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Descriptive Statistics of Tree Crown Condition in the Southern United States and Impacts on Data Analysis and Interpretation

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Abstract

The U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program (FIA) utilizes visual assessments of tree crown condition to monitor changes and trends in forest health. This report describes and discusses distributions of three FIA crown condition indicators (crown density, crown dieback, and foliage transparency) for trees in the Southern United States. Descriptive statistics are presented for all trees combined, by hardwood and softwood species groups, and for 53 individual species. Implications of these characteristics and other factors for the analysis of the phase 3 crown condition indicators are discussed.

Keywords: Crown density, crown dieback, FIA, foliage transparency, forest health.

Introduction

Given the charge of reporting on the status and trends in forest ecosystem health in the United States, the U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis Program (FIA) assesses a suite of forest health indicators on a network of phase 3 plots systematically located across the United States (Riitters and Tkacz 2004). Because a tree's health is generally reflected in the amount and condition of its foliage (Anderson and Belanger 1987, Innes 1993), tree crown condition is included as one of the FIA forest health indicators.

Healthy trees typically have crowns that are distributed symmetrically along the stem in a predictable way, but when a tree is subjected to stress it reacts by slowing its growth and shedding parts of its crown (Millers and others 1989). The shedding of parts, termed dieback for the loss of fine twigs and defoliation for the loss of leaves, alters not only the tree's appearance but also its rate of photosynthesis and carbohydrate production. Thus, the shedding of parts is a survival mechanism the tree uses to adjust and conserve its energy reserves.

Each year, FIA monitors the amount of dieback and defoliation present on the phase 3 plots. Nationwide, annual monitoring of this type is relatively new, however, and before comprehensive modeling of changes and trends in forest health can be accomplished, the basic characteristics of tree crown condition must be understood. Thus, the purpose of this report is to present a summary of the statistical characteristics of three phase 3 crown condition indicators (crown density, crown dieback, and foliage transparency) in the Southern United States, and to discuss the implications of these and other considerations for the analysis and interpretation of the crown condition data.

Methods

Data Collection

The data consisted of crown assessments from all forested phase 3 plots in Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia. Data were collected in 1995, 1997, 1998, and 1999. Each phase 3 plot is a cluster of four 1/60-ha (1/24-acre) circular subplots with subplot centers located 36.6 m (120 feet) apart. Crown condition was measured for every tree ≥ 12.7 cm (5.0 inches) in diameter at breast height on each subplot. The crown condition indicators included in this summary report are (fig. 1): (1) crown density—the amount of crown branches, foliage, and reproductive structures that blocks light visibility through the projected crown outline; (2) crown dieback—recent mortality of branches with fine twigs, which begins at the terminal portion of a branch and proceeds inward toward the trunk; and (3) foliage transparency—the amount of skylight visible through the live, normally foliated portion of the crown, excluding dieback, dead branches, and large gaps in the crown.[1]

Crown density and foliage transparency cannot be interpreted as exact inverses. Crown density measures the amount of sunlight blocked by all biomass produced by the tree (both live and dead) in the crown, whereas foliage transparency measures the amount of sunlight penetrating only the live portion of the crown. Deductions are made from the maximum possible crown density for spaces between branches and other large openings in the crown. However, large gaps in the crown where foliage is not expected to occur are excluded from consideration when foliage transparency is rated.

[1] U.S. Department of Agriculture Forest Service. 2003. Forest inventory and analysis national core field guide, FIA field methods for phase 3 measurements: crown condition classification. Version 1.7. Internal report. On file with: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis, 201 14th Street., Washington, DC 20250. http://fia.fs.fed.us/library/field-guides-methods-proc. [Date accessed: March 18, 2005].

Figure 1—The dashed line is the projected crown outline against which crown density is assessed. The dash-dot line within the projected crown outline defines the area of crown dieback. The striped areas are areas where foliage is not expected to occur and are not included in the foliage transparency estimate. Adapted from Millers and others (1992).

All three indicators were visually assessed by Two-person field crews, and were recorded in 5-percent increments from 0 to 100 percent. Higher crown density values, lower foliage transparency values, and lower crown dieback values are typically associated with better tree health. The trees were assessed during the summer, when trees maintain full crown foliage, typically between June and mid-August. More detailed descriptions of these and other crown condition indicators are available in the phase 3 data collection field guide (see footnote 1).

Data Summary

In order to correctly calculate means and variances, the unequal-sized clusters of trees on the FIA inventory plots must be taken into account. The SAS® procedure SURVEYMEANS (An and Watts 1998) can accommodate the FIA survey design through the designation of a "cluster" variable, i.e., the primary sampling unit of the survey. Plot number was designated as the cluster variable and SURVEYMEANS was used to calculate means and standard errors for all species combined, hardwood and softwood species groups, and individual species with at least 25 observations. Other descriptive statistics (skewness, kurtosis, minimum, maximum, and percentile values) were calculated also. All groupings of the data were examined for normality by means of normal probability plots and the Kolmogorov-Smirnov (KS) (if $n_{trees} \geq 2{,}000$) or Shapiro-Wilk (if $n_{trees} < 2{,}000$) test. Trees with foliage but by definition having no crown, i.e., 0 percent crown density, 99 percent crown dieback, and 99 percent foliage transparency were omitted from the summary.

Results

Crown condition was measured for 15,011 trees of 111 species. Of these trees, 56.9 percent were hardwoods and 43.1 percent were softwoods. Of the 111 species, 53 had 25 or more observations. Overall, crown density ranged from 5 to 85 percent with a mean of 44.6 percent (fig. 2; table 1). Crown dieback ranged from 0 to 95 percent and had a mean of 1.9 percent (fig. 3; table 1). Foliage transparency ranged from 0 to 95 percent also, with a mean of 16.9 percent (fig. 4; table 1). Although the values of each crown condition indicator spanned the range of possible values, the majority of the observations tended to concentrate in a small portion of the range. This was evident in the small interquartile ranges and in the low-valued 90th percentiles. The interquartile range is a measure of spread in the data and is equal to the difference between the 75th percentile and the 25th percentile. The widest interquartile range was 10 percent for crown density. Both crown dieback and foliage transparency had interquartile ranges of only 5 percent (table 1). The 90th percentiles for crown dieback and foliage transparency were 5 and 25 percent, respectively, indicating that high values are uncommon for these indicators. The 90th percentile for crown density was 60 percent, indicating that very dense trees are rare.

Skewness and kurtosis are measures of the degree of symmetry and relative peakedness of a distribution, respectively. These measures are often interpreted by reference to the normal (Gaussian) distribution, which has skewness equal to zero and kurtosis equal to three. (Kurtosis is often normalized so that the normal distribution has a kurtosis value of zero. The kurtosis values presented here have been normalized in this way.) Positive skewness values indicate that the observations to the right of the mean are more spread out than those to the left of the mean. Similarly, negative skewness values indicate that the observations to the left of the mean are more spread out than those to the right of the mean. When normalized to zero, positive kurtosis values indicate distributions with tails heavier than the normal distribution, and negative kurtosis values indicate distributions with tails lighter than the normal distribution. Crown density had skewness and kurtosis values most like those of

