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Descriptive Statistics of Tree Crown Condition in the North Central United States

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Cover photo: Paper birch (*Betula papyrifera*), Michigan. (photo by KaDonna Randolph, Southern Research Station)

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Abstract

The U.S. Forest Service Forest Inventory and Analysis (FIA) Program uses visual assessments of tree crown condition to monitor changes and trends in forest health. This report describes four crown condition indicators (crown dieback, crown density, foliage transparency, and sapling crown vigor) measured in Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin between 1996 and 1999. Descriptive statistics are presented by species and FIA species group. Inter- and intra-species variation, crown condition stressors, and statistical issues that should be considered when analyzing and interpreting the crown condition data are discussed.

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

Introduction

Tree crown condition is an important visual indicator of tree and forest health. A tree's crown is its principal engine for energy capture. Therefore, trees with full, vigorous crowns are generally associated with higher growth rates due to an increased capacity for photosynthesis. When crowns become degraded, photosynthetic capacity is reduced. Crown degradation is typically the result of past and present stressors such as insects, diseases, weather events (e.g. tornadoes and ice storms), drought, senescence, and competition or other stand conditions (Kenk 1993), and when severe enough, may result in tree mortality (Lawrence and others 2002).

Broad-scale assessment of tree crown condition was initiated by the U.S. Forest Service Forest Health Monitoring (FHM) Program when ground inventory plots were established in six Northeastern States in 1990 (Riitters and Tkacz 2004). Plots were added throughout the 1990s and by the end of the decade ground plots had been established in 32 States. In 1999, the network of FHM ground plots was integrated as the "phase 3" effort of the U.S. Forest Service enhanced Forest Inventory and Analysis (FIA) Program (Riitters and Tkacz 2004). Since that time, FIA has continued to assess tree crown condition as well as many of the other variables initiated by FHM.

At the State level, the 5-year FIA reports mandated by the 1998 Farm Bill [Agricultural Research, Extension, and Education Reform Act of 1998] (Public Law 105-185) are a primary outlet for reporting tree crown condition. These reports describe the current status and trends in forest extent and condition, and typically present data summaries in tabular format by species or species group (e.g. Woodall and others 2005, Miles and Brand 2007). The purpose of this crown condition summary is to document the species-specific crown conditions collected by FHM in the North Central United States (fig. 1) so that the FIA State-level summaries can be understood in their regional historical context. Stoyenoff and others (1998) reported on three crown condition indicators (crown dieback, foliage transparency, and crown density) in their summary of FHM in the North Central States. They presented averages for conditions in 1994, 1995, and 1996 and frequency histograms for conditions in 1996, by hardwood and conifer groups. Though based on a portion of the same data, this report goes beyond their summary by presenting detailed descriptive statistics at the species level. Similar regional summaries for the Northeastern (Randolph and others 2010b), Southern (Randolph 2006), Interior West (Randolph and Thompson 2010), and West Coast (Randolph and others 2010a) States are also available.

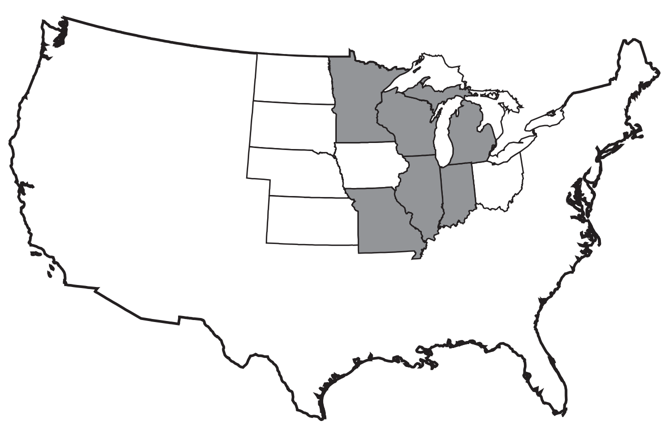

Figure 1—North Central States included in the crown condition summary are shaded gray.

