Tracking the Health of Trees Over Time on Forest Health Monitoring Plots

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Abstract.—The Forest Health Monitoring (FHM) Program was initiated in 1990 as a cooperative effort between the USDA Forest Service and the National Association of State Foresters. Program efforts include detecting changes in tree health from a national grid of one-sixth acre permanent sample plots. Tree data have been collected in various states since 1991, and include species, diameter at breast height (dbh), status (live, dead, or cut), and various ratings of crown condition and damage.

In this study, remeasured tree data were used to track changes in health over a 4-year period, by using status (live, dead, or cut), crown dieback, transparency, and density, and damage measurements of type, severity, and location. Initial analyses identified categories of individual crown and damage measurements associated with trees that eventually died. These thresholds were then integrated into categorical models to estimate the probability of mortality for trees with different combinations of crown and damage conditions. Separate models were constructed for different groups of tree species, with the premise that each group has a unique set of tolerable amounts of damage and foliage loss. Analyses also included statistical tests to verify differences among models.

Results will be incorporated into a field guide for use by land managers to help assess tree health, predict the likelihood of mortality, and rate the health of forest stands. Use of this tool will also help foresters make silvicultural decisions to select trees to be cut when regeneration, thinning, pre-salvage, or salvage operations are considered.

The Forest Health Monitoring (FHM) Program was initiated in 1990 as a cooperative effort between the USDA Forest Service and National Association of State Foresters. A main objective of the program is to detect spatial and temporal changes in tree health from a national grid of permanent sample plots. The health of individual trees is assessed by collecting quantitative measurements of different crown conditions and types of stem and root damage. Several years of data have now been collected from 18 states and summarized (Stolte 1997).

To date, the FHM program has focused on reporting descriptive statistics of measured values of tree health. However, interpretations of differences among tree species, locations, and measurement years are limited without a corresponding knowledge of what values represent healthy and unhealthy trees. Conversely, evaluations of tree health could be improved if models depicting overall conditions of trees were based on an integrated set of health indicators (Gillespie 1995).

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The primary purpose of this paper is to provide additional meaning to values of tree health indicators by relating them to tree longevity. Analytical methods were used to first identify the best integrated set of indicators of imminent tree mortality. These indicators were then used to quantify critical conditions that precede tree death. Additional analyses determined how far in advance dying trees can be distinguished from ones that survive. Associated procedures were used to evaluate the conditions of trees that are cut for comparison with conditions of trees that die or stay alive.

METHODS

Available Data

Data used in this study were from 14,791 sampled trees that were annually measured for at least 4 years from 1993 through 1997. Trees were from 648 one-sixth acre plots located in 15 states (Connecticut, Delaware, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia, and Wisconsin). The trees from this extensive area were represented by numerous species with no single genus representing more than 20 percent of the sample (table 1). Thus, trees were

Table 1.—*Frequency of sampled trees that stayed alive, died, or were cut during the measurement period*

Tree genera	Survived (n = 13,513)	Died (n = 598)	Cut (n = 680)	All trees (n = 14,791)
	- - - - - - - *Column percentages* - - - - - -			
Maple	21.3	11.4	11.0	20.4
Oak	13.9	7.7	3.2	13.1
Birch	7.4	10.7	3.7	7.4
Aspen/poplar	6.7	8.7	17.1	7.3
Ash	4.1	3.5	1.5	4.0
Yellow-poplar	2.5	0.8	4.9	2.5
Beech	2.3	1.8	0.9	2.2
Hickory	2.2	2.0	0.6	2.1
Basswood	2.0	1.0	0.0	1.9
30 other genera	7.1	11.4	8.4	7.3
All hardwoods	**69.4**	**59.0**	**51.2**	**68.1**
Pine	11.4	13.7	24.0	12.1
Whitecedar	5.7	9.0	0.3	5.6
Fir	5.0	10.0	9.7	5.4
Spruce	4.9	6.0	11.3	5.3
Hemlock	2.5	1.7	2.2	2.5
4 other genera	1.1	0.5	1.3	1.1
All softwoods	**30.6**	**41.0**	**48.8**	**31.9**
All Genera	**100.0**	**100.0**	**100.0**	**100.0**

only analyzed as hardwoods or softwoods to facilitate robust statistical testing. However, the diameter at breast height (dbh) and canopy position of individual trees were used to determine differences in health among overstory and understory trees of different sizes.