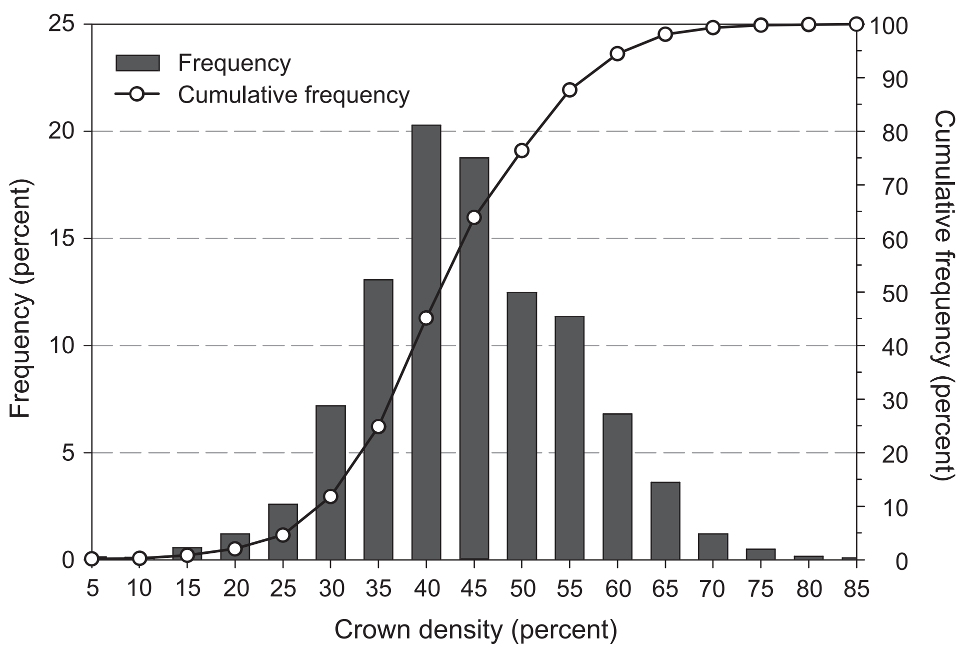

Figure 2—Crown density frequency histogram and cumulative frequency distribution for all trees combined for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

Table 1—Mean crown attributes and other statistics[a] for all live trees > 4.9 inches d.b.h., by species group for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999[b]

Crown condition indicator and species group	Plots	Trees	Mean	Standard error	Skewness	Kurtosis	Minimum	Percentile 10th	Percentile 25th	Percentile 50th	Percentile 75th	Percentile 90th	Maximum
	- - number - -		*- - - percent - - -*				*- - - - - - - - - - - - -percent - - - - - - - - - - - - -*						
Crown density													
All trees	635	15,011	44.6	0.324	0.130	0.296	5	30	40	45	50	60	85
Hardwoods	576	8,535	46.2	0.325	-0.005	0.311	5	35	40	45	55	60	85
Softwoods	437	6,476	42.1	0.522	0.249	0.538	5	30	35	40	50	55	85
Crown dieback													
All trees	635	15,011	1.9	0.093	8.079	105.351	0	0	0	0	5	5	95
Hardwoods	576	8,535	2.5	0.104	7.287	88.928	0	0	0	0	5	5	95
Softwoods	437	6,476	1.2	0.122	10.050	149.113	0	0	0	0	0	5	90
Foliage transparency													
All trees	635	15,011	16.9	0.212	1.972	14.400	0	10	15	15	20	25	95
Hardwoods	576	8,535	15.7	0.232	2.480	22.228	0	10	10	15	20	20	95
Softwoods	437	6,476	18.4	0.350	1.595	8.906	0	10	15	15	20	25	95

[a] The mean and standard error calculations consider the clustering of trees on plots.

[b] No data collected for 1996.

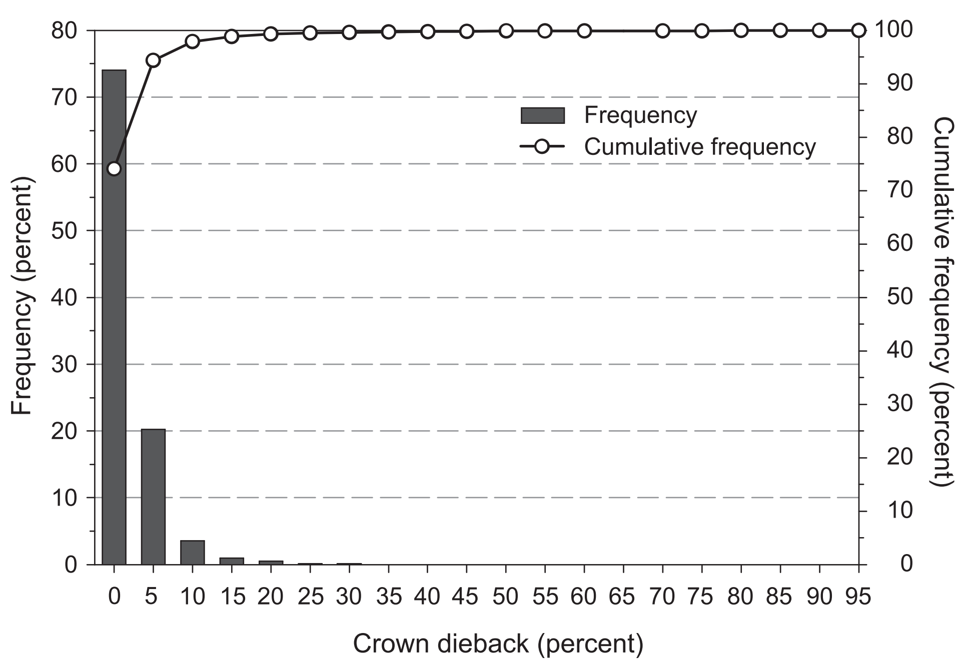

Figure 3—Crown dieback frequency histogram and cumulative frequency distribution for all trees combined for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

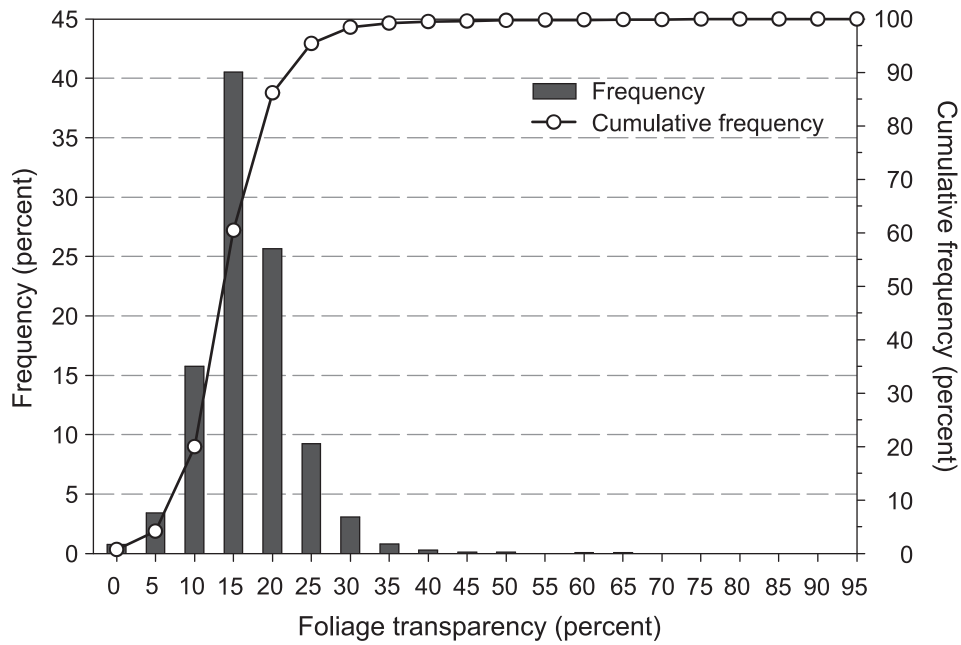

Figure 4—Foliage transparency frequency histogram and cumulative frequency distribution for all trees combined for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

the normal distribution: skewness was 0.130 and kurtosis was 0.296. Crown dieback and foliage transparency were both positively skewed, with skewness values equal to 8.079 and 1.972, respectively. The tails of the foliage transparency (kurtosis = 14.400) and crown dieback (kurtosis = 105.351) distributions were heavier than those of the normal distribution. The tail of the crown dieback distribution was extremely so.

The null hypothesis of the KS test (H_0: data are normally distributed) was rejected for all three indicators ($p < 0.01$). Extremely large sample sizes, however, can lead the normality test to detect deviations from normality that are statistically significant but practically unimportant. This was likely the case for crown density since the straight-lined normal probability plot (fig. 5), bell-shaped histogram (fig. 2), and skewness and kurtosis values are characteristic of a normal distribution. On the other hand, the normal probability plots for crown dieback (fig. 6) and foliage transparency (fig. 7) support the KS test conclusion of nonnormality, with figure 7 providing additional evidence that foliage transparency is right-skewed (Neter and others 1996).