Methods

Data Collection

In order to have complete statewide coverage for as many North Central States as possible, we elected to summarize the crown condition data collected by FHM between 1996 and 1999 to serve as a baseline against which more recent data can be referenced. No modifications were made to the data collection protocols in the transition from FHM to FIA administration for the four crown condition indicators being summarized, so the data from the FHM period is compatible with the data now collected by FIA. The data for this summary consisted of the crown condition assessments from all forested FHM plots in Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin (table 1). Each inventory plot is a cluster of four 1/24-acre circular subplots with subplot centers located 120 feet apart (U.S. Department of Agriculture Forest Service 1999). The four crown condition indicators included in this summary are: (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; (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; and (4) sapling crown vigor—a visual measure designed to categorize saplings into three broad classes based on the amount and condition of the foliage present (Schomaker and others 2007). Crown density, crown dieback, and foliage transparency (fig. 2) were measured for every live tree ≥ 5.0 inches in diameter at breast height (d.b.h.) on each subplot. Sapling crown vigor was assessed for every live tree (sapling) with d.b.h. ≥ 1.0 inch but < 5.0 inches on a 1/300-acre microplot located 12 feet east from each subplot center.

Table 1—Number of FHM plots with at least one accessible forested condition by State and year

	Year				
State	1996	1997	1998	1999	Total
			number		
Illinois	—	17	10	13	40
Indiana	11	7	9	10	37
Michigan	20	35	31	46	132
Minnesota[a]	—	53	29	29	111
Missouri	—	—	—	116	116
Wisconsin	12	23	28	26	89
All States	43	135	107	240	525

FHM = Forest Health Monitoring.
— = no sample.
[a] Intensification plots are not included.

All four indicators were visually assessed by two-person field crews. Crown density, crown dieback, and foliage transparency were measured in 5-percent increments and recorded as a two-digit code: 00, 05, 10… 99, where the code represents the upper limit of the class, e.g. 1 to 5 percent is code 05 and 96 to 100 percent is code 99. Sapling crown vigor was recorded in one of three classes: good (vigor class 1), fair (vigor class 2), and poor (vigor class 3). Though foliage transparency and crown density are similar measures, they 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, foliated 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. Within a species, higher crown density values, lower foliage transparency values, and lower crown dieback values typically are associated with better tree health. More detailed descriptions of the crown condition indicators are available in Schomaker and others (2007).

Data Summary

Ratio-of-means (ROM) estimators (Cochran 1977) were used to estimate the tree crown condition means and standard errors for all species combined, hardwood and softwood groups, FIA species groups, and individual species with at least 25 observations. Some of the FHM plots were measured more than once between 1996 and 1999, but only the latest measurement was included in the summary. To maintain an equal sampling intensity in all States, intensification plots in Minnesota were excluded. Estimates were made with the SAS® procedure SURVEYMEANS (An and Watts 1998) and the following statement options: (1) CLUSTER—to designate the primary sampling unit of the survey, i.e., the plot; (2) RATIO—to request ROM estimates; and (3) DOMAIN—to identify the subpopulations, or domains, of interest, e.g. hardwoods and softwoods. Other descriptive statistics (minimum, maximum, and median or 90th percentile) also were calculated for the trees. Summaries by FIA species group

Figure 2—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).

are presented for completeness (tables A.1 through A.3) and to allow flexibility in future reporting. However, discussion of observed tree crown condition primarily focuses on individual species. ROM estimators also were used to estimate the percentage of saplings in each vigor class and associated standard errors for all species combined, hardwood and softwood groups, and FIA species groups. Sample sizes were not adequate to summarize the saplings at the individual species level.

Results

Tree Crown Condition

Tree crown condition was assessed for 10,985 trees on 514 of the 525 forested plots. A total of 87 individual species was observed, and of these, 54 species had 25 or more observations. For all trees combined, the range of possible values from 0 to 99 percent was observed for crown dieback and foliage transparency, though the majority of values tended to concentrate in a small portion of the possible range. Ninety-six percent of the trees exhibited < 15 percent crown dieback (fig. 3) and 92 percent had foliage transparency < 30 percent (fig. 4). The values observed for crown density ranged from 0 to 95. Crown densities were concentrated in the middle of this range; 87 percent of the trees had a crown density of 35 to 65 percent (fig. 5). On average, the crown conditions of the softwood and hardwood groups were very similar. Overall, mean crown conditions were 3.9 percent crown dieback, 19.5 percent foliage transparency, and 47.7 percent crown density (table 2).