Quantitative indicators of tree health used in this study consisted of standardized measures of crown loss and damage to tree stems and surface roots (USDA Forest Service 1997a). Measurements of tree crowns included live crown ratio, and percentages of crown dieback, crown density, foliage transparency, foliage damage or discoloration, and broken branches. Measurements of stem and root damage included severity ratings (in percent) of decay, cankers, resinosis, and wounds. Symptoms of decay were recorded in the field as present or absent and given corresponding severity ratings of 95 or 0 percent in this study. A stem/root damage index value was assigned to each tree by summing the severity ratings of all recorded damages. A better method for calculating a damage index has been developed, but was not available in time for this study (USDA Forest Service 1997b).

Analyses

Preliminary analyses examined the distribution of values for individual indicators of crown loss and stem/root damage (table 2). Live crown ratio and crown density were found to be normally distributed, but all other measures indicative of crown loss and stem/root damage had peaked and right-tailed distributions with means relatively close to zero.

These distributions signify that most sampled trees were in good health, which is not surprising considering only 5 percent of the trees died during the measurement period. Also, the sampled time period and geographic area had no widespread damage from insects, diseases, or weather events. It is more likely that the conditions of the diversity of sampled tree species were influenced by a variety of factors including competition from other trees.

Most indicators were significantly ($p < 0.05$) but weakly correlated with each other (absolute values of r coefficients near 0.2). An exception was crown dieback, which was strongly correlated with foliage transparency ($r = 0.5$), broken branches ($r = 0.4$), and crown density ($r = -0.4$). Crown density was also correlated with foliage

Table 2.—*Means, standard deviations (SD), and skewness (SKEW) of measurements from all sampled trees*

Measurement	Hardwoods			Softwoods		
	Mean	SD	SKEW[1]	Mean	SD	SKEW[1]
Dbh (inches)	9.1	3.8	2.1	8.5	3.3	2.2
Live crown ratio (%)	46.7	18.2	0.5	56.7	22.2	0.1
Crown dieback (%)	5.5	10.6	6.0	4.0	7.8	6.4
Crown density (%)	51.0	13.3	-0.4	49.3	13.5	0.0
Foliage transparency (%)	15.0	9.4	4.4	16.1	7.2	2.5
Broken branches (%)	2.0	10.6	6.9	1.1	7.5	9.7
Foliage damage (%)	0.5	5.2	13.0	0.2	3.6	19.4
Stem/root damage (index)	19.5	43.2	2.4	7.6	27.6	4.4
Decay	16.1	40.1	2.6	5.4	24.2	5.2
Wounding	0.8	6.3	9.9	0.4	5.0	15.5
Cankers	1.2	8.9	10.2	0.2	3.5	17.0
Other	1.3	9.9	8.8	1.5	10.7	8.2

[1]Deviations from zero indicate the degree of skewness where positive and negative deviations indicate right-tailed and left-tailed skewness, respectively.

transparency (r = -0.3) and broken branches (r = -0.3). Tree dbh was not strongly correlated with any of the indicators of tree health.

Discriminant analysis was used as an exploratory tool to identify which measures of crown loss and stem/root damage were most indicative of which trees died one year later. Stepwise methods were used to select the most significant ($p < 0.05$) combination of variables that distinguished trees that died from those that stayed alive. Tested models allowed entry of tree dbh and canopy position as predictors but showed that the best model contained only crown dieback, crown density, and stem/root damage. These were the best predictors for both hardwood and softwood trees, and crown dieback was most significant for each group. Several other measures including dbh and canopy position were statistically significant but relatively weak predictors of tree mortality.

A subsequent procedure was used to determine thresholds of crown dieback, crown density, and stem/root damage that were most frequently associated with tree mortality one year later. A gradient of thresholds was tested using an iterative process that compared percentages of trees that died in differently defined "low" and "high" categories of crown loss or stem/root damage. Chi-square tests of independence were used to select thresholds producing the greatest significant difference in percentages of dead trees between categories.

The final procedure examined changes in crown loss and stem/root damage over the full 4-year measurement period. This was done to determine how far in advance trees that died could be distinguished from trees that survived. Mean values were compared at each year using non-parametric tests because data were not normally distributed. Each measurement was evaluated individually, and hardwoods and softwoods were examined separately.