Species Groups

Hardwood crown density was about 5 percent higher than softwood density, both at the mean and at each percentile level (table 1). Mean foliage transparency was slightly higher for softwoods (18.4 percent) than for hardwoods (15.7 percent), but on average both groups exhibited about the same crown dieback (table 1). Figures 8, 9, and 10 show that hardwood crown density, crown dieback, and foliage transparency values were spread across the ranges much as the values for softwoods, although hardwood density was skewed slightly negatively while softwood density was skewed positively. There was much variation in the kurtosis values for the three indicators (table 1). The softwood group had a much higher crown dieback kurtosis (149.113) than did the hardwood group (88.928), though both kurtosis values were extremely high. In contrast, foliage transparency kurtosis was higher for the hardwoods (22.228) than for the softwoods (8.906). The KS test for normality by species group was rejected for all three indicators ($p < 0.01$); but as before, skewness, kurtosis, histograms (figs. 8, 9, and 10), and normal probability plots (fig. 11) indicate that the conclusion of nonnormailty is appropriate only for crown dieback and foliage transparency.

Individual Species

For each of the crown condition indicators, the 53 species examined individually exhibited a broad range of average conditions. Mean crown density ranged from 38.8 percent for swamp tupelo to 57.8 percent for eastern hemlock; median density ranged from 40 to 55 percent (table 2). Mean crown dieback was lowest for eastern hemlock (0.4 percent)

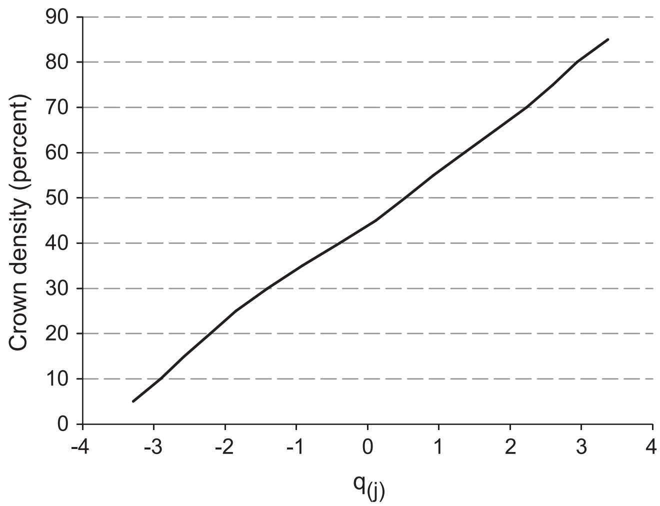

Figure 5—Normal probability plot for crown density, all trees combined for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

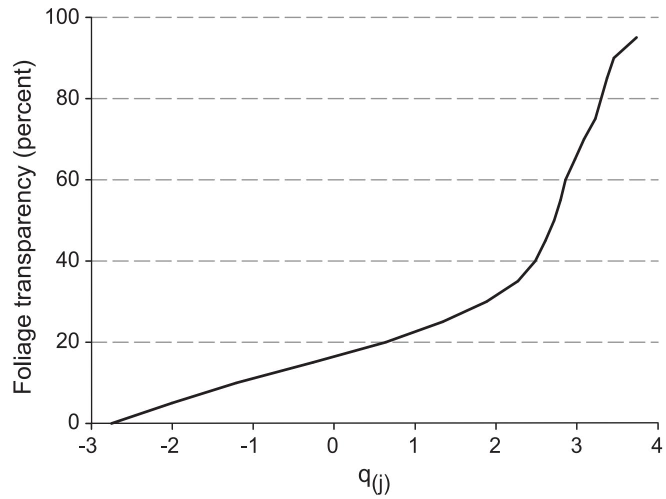

Figure 7—Normal probability plot for foliage transparency, all trees combined for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

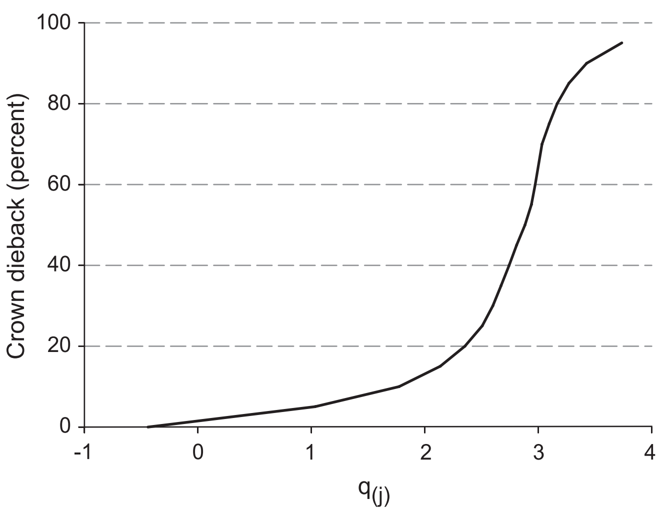

Figure 6—Normal probability plot for crown dieback, all trees combined for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

and highest for hackberry (4.7 percent); median dieback ranged from 0 to 5 percent (table 3). Mean foliage transparency was lowest for laurel oak (13.4 percent) and highest for Virginia pine (23.4 percent); median foliage transparency ranged from 12.5 to 20 percent (table 4).

Percentile values indicated that the crown condition indicator distributions differed from species to species in more ways than the measure of central tendency. The greatest difference among the species was at the 90th percentile of crown density. There, the lowest value was 45 percent for swamp tupelo and the highest value was 75 percent for eastern hemlock, a difference of 30 percent (table 2). The difference between the lowest and highest values at the 75th percentile was 25 percent. Even at the lower percentiles of crown density, the difference between the lowest and highest values was 15 percent, suggesting that there is a tendency for some species to maintain less dense crowns than others. Differences among the crown dieback and foliage transparency percentiles were less extreme. The greatest differences were at the 90th percentile for crown dieback (table 3), and at the 90th and 75th percentiles for foliage transparency (table 4).

Skewness and kurtosis values for the three crown condition indicators varied among the individual species. Distributions of crown density were both positively and negatively skewed (table 2). The most left-skewed distribution was shagbark hickory (-1.213) and the most right-skewed distribution was baldcypress (0.721). The heaviest tails (kurtosis) for the crown density distribution were in shagbark hickory (3.233). All of the crown dieback distributions were positively skewed (table 3). Redbay had the least skewed dieback distribution (0.687), while loblolly pine had the most skewed dieback distribution (12.016). Loblolly pine also had the heaviest tails with a kurtosis value of 222.673. The foliage transparency distributions were skewed both to the left and to the right (table 4). Sweetbay had the most negatively skewed foliage transparency distribution (-0.757) and sweet birch had the most positively skewed distribution (4.420). The tails of the sweet birch foliage transparency distribution were the heaviest of all species with a kurtosis value of 24.793.

The tests for normality (KS or Shapiro-Wilk) indicated that all crown dieback distributions, all foliage transparency

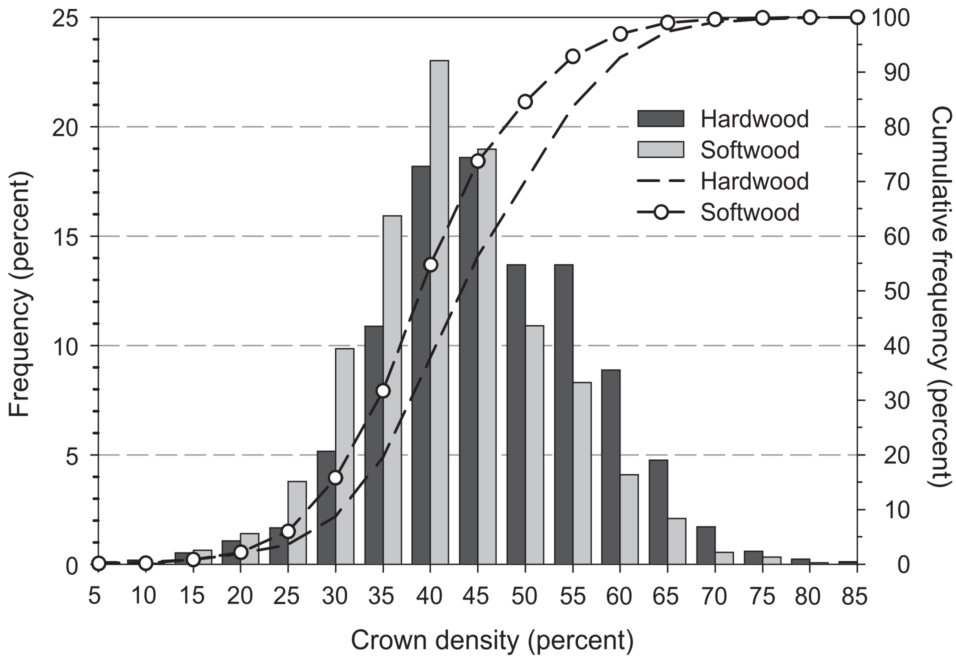

Figure 8—Frequency histograms and cumulative frequency distributions for crown density, by species group for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