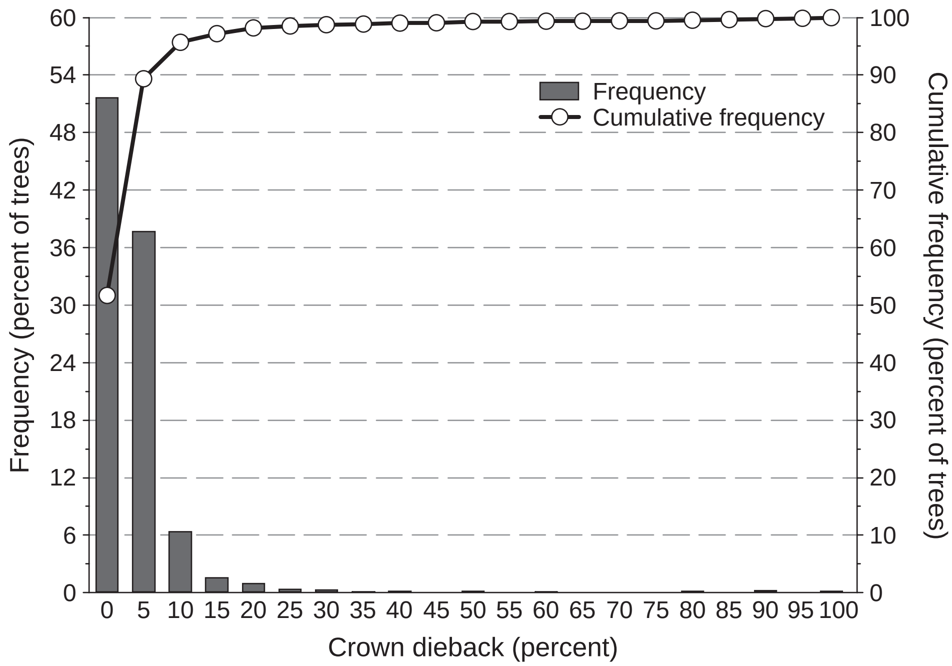

Figure 3—Crown dieback frequency histogram and cumulative frequency distribution for all trees combined for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996−99.

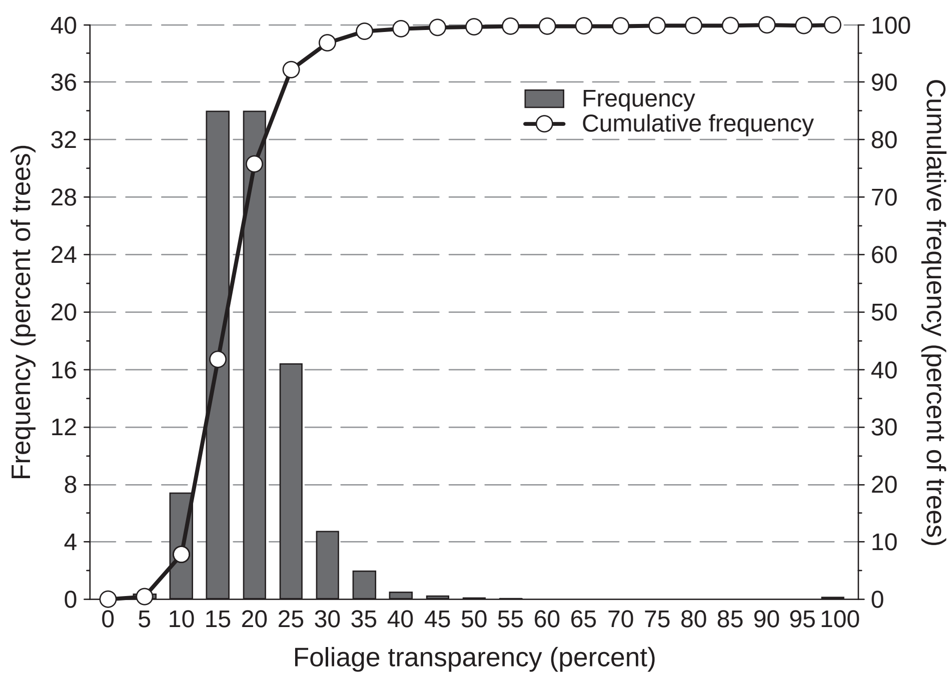

Figure 4—Foliage transparency frequency histogram and cumulative frequency distribution for all trees combined for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996−99.