RESULTS

Critical Thresholds of Crown Loss and Stem/Root Damage

In this study, crown dieback followed by crown density and stem/root damage were found to be the best set of indicators for estimating the probability of trees dying within one year. These were the best measurements for both hardwood and softwood species although each group had a unique set of critical thresholds. Tests to determine critical thresholds of crown dieback showed that hardwoods with more than 30 percent dieback were most likely to die within one year, while softwoods with more than 20 percent dieback were most likely to die within one year. For both hardwoods and softwoods, trees with crown densities less than 30 percent were most likely to die. Critical index values for stem/root damage were 50 for hardwoods and only 20 for softwoods. Foliage transparency and other measures were found to be weaker indicators of tree mortality.

Each category of tree conditions defined by different combinations of crown dieback, crown density, and stem/root damage was found to have a unique percentage of trees that died (table 3). As expected, trees most likely to die were in categories with high dieback, low crown density, and high damage. Conversely, trees with values in opposite categories were least likely to die. Other categories where two measures indicated poor tree health

Table 3.—*Percentages of trees with different combinations of crown dieback, crown density, and stem/root damage that died within 1 year*

a) Hardwoods

Stem/root damage index[1]	**Crown dieback ≤ 30 %** Crown density > 30%	**Crown dieback ≤ 30 %** Crown density ≤ 30%	**Crown dieback > 30%** Crown density > 30%	**Crown dieback > 30%** Crown density ≤ 30%
	percentage of sampled trees that died (number of sampled trees)			
≤ 50	1 (7,451)	9 (463)	11 (27)	43 (119)
> 50	3 (1,352)	23 (171)	35 (17)	62 (68)

b) Softwoods

Stem/root damage index[1]	**Crown dieback ≤ 20 %** Crown density > 30%	**Crown dieback ≤ 20 %** Crown density ≤ 30%	**Crown dieback > 20%** Crown density > 30%	**Crown dieback > 20%** Crown density ≤ 30%
	percentage of sampled trees that died (number of sampled trees)			
≤ 20	2 (3,486)	11 (340)	21 (24)	40 (30)
> 20	5 (335)	17 (53)	23 (13)	59 (29)

[1]The damage index is calculated for an individual tree by summing the percent severities of decay, cankers, resinosis, and wounds.

had greater percentages of trees that died than categories where just one measure indicated a poor health condition. Few trees died without some indication of poor health. This categorical analysis confirmed preliminary discriminant analyses showing that crown dieback was the best but not the solitary indicator for distinguishing which trees died.

Early Symptoms of Impending Mortality

Other analyses compared the amount of crown loss and stem/root damage that trees had 2 and 3 years prior to death or their most recent measurement if they survived. Crowns of trees that died had noticeably more dieback and lower densities than trees that survived for as long as 3 years before death (figs. 1 and 2). Damage was also greater in trees that died but at constant amounts throughout the measurement period (fig. 3). Mean values of crown dieback, crown density, and stem/root damage for trees that survived and trees that died were significantly different 1, 2, and 3 years before their most recent measurement. Differences between live and dead trees were more pronounced in hardwoods than in softwoods.

Values of foliage transparency were also compared even though this was not as good as an indicator to predict mortality (fig. 4). Hardwood trees that died had an average foliage transparency that was greater than the transparency of trees that stayed alive for at least 3 years before death. However, the difference in transparency between trees that died and those that stayed alive was less distinguishable for softwoods.