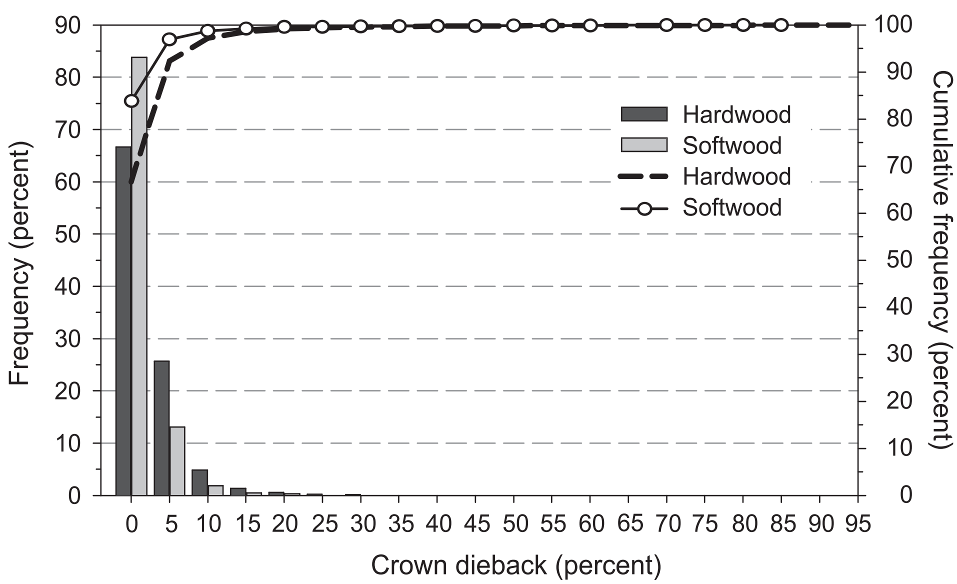

Figure 9—Frequency histograms and cumulative frequency distributions for crown dieback, by species group for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

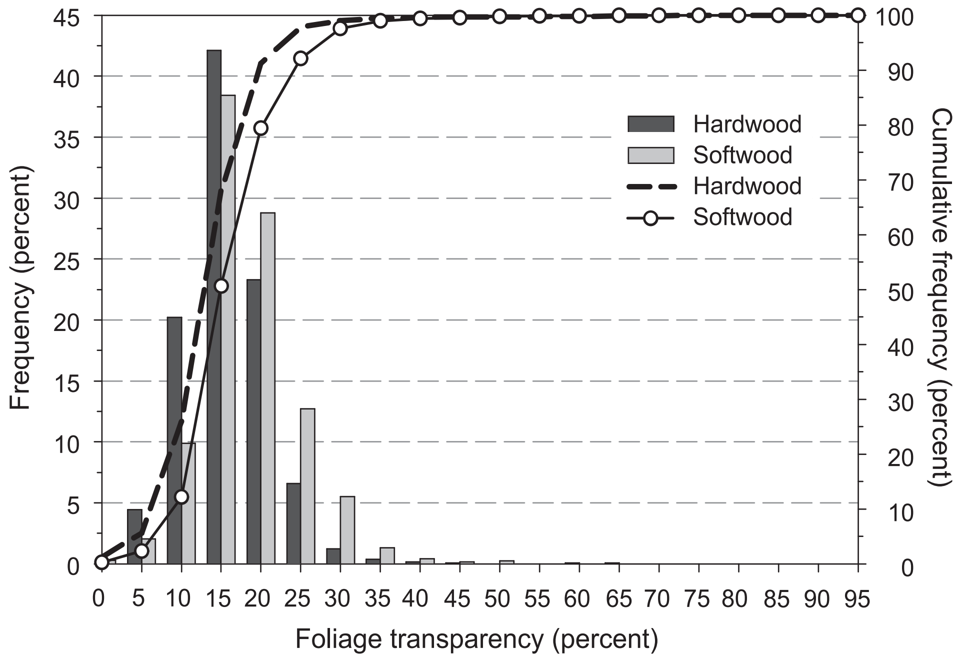

Figure 10—Frequency histograms and cumulative frequency distributions for foliage transparency, by species group for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

distributions except one (river birch), and all but 15 crown density distributions were nonnormal (alpha = 0.05). The species with normally distributed crown density were eastern hemlock, sweet birch, American hornbeam, hackberry, American beech, white ash, American holly, water tupelo, eastern hophornbeam, redbay, sycamore, live oak, black locust, sassafras, and winged elm. An examination of the normal probability plots and histograms confirmed the conclusions of nonnormality for crown dieback and indicated that the deviations from normality for crown density were minimal. The histograms also indicated that the lack of normality for foliage transparency was in many cases due to one or two outlying observations in the far right tail of the distribution.

Discussion

FIA, in conjunction with the USDA Forest Service, Forest Health Monitoring Program, uses the crown condition (and other phase 3) indicators to report on the status of and changes in forest health in the United States. In this effort, there are two basic avenues of inferential analysis: (1) the detection of differences among groups of observations at a single point in time, and (2) the detection of changes over time for a specific group of observations. In each case the overall task is to determine the equality of two groups, but a number of factors influence the way these analyses are implemented and the manner in which the results are interpreted. Some of these factors include the influence of species and natural stand dynamics on individual tree crown condition, the statistical characteristics of the crown condition indicators, i.e., distributional form, the FIA sampling design by which the data are collected, the interest in identifying the poorest and best crowns in addition to measures of central tendency, and the need to evaluate biological significance relative to statistical significance.

Influence of Species and Stand Dynamics

Before the equality of two groups can be determined, confounding influences must be addressed so that real differences between the groups are not obscured. Given that tree crown condition is the result of a combination of many factors, e.g., species, site conditions, and external stresses, these factors need to be controlled to ensure unambiguous test results. For example, the data summarized here indicate that the crown density indicator varies by species. At the species level, the range in average crown density was 19 percent, from 38.8 percent for swamp tupelo to 57.8 percent for eastern hemlock (table 2). Such great variability inhibits direct comparisons of species because some species clearly tend to have denser crowns than others. Interspecies variability also complicates stand-level analyses in which species are combined to calculate plot averages. In a mixed hardwood stand, for example, plots dominated by hickory would probably tend to have higher average crown density than plots dominated by elm (table 2). Results of a hypothesis test

