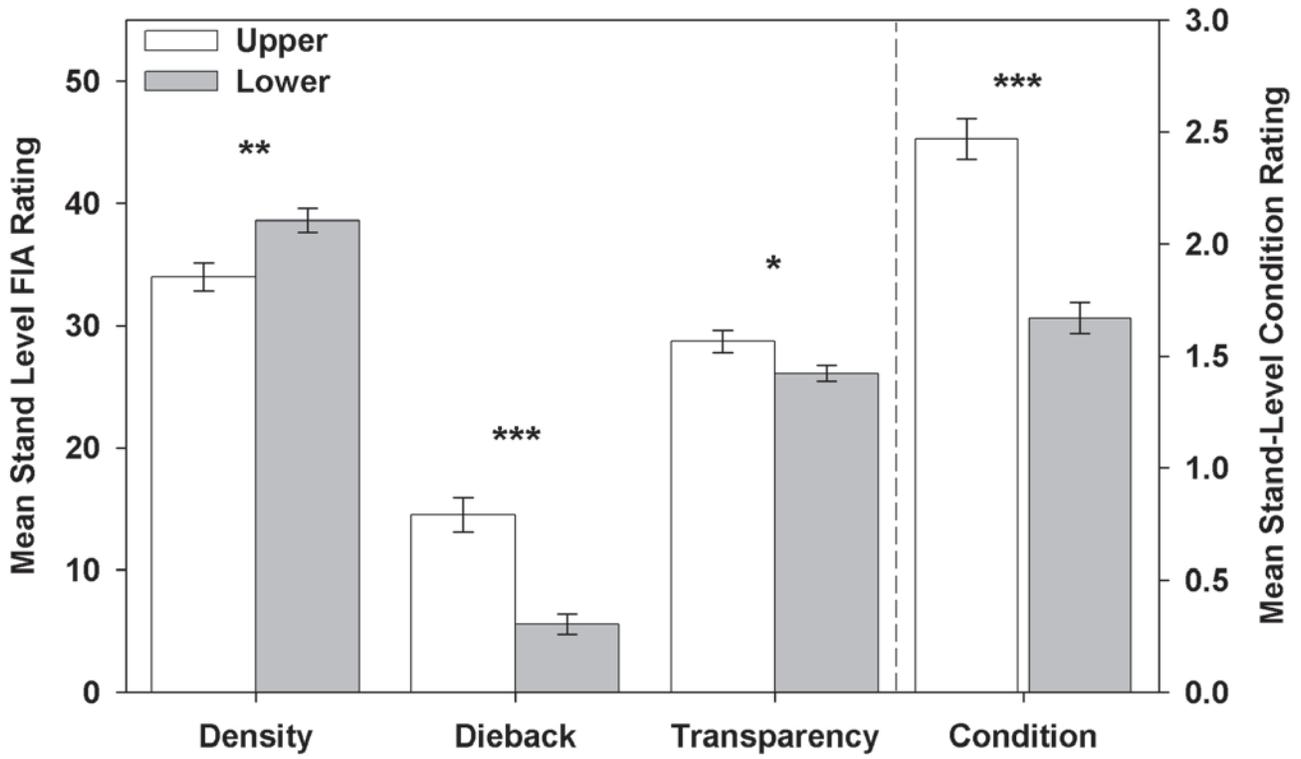


Figure 2—Mean crown health values (± 1 SE) of FIA Phase 3 measures of density, dieback, and transparency as well as a categorical rating (1=healthy, 5=dead, 2-4 increasing dieback) of white ash trees on stands on upper and lower slope positions. Asterisks denote significant differences from analysis of variance (* = < 0.05 , ** = < 0.01 , *** = < 0.001).

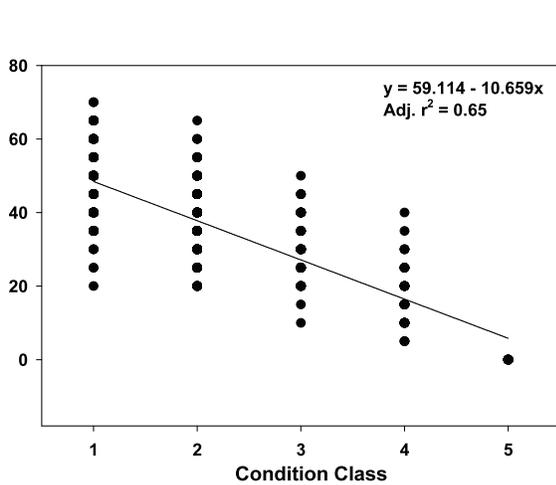


Figure 3—Linear regression between categorical crown rating system and FIA Phase 3 measure of crown density.

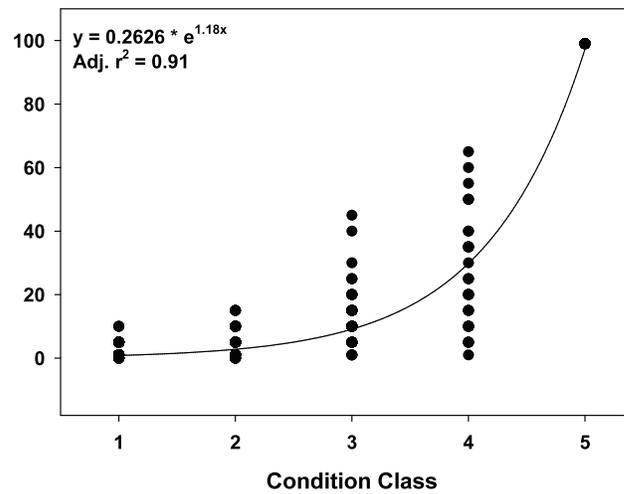


Figure 4—Exponential regression between categorical crown rating system and FIA Phase 3 measure of crown dieback