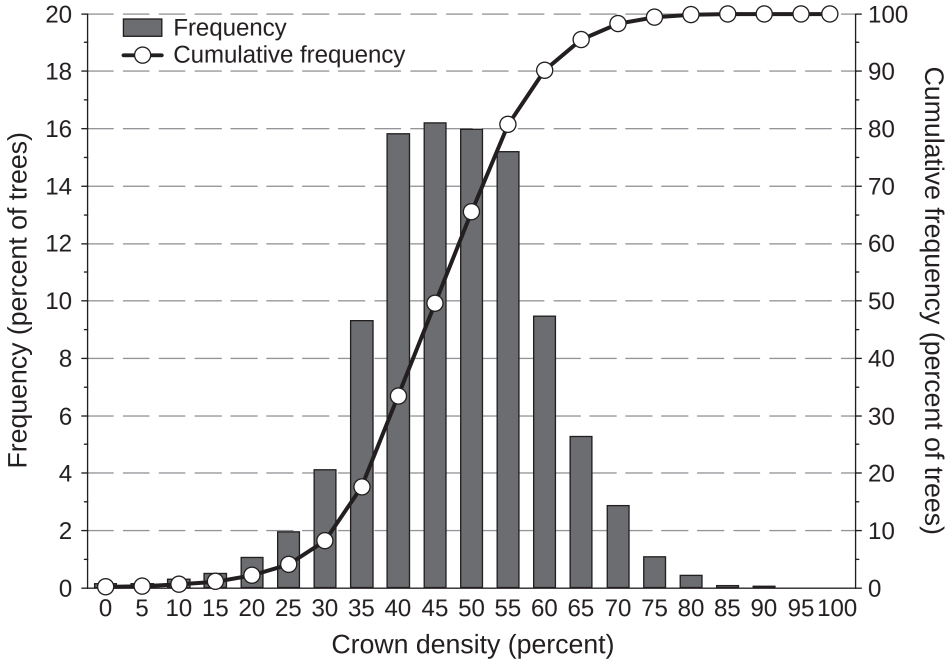

Figure 5—Crown density frequency histogram and cumulative frequency distribution for all trees combined for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99.

Table 2—Mean crown attributes and other statistics[a] for all live trees ≥ 5.0 inches diameter by crown condition indicator and species group for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99

Crown condition indicator and species group	Plots[b]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	number	*number*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*
Crown density									
Softwoods	223	2,893	47.0	0.8	45.5	48.5	0	45	95
Hardwoods	481	8,092	47.9	0.3	47.3	48.5	0	50	90
All trees	514	10,985	47.7	0.3	47.0	48.3	0	50	95
Crown dieback									
Softwoods	223	2,893	3.3	0.5	2.3	4.3	0	0	99
Hardwoods	481	8,092	4.2	0.3	3.6	4.8	0	5	99
All trees	514	10,985	3.9	0.3	3.5	4.4	0	0	99
Foliage transparency									
Softwoods	223	2,893	19.5	0.5	18.6	20.4	5	20	99
Hardwoods	481	8,092	19.5	0.2	19.0	19.9	0	20	99
All trees	514	10,985	19.5	0.2	19.1	19.9	0	20	99

SE = standard error.

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

[b] Total number of forested plots on which trees were measured. Plot totals are not cumulative because multiple species may occur on any given plot.

A broad range of average conditions was exhibited for each of the crown condition indicators among the species. Mean crown dieback ranged from 0.2 percent for eastern redcedar (*Juniperus virginiana*) to 11.2 percent for silver maple (*Acer saccharinum*) (table 3). Mean foliage transparency ranged from 14.2 percent for mockernut hickory (*Carya alba*) to 27.6 percent for honeylocust (*Gleditsia triacanthos*) (table 4), and mean crown density ranged from 41.2 percent for honeylocust to 55.0 percent for yellow-poplar (*Liriodendron tulipifera*) (table 5).

Sapling Crown Vigor

Crown vigor was assessed for 2,759 saplings on 439 of the 525 forested plots. The percentage of saplings in each vigor category was about the same for both the softwood and hardwood groups. Overall, 73.1 percent of the sapling crowns were categorized as good (table 6). Among the softwood species groups with at least 25 observations, the eastern white and red pines (*Pinus strobus* and *P. resinosa*) group had the highest percentage of saplings in the good category (77.1 percent) and the other eastern softwoods group had the lowest percentage of saplings in the good category (69.4 percent). Likewise, the eastern white and red pines group had the lowest percentage of saplings in the poor category (0.0 percent), whereas the other eastern softwoods group had the highest percentage of saplings in the poor category (4.9 percent) (table 6). Among the hardwood species groups with at least 25 observations, the select red oaks (*Quercus* spp.) group had the highest percentage of saplings in the good category (88.5 percent) and the basswood (*Tilia* spp.) group had the lowest percentage of saplings in the good category (55.6 percent). The other eastern hard hardwoods group had the highest percentage of trees in the poor category (8.1 percent), whereas the select white oaks (*Q.* spp.) and select red oaks groups had no trees in the poor category (table 6).