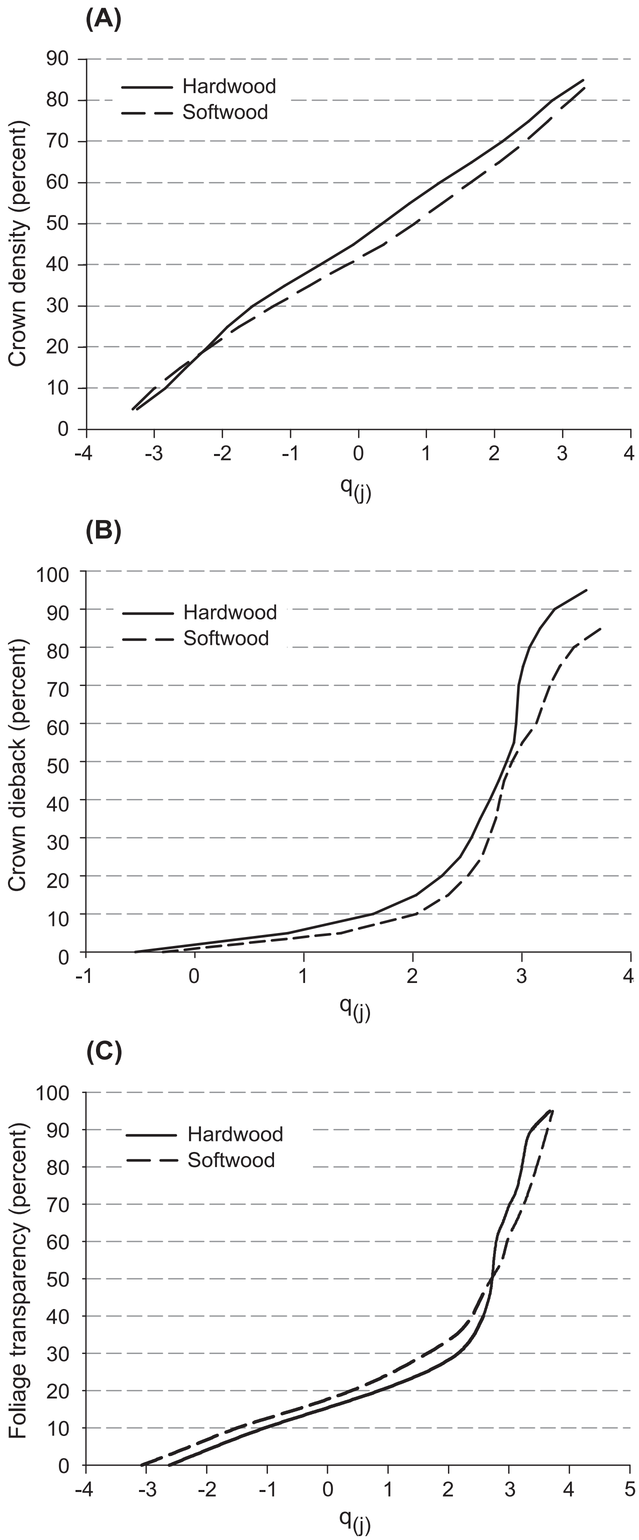

Figure 11—Normal probability plots for (A) crown density, (B) crown dieback, and (C) foliage transparency, by species group for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

indicating statistically significant differences between such plots would be confounded by species, and this would make it harder to reach definite conclusions about the relative health of the plots.

One way to accommodate the species (and stand condition) influences is stratification, i.e., grouping together sets of homogeneous observations and making comparisons only among those sets. Stratification reduces variation in descriptive statistics and summaries, but it does not necessarily facilitate further inferential analyses. In broadscale surveys such as the phase 3 program, complete stratification leads to small and unbalanced sample sizes that complicate analyses or limit interpretations of the results, or have both of these effects. To avoid the pitfalls of stratification and still account for species and stand influences, Zarnoch and others (2004) propose standardizing or residualizing, or both, the crown condition indicators prior to inferential analyses. Standardization adjusts the crown indicators for species differences by expressing the indicators in terms of standard deviation units. This allows the indicators to be combined across species or for direct comparison of the indicators among species. Residualization adjusts the crown indicators for natural stand dynamics by redefining the indicators as the residuals from a model that predicts crown condition based on tree and stand conditions. Residualization allows the combination or comparison of trees from many different plots within a given species. Residualized indicators may be standardized to allow for comparisons or combinations of many species across many plot conditions.

Statistical Characteristics

Any data analyzed via inferential hypotheses must meet the underlying assumptions of the tests being used. The typical hypothesis tests applicable to the crown condition data, e.g., the *t*-test and analysis of variance, or ANOVA, require an assumption of normality. For the data examined here, it is reasonable to assume that crown density meets this requirement and that the *t*-test and ANOVA may be safely applied to the crown density indicator. On the other hand, crown dieback and foliage transparency are best considered nonnormal. The deviation from normality of foliage transparency values is primarily due to a few outlying observations that cause right skewness, and since the *t*-test and ANOVA are robust against skewness and outliers, these tests may also be applied to the foliage transparency indicator as long as the sample sizes of the groups being compared are about equal and sufficiently large ($n \geq 30$). Because of the extreme deviation from normality, such tests should not be applied to the crown dieback indicator. Other avenues for analyzing the crown dieback data include nonparametric techniques or categorical methods for ordinal data.

Table 2—Mean crown density and other statistics[a] for all live trees > 4.9 inches d.b.h., by species for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999[b]

Species[c]	Plots	Trees	Mean	Standard error	Skewness	Kurtosis	Mini-mum	Percentile					Maxi-mum
								10th	25th	50th	75th	90th	
	- - *number* - -		- - - *percent* - - -				- - - - - - - - - - - - - - *percent* - - - - - - - - - - - - - -						
Eastern redcedar	50	111	48.0	1.565	-0.141	-0.506	20	35	40	45	55	65	75
Shortleaf pine	91	357	43.0	1.033	-0.155	0.520	5	30	35	45	50	55	75
Slash pine	38	444	40.0	1.015	-0.181	1.228	5	30	35	40	45	50	70
Longleaf pine	32	169	40.8	1.529	-0.021	-0.093	20	30	35	40	45	55	60
Pond pine	9	65	42.4	1.796	-0.327	0.018	20	30	40	45	50	55	60
Eastern white pine	33	134	44.9	1.531	-0.184	-0.203	15	30	35	45	55	60	70
Loblolly pine	254	4,355	42.0	0.696	0.266	0.445	5	30	35	40	50	55	85
Virginia pine	88	641	41.1	1.359	0.117	-0.108	5	25	35	40	50	60	75
Baldcypress	12	68	42.0	2.178	0.721	2.712	15	30	35	40	45	55	85
Eastern hemlock	10	34	57.8	5.000	-0.012	-1.068	30	40	45	55	70	75	85
Boxelder	12	35	48.4	2.628	0.464	0.998	30	35	40	45	55	60	80
Red maple	234	879	46.1	0.627	0.105	0.243	10	35	40	45	55	60	85
Sugar maple	39	106	48.1	1.644	-0.335	-0.280	15	35	40	50	55	60	70
Sweet birch	18	45	50.7	2.624	0.145	0.151	20	35	40	50	60	65	80
River birch	18	37	47.2	1.340	-0.408	0.616	20	40	40	45	55	55	65
American hornbeam	24	54	44.4	2.138	0.099	0.622	15	35	35	45	50	55	70
Pignut hickory	59	137	51.6	1.500	-0.142	-0.167	25	40	45	55	60	65	80
Shagbark hickory	26	57	50.6	1.764	-1.213	3.233	5	35	45	50	60	60	75
Mockernut hickory	80	190	49.5	1.120	-0.491	0.449	10	35	40	50	60	65	80
Hackberry	8	37	40.4	1.813	0.013	-0.693	20	25	30	40	50	55	60
Flowering dogwood	60	103	41.5	1.487	0.247	0.569	10	30	35	40	50	55	80
Persimmon	19	34	40.1	1.430	-0.011	2.198	15	35	35	40	45	50	60
American beech	43	95	55.4	1.343	-0.060	-0.199	20	40	45	55	65	70	85
White ash	25	52	48.8	4.298	0.192	-0.217	15	35	40	45	60	70	80
Green ash	42	125	41.9	2.563	-0.172	0.098	5	25	35	40	50	55	70
American holly	19	50	50.6	2.191	-0.458	0.422	15	32.5	45	52.5	60	65	80
Sweetgum	244	939	47.2	0.663	-0.252	0.370	5	35	40	45	55	60	75
Yellow-poplar	215	766	49.4	0.691	-0.013	-0.027	10	35	40	50	55	65	80
Sweetbay	30	102	40.5	1.360	0.648	0.443	20	30	35	40	45	50	70
Water tupelo	14	68	42.6	1.990	-0.225	0.221	15	30	35	42.5	50	55	70
Blackgum	146	294	45.9	1.068	-0.066	0.172	10	30	35	45	55	60	85
Swamp tupelo	25	184	38.8	1.207	-0.503	0.298	15	30	35	40	45	45	55
Eastern hophornbeam	20	31	47.1	2.345	0.480	0.398	25	35	40	45	55	60	75
Sourwood	101	261	46.9	1.097	0.442	0.178	20	35	40	45	55	60	85
Redbay	9	26	45.0	2.357	0.571	0.489	30	35	40	45	50	55	70
Sycamore	14	25	52.4	2.394	0.610	0.932	30	40	45	55	55	70	85
Black cherry	83	132	43.1	1.177	-0.080	-0.067	10	30	35	40	50	60	70
White oak	184	633	47.8	0.648	0.039	0.768	5	35	40	45	55	60	85
Scarlet oak	78	232	45.6	0.781	0.169	0.328	20	35	40	45	50	60	75
Southern red oak	93	220	45.7	0.982	-0.139	-0.093	15	35	40	45	55	60	70
Laurel oak	23	70	45.7	1.801	0.019	0.123	20	35	40	45	50	60	65
Water oak	134	390	44.6	0.851	0.161	0.286	15	30	40	45	50	60	85
Willow oak	38	91	48.2	1.522	0.175	-0.548	25	35	40	45	55	65	70
Chestnut oak	86	629	46.2	0.885	-0.237	0.517	5	35	40	45	55	60	75
Northern red oak	73	197	46.0	0.941	0.029	0.180	10	35	40	45	50	60	70
Post oak	58	105	42.0	1.324	0.244	0.947	15	30	35	40	45	55	75
Black oak	85	170	45.9	1.043	-0.374	0.916	10	35	40	45	55	60	75
Live oak	13	30	45.7	2.103	-0.558	0.695	25	35	40	45	50	57.5	60
Black locust	28	49	40.1	1.643	0.206	0.479	15	25	35	40	45	55	70
Sassafras	19	42	41.1	2.046	-0.232	0.027	10	25	35	40	50	55	65
Winged elm	28	54	44.3	1.465	0.385	-0.286	25	30	35	45	50	60	70
American elm	27	46	42.3	2.250	-0.830	0.854	5	25	35	40	55	60	60
Slippery elm	18	36	45.6	1.770	0.375	-0.899	35	35	40	45	52.5	55	60