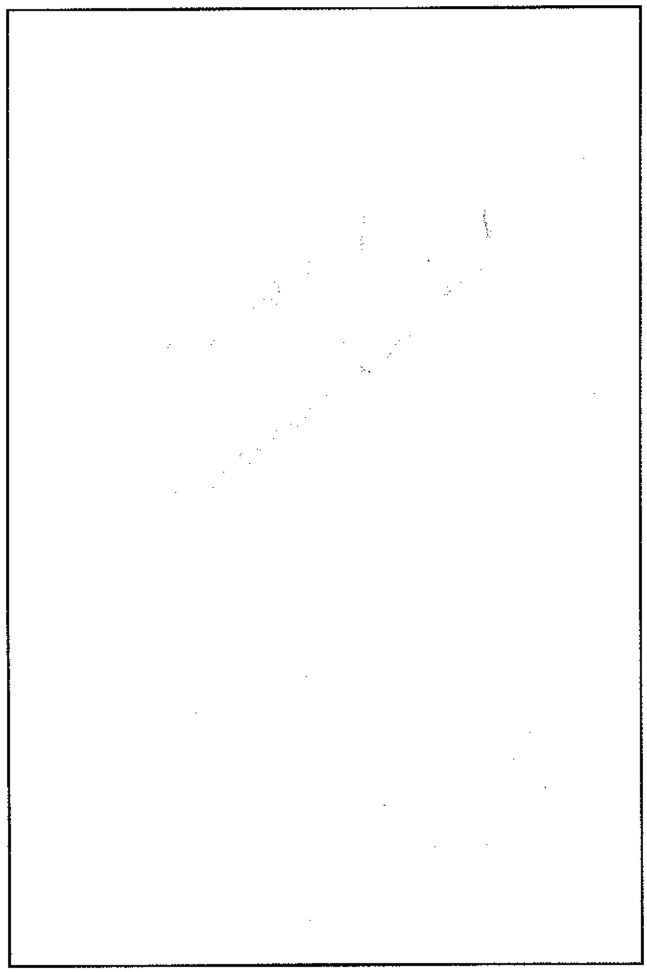

Figure 1.—*Average annual changes in crown dieback of trees that survived, died, or were cut.*

Figure 2.—*Average annual changes in crown density of trees that survived, died, or were cut.*

Figure 3.—*Average annual changes in stem and root damage of trees that survived, died, or were cut.*

Secondary results showed that conditions of trees that were eventually cut were more similar to trees that stayed alive than to trees that died (figs. 1 through 4). At each year before the most recent measurement, values for crown dieback, crown density, stem/root damage, and foliage transparency of trees that were cut were almost equal to those for trees that stayed alive.

DISCUSSION

Precision of Estimates

Some uncertainty remains about the precision of estimates in this study even though results show relationships that could be useful. As mentioned, trees were sampled from an extensive and diverse geographic area, which prevented stratifying the data to examine specific relationships for individual tree species or sites. Measured conditions indicate that the vast majority of trees were in good health as indicated by the relatively low percentage of trees that died or had poor crowns and severe damage. The selected set of indicators and their critical thresholds should both be validated before use.

Even so, results from analyses of the health conditions of sugar maple (*Acer saccharum*) conducted by the North American Maple Project (NAMP) were comparable to those found in this study (Allen *et al.* 1995). Crown dieback exceeding 35 percent was found to be a key indicator of imminent mortality, and less than 5 percent of all live sugar maple were observed to have greater amounts. Results were also comparable to this study in that foliage transparency was found to be a poor predictor of mortality and poorly correlated with crown dieback. Crown density and damage to stems and roots of sugar maple were not available for comparison with measurements from this study.

Continual measuring of existing FHM plots will provide additional data to track trees for a longer period of time. Data from the 1998 field season will be available in about 6 months and could help validate findings in this study by showing the fate of live trees that had poor crowns in

Figure 4.—*Average annual changes in foliage transparency of trees that survived, died, or were cut.*

1997. Other future interests will include using a more refined damage index that is currently being developed (USDA Forest Service 1997b). This index will adjust the severity ratings of stem damage as related to where they are located, with damages close to the ground receiving the highest ratings.

Potential Applications

Information about critical conditions of crown loss and stem/root damage indicative of tree mortality has two potential uses. One use would be to incorporate this information into the reporting component of the Forest Health Monitoring Program. Reports showing which sample plots contain trees with threshold conditions could help identify locations with tree health problems. Depictions of percentage of trees on individual plots that have threshold conditions could also be more informative than alternative representations that show average values of indicator measurements.

Information from this study may also be useful as a forest management tool to help decide which trees to remove during silvicultural treatments. Results imply that trees with good crowns and little damage were purposely selected to be cut over weaker trees. Current harvesting trends in the northeastern U.S. correspond to this premise considering that many stands are selectively cut (high-graded) for the most merchantable trees (Smith 1986).

Most foresters are skilled at rating the health of trees based on the overall appearance of crowns and stems. However, there is still a need to accurately select high-risk trees during harvesting operations and convey this technique to non-industrial private landowners who cut their own trees. A transfer of this information could be a valuable means to improve forest stewardship efforts.

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