Table 3—Mean crown dieback and other statistics[a] for all live trees ≥ 5.0 inches diameter by species for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99

					95% confidence				
Species[b]	Plots[c]	Trees	Mean	SE	Lower	Upper	Mini-mum	90th percentile	Maxi-mum
	- - - *number* - - -		- - - *percent* - - -						
Softwoods									
Eastern redcedar	35	186	0.2	0.1	0.1	0.4	0	0.0	15
Red pine	25	486	0.6	0.3	-0.1	1.2	0	5.0	10
Shortleaf pine	12	96	0.8	0.3	0.2	1.4	0	5.0	10
Eastern white pine	33	177	1.5	0.6	0.3	2.7	0	5.0	20
White spruce	27	127	2.3	1.0	0.4	4.2	0	5.0	50
Tamarack	21	135	2.6	1.0	0.7	4.6	0	5.0	30
Eastern hemlock	15	61	2.8	1.2	0.4	5.2	0	10.0	15
Balsam fir	84	411	2.9	0.5	1.9	3.9	0	5.0	70
Black spruce	40	288	3.3	0.8	1.7	4.9	0	5.0	80
Northern white-cedar	43	750	6.4	1.4	3.5	9.2	0	15.0	99
Jack pine	19	148	6.7	1.8	3.1	10.2	0	15.0	25
Hardwoods									
Black hickory	25	63	1.0	0.3	0.4	1.7	0	5.0	10
Common persimmon	8	26	1.2	0.7	-0.2	2.5	0	5.0	10
Hackberry	24	94	1.5	0.4	0.8	2.2	0	5.0	5
Mockernut hickory	27	45	1.7	0.5	0.7	2.7	0	5.0	10
Shagbark hickory	41	95	1.7	0.4	0.9	2.6	0	5.0	15
Black locust	11	38	1.8	0.4	1.1	2.6	0	5.0	5
American beech	19	65	1.9	0.5	1.0	2.8	0	5.0	10
Pignut hickory	14	29	2.2	0.5	1.2	3.3	0	5.0	10
Yellow-poplar	11	45	2.4	0.9	0.7	4.2	0	10.0	15
Sugar maple	123	1,093	2.5	0.3	1.9	3.1	0	5.0	80

continued

Table 3—Mean crown dieback and other statistics[a] for all live trees ≥ 5.0 inches diameter by species for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99 (continued)