[a] The mean and standard error calculations consider the clustering of trees on plots.
[b] No data collected for 1996.
[c] See appendix for scientific names.

Table 3—Mean crown dieback and other statistics[a] for all live trees > 4.9 inches d.b.h., by species for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999[b]

Species[c]	Plots	Trees	Mean	Standard error	Skewness	Kurtosis	Minimum	Percentile 10th	Percentile 25th	Percentile 50th	Percentile 75th	Percentile 90th	Maximum
	- - *number* - -		- - - *percent* - - -				- - - - - - - - - - - - - *percent* - - - - - - - - - - - - -						
Eastern redcedar	50	111	3.6	0.955	2.419	5.948	0	0	0	0	5	10	30
Shortleaf pine	91	357	1.4	0.261	2.237	5.300	0	0	0	0	0	5	15
Slash pine	38	444	0.8	0.351	3.532	16.613	0	0	0	0	0	5	20
Longleaf pine	32	169	0.9	0.302	2.829	7.233	0	0	0	0	0	5	10
Pond pine	9	65	2.2	0.868	3.375	16.750	0	0	0	0	5	5	25
Eastern white pine	33	134	1.9	0.524	6.099	45.546	0	0	0	0	0	5	50
Loblolly pine	254	4,355	0.8	0.130	12.016	222.673	0	0	0	0	0	5	80
Virginia pine	88	641	3.2	0.516	6.673	57.119	0	0	0	0	5	5	90
Baldcypress	12	68	1.0	0.436	2.007	3.348	0	0	0	0	0	5	10
Eastern hemlock	10	34	0.4	0.271	3.039	7.686	0	0	0	0	0	0	5
Boxelder	12	35	2.6	0.837	2.364	6.183	0	0	0	0	5	5	20
Red maple	234	879	1.6	0.169	4.230	28.946	0	0	0	0	0	5	40
Sugar maple	39	106	2.0	0.548	3.309	15.428	0	0	0	0	5	5	25
Sweet birch	18	45	2.0	0.711	1.914	3.897	0	0	0	0	5	5	15
River birch	18	37	3.1	0.699	2.221	6.601	0	0	0	0	5	5	20
American hornbeam	24	54	2.8	0.926	4.990	30.860	0	0	0	0	5	5	40
Pignut hickory	59	137	1.2	0.220	1.670	1.840	0	0	0	0	0	5	10
Shagbark hickory	26	57	2.1	1.270	7.244	53.796	0	0	0	0	0	5	80
Mockernut hickory	80	190	2.3	0.506	7.788	76.640	0	0	0	0	5	5	75
Hackberry	8	37	4.7	1.437	2.909	8.750	0	0	0	0	5	10	40
Flowering dogwood	60	103	4.6	1.127	5.882	37.964	0	0	0	0	5	10	90
Persimmon	19	34	2.1	0.661	2.920	10.622	0	0	0	0	5	5	20
American beech	43	95	0.7	0.206	2.903	8.297	0	0	0	0	0	5	10
White ash	25	52	2.1	0.555	2.012	3.996	0	0	0	0	5	5	15
Green ash	42	125	3.3	0.713	3.683	19.059	0	0	0	0	5	10	45
American holly	19	50	1.3	0.399	1.128	-0.759	0	0	0	0	5	5	5
Sweetgum	244	939	2.3	0.298	8.476	90.445	0	0	0	0	5	5	95
Yellow-poplar	215	766	1.0	0.167	6.921	81.346	0	0	0	0	0	5	45
Sweetbay	30	102	1.6	0.324	1.272	0.579	0	0	0	0	5	5	10
Water tupelo	14	68	2.7	0.984	1.872	3.178	0	0	0	0	5	10	20
Blackgum	146	294	1.8	0.208	2.486	7.648	0	0	0	0	5	5	20
Swamp tupelo	25	184	2.1	0.538	1.969	4.445	0	0	0	0	5	5	20
Eastern hophornbeam	20	31	1.1	0.427	1.379	-0.109	0	0	0	0	0	5	5
Sourwood	101	261	2.6	0.523	5.288	39.170	0	0	0	0	5	5	55
Redbay	9	26	1.7	0.701	0.687	-1.662	0	0	0	0	5	5	5
Sycamore	14	25	1.8	1.305	4.201	18.632	0	0	0	0	0	5	30
Black cherry	83	132	3.6	0.696	3.760	20.436	0	0	0	0	5	10	50
White oak	184	633	3.1	0.346	7.479	80.168	0	0	0	0	5	5	95
Scarlet oak	78	232	4.0	0.484	2.762	11.380	0	0	0	5	5	10	35
Southern red oak	93	220	3.2	0.402	1.802	4.164	0	0	0	0	5	10	25
Laurel oak	23	70	1.8	0.471	1.170	0.400	0	0	0	0	5	5	10
Water oak	134	390	3.2	0.349	2.135	7.315	0	0	0	0	5	7.5	30
Willow oak	38	91	2.4	0.492	1.198	2.038	0	0	0	0	5	5	15
Chestnut oak	86	629	2.7	0.399	8.729	133.572	0	0	0	0	5	5	95
Northern red oak	73	197	4.1	0.489	3.324	17.109	0	0	0	5	5	10	40
Post oak	58	105	3.1	0.479	2.640	10.075	0	0	0	0	5	5	25
Black oak	85	170	4.1	0.504	1.731	3.958	0	0	0	2.5	5	10	30
Live oak	13	30	3.2	1.161	1.174	0.575	0	0	0	0	5	10	15
Black locust	28	49	2.8	0.645	1.274	1.016	0	0	0	0	5	10	15
Sassafras	19	42	3.9	0.810	2.768	10.955	0	0	0	5	5	10	30
Winged elm	28	54	1.5	0.430	3.634	17.825	0	0	0	0	0	5	20
American elm	27	46	4.1	1.266	4.108	17.213	0	0	0	0	5	5	50
Slippery elm	18	36	2.2	0.592	1.292	0.384	0	0	0	0	5	10	10

[a] The mean and standard error calculations consider the clustering of trees on plots.

[b] No data collected for 1996.

[c] See appendix for scientific names.

Table 4—Mean foliage transparency and other statistics[a] for all live trees > 4.9 inches d.b.h., by species for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999[b]

Species[c]	Plots	Trees	Mean	Standard error	Skewness	Kurtosis	Minimum	Percentile 10th	25th	50th	75th	90th	Maximum
	- - number - -		- - - percent - - -				- - - - - - - - - - - - - percent - - - - - - - - - - - - -						
Eastern redcedar	50	111	17.3	1.465	1.619	6.129	0	10	10	15	20	25	65
Shortleaf pine	91	357	18.2	0.857	0.519	0.253	0	10	15	20	20	25	40
Slash pine	38	444	16.3	0.544	0.907	4.001	5	10	15	15	20	20	40
Longleaf pine	32	169	17.9	1.123	0.258	1.253	0	15	15	15	20	25	30
Pond pine	9	65	21.1	2.748	0.334	-0.601	10	10	15	20	30	30	40
Eastern white pine	33	134	21.7	1.157	3.439	20.230	5	15	15	20	25	30	95
Loblolly pine	254	4,355	17.8	0.424	0.795	4.376	0	10	15	15	20	25	75
Virginia pine	88	641	23.4	1.098	1.541	4.125	5	15	15	20	30	35	75
Baldcypress	12	68	19.6	0.424	0.412	0.902	10	15	15	20	22.5	25	35
Eastern hemlock	10	34	20.6	1.272	0.098	-0.802	10	15	15	20	25	25	30
Boxelder	12	35	14.1	1.366	0.363	-0.855	5	10	10	15	20	20	25
Red maple	234	879	16.3	0.332	0.792	5.272	0	10	15	15	20	25	60
Sugar maple	39	106	15.8	1.081	2.796	17.503	0	10	15	15	20	25	60
Sweet birch	18	45	19.2	1.445	4.420	24.793	10	10	15	20	20	25	75
River birch	18	37	20.4	1.521	0.513	0.310	5	10	15	20	25	30	40
American hornbeam	24	54	14.7	0.988	0.432	0.376	5	10	10	15	20	20	30
Pignut hickory	59	137	14.5	0.498	0.844	1.035	5	10	10	15	15	20	30
Shagbark hickory	26	57	14.9	0.860	-0.273	1.151	0	10	10	15	20	20	25
Mockernut hickory	80	190	13.9	0.453	1.134	4.764	5	10	10	15	15	20	40
Hackberry	8	37	21.9	2.233	2.138	6.412	10	15	15	20	25	30	60
Flowering dogwood	60	103	16.1	0.723	3.032	17.802	5	10	15	15	20	20	60
Persimmon	19	34	17.4	0.918	-0.206	-0.549	10	10	15	20	20	20	25
American beech	43	95	14.8	0.544	0.174	1.382	5	10	15	15	15	20	30
White ash	25	52	18.6	0.940	0.172	-0.474	10	15	15	20	20	25	30
Green ash	42	125	19.3	1.095	1.237	2.873	10	15	15	20	20	25	45
American holly	19	50	17.0	0.890	3.829	21.182	5	10	10	15	20	25	75
Sweetgum	244	939	13.6	0.307	0.508	3.763	0	10	10	15	15	20	50
Yellow-poplar	215	766	14.4	0.406	0.026	1.868	0	10	10	15	15	20	40
Sweetbay	30	102	14.0	1.353	-0.757	2.129	0	10	15	15	15	20	30
Water tupelo	14	68	16.2	0.718	0.101	-0.483	10	10	15	15	20	20	25
Blackgum	146	294	15.4	0.483	0.335	1.867	0	10	10	15	20	20	40
Swamp tupelo	25	184	14.6	1.468	-0.053	1.689	0	5	10	15	15	20	35
Eastern hophornbeam	20	31	13.7	1.193	0.248	-0.602	5	5	10	15	20	20	25
Sourwood	101	261	15.9	0.505	0.051	0.119	5	10	15	15	20	20	30
Redbay	9	26	17.9	1.214	-0.515	-0.068	10	10	15	20	20	20	25
Sycamore	14	25	16.2	2.046	1.041	1.138	5	10	10	15	20	25	35
Black cherry	83	132	19.5	0.892	2.507	12.073	0	10	15	20	25	25	70
White oak	184	633	15.3	0.467	2.615	20.484	0	10	10	15	20	20	75
Scarlet oak	78	232	17.5	0.719	1.357	9.140	5	10	15	20	20	25	60
Southern red oak	93	220	15.1	0.633	-0.462	0.838	0	10	15	15	20	20	25
Laurel oak	23	70	13.4	1.102	0.432	1.354	5	5	10	15	15	20	30
Water oak	134	390	14.5	0.431	0.671	3.765	0	10	10	15	15	20	45
Willow oak	38	91	15.4	0.921	-0.429	0.211	0	5	10	15	20	20	30
Chestnut oak	86	629	18.5	1.188	4.023	24.269	0	10	15	15	20	25	95
Northern red oak	73	197	17.3	0.885	2.576	16.910	0	10	15	15	20	25	70
Post oak	58	105	15.7	0.539	-0.448	2.784	0	10	15	15	20	20	30
Black oak	85	170	16.4	0.623	2.396	20.246	0	10	15	15	20	20	65
Live oak	13	30	13.7	1.447	0.818	0.164	5	10	10	12.5	15	20	25
Black locust	28	49	19.2	1.671	-0.383	0.931	0	10	15	20	25	25	35
Sassafras	19	42	19.4	1.114	0.127	-0.561	10	15	15	20	25	25	30
Winged elm	28	54	17.5	0.950	-0.368	0.814	0	10	15	15	20	25	30
American elm	27	46	19.7	1.723	4.282	24.231	5	10	15	20	20	25	85
Slippery elm	18	36	16.2	0.906	1.011	2.267	10	10	15	15	20	20	30

[a] The mean and standard error calculations consider the clustering of trees on plots.
[b] No data collected for 1996.
[c] See appendix for scientific names.

A second assumption of the *t*-test and ANOVA is an assumption of equal variance (homoscedasticity) among the populations being compared. It is useful to note violations of this assumption because the two-sample *t*-test can be formulated to accommodate unequal variances (heteroscedasticity) (Montgomery 1997). Since no specific hypothesis tests are included here, tests for equal variance among species or species groups were not performed. As with the assumption of normality, analyses of variance are fairly robust against heteroscedasticity and may be applied to populations with different variances as long as the sample sizes of the compared groups are about equal.

Accommodating the FIA Sampling Design

Descriptive statistics for and inferential testing of the crown condition data must correctly account for the FIA sampling design in which trees are clustered on plots. The clustering of trees on plots affects the manner in which the overall variance in the data must be allocated. That is, the covariance among trees located on the same plot must be taken into consideration when calculating descriptive statistics or performing hypothesis tests. The clustering often results in unequal sample sizes among the groups under comparison (an unbalanced design). As mentioned above, the *t*-test and ANOVA are robust against nonnormality and heteroscedasticity only if the sample sizes are about equal; therefore, extra attention must be given to the specification of the hypothesis tests when sample sizes are unequal. Statistical software packages are capable of handling unbalanced or clustered data, or both, by means of blocked or nested designs, but the specific structure of the hypothesis tests must be declared by the analyst.

Interest in the Poorest and Best Crowns

The hypothesis tests so often employed to test for differences between two groups make primary use of the distribution's central tendency and spread. Unfortunately, only comparing differences in central tendencies may overlook important features of the differences among groups. This is especially true for the crown condition indicators where it is differences across the entire distribution, particularly toward the distribution tails, that are important in the detection of potential forest health problems. Ideally, comparisons of crown condition should incorporate analyses that provide a broader description of the overall distribution than is provided by the mean and variance alone. FIA has previously categorized the distribution of trees into discrete classes of "good, average, and poor" (Bechtold and others 1992) and compared groups based upon the proportion of observations in each of these classes (Stoyenoff and others 1998). This approach improves upon examining central tendency alone, but it has obvious limitations if the same set of thresholds is applied to all species. This is commonly the case because species-level, biologically based thresholds have yet to be developed for the crown indicator.