Species[b]	Plots[c]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	90th percentile	Maximum
	- - - *number* - - -		- - - *percent* - - -						
Hardwoods (continued)									
Bitternut hickory	30	65	2.5	1.1	0.4	4.7	0	5.0	60
White oak	114	569	2.6	0.3	1.9	3.2	0	5.0	99
Black walnut	31	64	2.7	1.4	-0.1	5.6	0	5.0	90
Sassafras	24	59	2.9	0.7	1.5	4.3	0	10.0	20
Scarlet oak	27	61	3.0	0.6	1.9	4.2	0	5.0	15
Chinkapin oak	18	60	3.3	0.8	1.7	4.8	0	5.0	35
Bigtooth aspen	37	182	3.4	0.4	2.6	4.1	0	5.0	20
Quaking aspen	116	817	3.5	0.4	2.8	4.2	0	5.0	50
Post oak	53	212	3.7	0.9	1.9	5.6	0	5.0	95
Black willow	10	25	3.8	0.9	2.0	5.6	0	10.0	10
Blackjack oak	17	34	4.0	0.6	2.9	5.1	0	10.0	10
Slippery elm	34	76	4.1	0.4	3.3	4.9	0	10.0	20
Eastern hophornbeam	24	40	4.1	0.6	2.9	5.3	0	10.0	10
Paper birch	94	419	4.1	0.3	3.5	4.7	0	5.0	35
Shingle oak	12	30	4.2	0.9	2.4	6.0	0	10.0	15
Black oak	86	396	4.2	0.4	3.3	5.0	0	10.0	60
Red maple	132	725	4.2	0.5	3.2	5.2	0	10.0	99
Honeylocust	13	25	4.2	1.3	1.7	6.7	0	10.0	30
Green ash	33	105	4.4	1.3	1.8	7.0	0	5.0	99
American sycamore	17	40	4.6	0.7	3.2	6.1	0	10.0	15
Bur oak	46	182	4.6	0.6	3.4	5.9	0	10.0	25
Black cherry	56	120	4.7	0.9	2.8	6.5	0	10.0	90
Pin oak	8	25	4.8	0.8	3.2	6.4	0	5.0	15
White ash	68	213	4.9	0.8	3.4	6.4	0	10.0	80
Yellow birch	29	80	5.2	0.7	3.8	6.6	0	10.0	20
Northern red oak	98	389	5.4	0.9	3.7	7.1	0	10.0	85
American elm	104	269	6.1	1.0	4.1	8.0	0	10.0	90
Balsam poplar	31	89	6.1	1.0	4.2	8.0	0	15.0	40
Black ash	46	320	6.7	1.0	4.7	8.6	0	12.5	99
Northern pin oak	13	41	7.9	1.5	5.1	10.8	0	15.0	30
Boxelder	19	108	8.3	2.0	4.4	12.1	0	10.0	99
Basswood	62	318	9.6	5.2	-0.7	19.8	0	10.0	95
Silver maple	12	103	11.2	6.3	-1.2	23.6	0	25.0	99

SE = standard error.

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

[b] See appendix table A.4.

[c] Total number of forested plots on which the species was measured.

Table 4—Mean foliage transparency and other statistics[a] for all live trees ≥ 5.0 inches diameter by species for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99

Species[b]	Plots[c]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - *number* - - -		- - - - - - - - - -	- - - -	- - - - -	*percent*	- - - - -	- - - - -	- - - - -
Softwoods									
White spruce	27	127	15.9	0.7	14.6	17.3	5	15.0	25
Black spruce	40	288	16.2	0.7	14.7	17.6	5	15.0	35
Balsam fir	84	411	17.8	0.5	16.9	18.7	5	15.0	35
Shortleaf pine	12	96	18.2	1.3	15.6	20.8	10	20.0	45
Red pine	25	486	18.5	0.7	17.1	20.0	10	20.0	30
Eastern redcedar	35	186	19.1	1.2	16.8	21.4	5	20.0	35
Tamarack	21	135	19.9	2.1	15.8	24.0	10	15.0	65
Eastern white pine	33	177	20.6	1.1	18.5	22.7	10	20.0	35
Eastern hemlock	15	61	20.8	2.5	15.9	25.8	10	20.0	35
Jack pine	19	148	21.7	1.7	18.4	25.0	10	20.0	40
Northern white-cedar	43	750	22.4	1.0	20.4	24.4	5	20.0	99
Hardwoods									
Mockernut hickory	27	45	14.2	0.7	12.8	15.6	5	15.0	25
Yellow-poplar	11	45	15.0	1.8	11.4	18.6	5	15.0	30
Black hickory	25	63	15.6	0.7	14.3	17.0	10	15.0	30
Bitternut hickory	30	65	15.7	0.6	14.5	16.9	5	15.0	30
Blackjack oak	17	34	15.9	0.6	14.7	17.1	10	15.0	25
American beech	19	65	16.0	0.8	14.5	17.5	5	15.0	30
Sugar maple	123	1,093	16.3	0.5	15.3	17.3	0	15.0	35
Sassafras	24	59	16.5	0.9	14.7	18.3	5	15.0	35
Pin oak	8	25	16.8	1.3	14.3	19.3	10	15.0	30
Shingle oak	12	30	17.3	1.5	14.4	20.3	10	15.0	55
Shagbark hickory	41	95	17.4	0.8	15.9	19.0	10	15.0	30
Common persimmon	8	26	17.5	0.9	15.7	19.3	15	15.0	30
White oak	114	569	17.7	0.4	16.8	18.5	10	15.0	99
Pignut hickory	14	29	17.9	0.8	16.3	19.6	10	20.0	25
American sycamore	17	40	18.0	0.7	16.5	19.5	10	15.0	30
Yellow birch	29	80	18.5	0.9	16.7	20.3	10	17.5	30
Black walnut	31	64	18.5	0.7	17.1	19.9	10	17.5	35
Scarlet oak	27	61	18.5	0.5	17.6	19.4	15	20.0	25
Red maple	132	725	18.6	0.5	17.7	19.5	10	20.0	99
Eastern hophornbeam	24	40	18.6	0.8	17.1	20.2	10	20.0	30
Chinkapin oak	18	60	18.9	1.0	17.0	20.8	10	20.0	35
Basswood	62	318	19.0	0.7	17.6	20.4	5	20.0	45
Hackberry	24	94	19.1	1.1	16.9	21.2	0	20.0	45
Post oak	53	212	19.3	0.8	17.8	20.8	10	20.0	85
White ash	68	213	19.3	0.6	18.2	20.4	10	20.0	45
Bur oak	46	182	19.3	0.8	17.7	21.0	0	20.0	45
Black oak	86	396	19.5	0.5	18.6	20.5	5	20.0	50
Paper birch	94	419	19.8	0.7	18.5	21.2	5	20.0	60