When thresholds are applied universally across species, shifts of observations into the poor category over time indicate declines in forest health; however, since some species tend to have "better" crowns than other species, species-specific declines could go undetected. Figure 12, which shows the cumulative (empirical) distribution function of one of the most extreme crown density distributions, that of eastern hemlock, illustrates this problem. Eastern hemlock tends to have very dense crowns, so the trees are concentrated in the good and average categories. For this species then, an increase in the proportion of observations in the average category would be the first signal of declining conditions, whereas analyses primarily focused on detecting increases in the poor category would overlook this early indication of trouble.

A second limitation of utilizing good, average, and poor classes is that information in the extreme tails of the distribution is lost when the data are grouped into so few categories. Since the crown condition indicators are recorded in 5-percent increments, it would be possible to leave the data ungrouped and test for differences among the 21 categories using categorical methods, e.g., chi-square tests. However, in the ungrouped data the number of categories with zero observations can be excessive. This

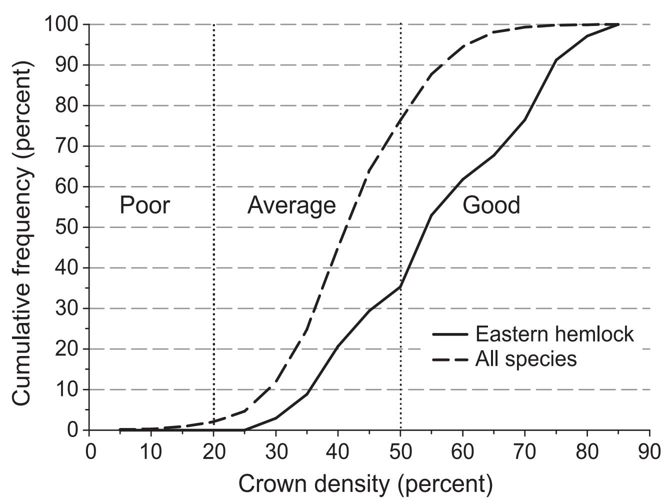

Figure 12—Thresholds of crown condition divide the cumulative (empirical) distribution function for eastern hemlock crown density into categories of poor, average, and good condition for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999.

may give rise to a sparse contingency table, and testing differences among contingency tables with many zeroes can lead to errant results (Agresti 1996). The potential for this is especially great for crown dieback and foliage transparency because observations of these indicators tend to concentrate in a small range of the overall possible values (figs. 3 and 4).

In an effort to overcome the limitations of grouping the crown condition data and of only considering measures of central tendency when testing for differences between two groups, Randolph (2004) calculated the differences between selected percentiles of two groups' empirical distribution functions and employed bootstrapping to calculate simultaneous confidence intervals for the differences. Calculation of confidence intervals for the differences between the 10th, 25th, 50th, 75th, and 90th percentiles made differences in the extreme tails of the distributions, as well as in the degree of central tendency, detectable.

Distinguishing Biological and Statistical Significance

Determining statistically significant differences between two groups is only the first step in describing forest health conditions. Reporting the status of and changes in forest health must go beyond stating statistical significance and place any detected differences in the context of biological significance. Although researchers in the past have had varying success in relating crown condition to tree vigor as measured by radial or basal area growth (e.g., Anderson and Belanger 1987; Grano 1957; Juknys and Augustaitis 1998; Kenk 1993), the inherent assumption is that crown condition does indeed reflect overall tree health. Because little is known about the relationship between crown condition and tree vitality, thresholds among health categories are now based on isolating observations in the tails of statistical distributions. The difficulty with such thresholds is that even in the absence of a problem some observations are designated as poor (Zarnoch and others 2004). Thus, as repeated measurements from the phase 3 plots become available it will be necessary to evaluate the relationship between crown condition and other measures of vitality so that statistically significant changes in crown condition can be placed in a biological context.

Conclusion

Several factors must be addressed in the analysis of the phase 3 crown condition indicators. These factors range from intrinsic species differences in crown form to the sampling procedure used to survey the forest. Incorrect conclusions may be drawn about forest health if any one of these factors is ignored. Fortunately, most of the factors highlighted here can be accommodated with available statistical methods, but it is essential that the analytical techniques chosen are appropriate given the data and the objectives of the analysis. Otherwise, invalid inferences may be drawn from the results. Specification of analytical techniques for the crown condition data is underway,[2] leaving the determination of biological thresholds as the most significant remaining issue. As FIA forest health assessment continues, development of these thresholds will be investigated. In the meantime, the crown condition summaries presented here establish a baseline against which changing conditions over time may be referenced.

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Appendix

Common and scientific names for the species included in the individual analyses for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, 1995 through 1999[1]

Common name	Scientific name[2]	Common name	Scientific name[2]
Softwoods		Hardwoods (continued)	
Eastern redcedar	*Juniperus virginiana*	Sweetgum	*Liquidambar styraciflua*
Shortleaf pine	*Pinus echinata*	Yellow-poplar	*Liriodendron tulipifera*
Slash pine	*P. elliottii*	Sweetbay	*Magnolia virginiana*
Longleaf pine	*P. palustris*	Water tupelo	*Nyssa aquatica*
Pond pine	*P. serotina*	Blackgum	*N. sylvatica*
Eastern white pine	*P. strobus*	Swamp tupelo	*N. sylvatica var. biflora*
Loblolly pine	*P. taeda*	Eastern hophornbeam	*Ostrya virginiana*
Virginia pine	*P. virginiana*	Sourwood	*Oxydendrum arboretum*
Baldcypress	*Taxodium distichum*	Redbay	*Persea borbonia*
Eastern hemlock	*Tsuga canadensis*	Sycamore	*Platanus occidentalis*
		Black cherry	*Prunus serotina*
Hardwoods		White oak	*Quercus alba*
Boxelder	*Acer negundo*	Scarlet oak	*Q. coccinea*
Red maple	*A. rubrum*	Southern red oak	*Q. falcata var. falcata*
Sugar maple	*A. saccharum*	Laurel oak	*Q. laurifolia*
Sweet birch	*Betula lenta*	Water oak	*Q. nigra*
River birch	*B. nigra*	Willow oak	*Q. phellos*
American hornbeam	*Carpinus caroliniana*	Chestnut oak	*Q. prinus*
Pignut hickory	*Carya glabra*	Northern red oak	*Q. rubra*
Shagbark hickory	*C. ovata*	Post oak	*Q. stellata*
Mockernut hickory	*C. tomentosa*	Black oak	*Q. velutina*
Hackberry	*Celtis occidentalis*	Live oak	*Q. virginiana*
Flowering dogwood	*Cornus florida*	Black locust	*Robinia pseudoacacia*
Persimmon	*Diospyros virginiana*	Sassafras	*Sassafras albidum*
American beech	*Fagus grandifolia*	Winged elm	*Ulmus alata*
White ash	*Fraxinus americana*	American elm	*U. americana*
Green ash	*F. pennsylvanica*	Slippery elm	*U. rubra*
American holly	*Ilex opaca*		

[1] No data collected for 1996.
[2] Little (1979).

Randolph, KaDonna C. 2006. Descriptive statistics of tree crown condition in the Southern United States and impacts on data analysis and interpretation. Gen. Tech. Rep. SRS–94. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

The U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program (FIA) utilizes visual assessments of tree crown condition to monitor changes and trends in forest health. This report describes and discusses distributions of three FIA crown condition indicators (crown density, crown dieback, and foliage transparency) for trees in the Southern United States. Descriptive statistics are presented for all trees combined, by hardwood and softwood species groups, and for 53 individual species. Implications of these characteristics and other factors for the analysis of the phase 3 crown condition indicators are discussed.

Keywords: Crown density, crown dieback, FIA, foliage transparency, forest health.

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