continued

Table 4—Mean foliage transparency and other statistics[a] for all live trees ≥ 5.0 inches diameter by species for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99 (continued)

Species[b]	Plots[c]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - number - - -		*- percent*	*- - - - - - - - - - - - - - - - - - - -*					
Hardwoods (continued)									
Black ash	46	320	20.2	1.0	18.1	22.2	10	20.0	99
Slippery elm	34	76	20.2	0.6	19.0	21.4	10	20.0	40
Northern pin oak	13	41	21.1	1.5	18.1	24.1	10	20.0	40
Northern red oak	98	389	21.1	0.6	19.9	22.4	10	20.0	50
Balsam poplar	31	89	21.7	0.6	20.5	22.9	15	20.0	45
American elm	104	269	21.9	0.8	20.4	23.4	10	20.0	95
Quaking aspen	116	817	22.3	0.8	20.8	23.8	0	20.0	85
Black locust	11	38	22.4	2.0	18.3	26.4	5	25.0	40
Bigtooth aspen	37	182	22.4	1.3	19.9	24.9	10	20.0	40
Green ash	33	105	22.9	1.6	19.7	26.1	10	20.0	99
Silver maple	12	103	23.1	3.4	16.4	29.8	10	20.0	99
Black cherry	56	120	23.6	1.2	21.2	26.0	10	20.0	75
Black willow	10	25	24.2	1.6	21.1	27.3	15	20.0	40
Boxelder	19	108	24.6	1.8	21.0	28.1	5	20.0	99
Honeylocust	13	25	27.6	2.6	22.5	32.7	15	25.0	60

SE = standard error.

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

[b] See appendix table A.4.

[c] Total number of forested plots on which the species was measured.

Table 5—Mean crown density and other statistics[a] for all live trees ≥ 5.0 inches diameter by species for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99

Species[b]	Plots[c]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - *number* - - -		- - - *percent* - - -						
Softwoods									
Eastern redcedar	35	186	52.9	3.1	46.8	59.1	20	50.0	95
White spruce	27	127	50.4	1.9	46.6	54.2	15	50.0	90
Balsam fir	84	411	50.4	1.0	48.5	52.3	20	50.0	80
Tamarack	21	135	50.0	3.2	43.8	56.3	10	50.0	80
Black spruce	40	288	48.9	1.8	45.4	52.4	15	50.0	85
Red pine	25	486	48.1	2.2	43.7	52.4	10	45.0	85
Eastern white pine	33	177	47.7	2.7	42.5	52.9	15	45.0	75
Shortleaf pine	12	96	45.6	2.0	41.6	49.6	20	45.0	70
Jack pine	19	148	45.1	1.8	41.5	48.7	15	45.0	75
Eastern hemlock	15	61	44.3	2.7	39.0	49.7	25	45.0	65
Northern white-cedar	43	750	41.8	1.3	39.2	44.4	0	40.0	85
Hardwoods									
Yellow-poplar	11	45	55.0	1.9	51.3	58.7	30	55.0	80
Black hickory	25	63	54.0	1.0	52.1	56.0	20	55.0	70
Mockernut hickory	27	45	53.8	1.6	50.6	57.0	15	55.0	65
Pin oak	8	25	53.2	2.6	48.1	58.3	30	50.0	75
Pignut hickory	14	29	53.1	1.9	49.5	56.7	25	55.0	75
Paper birch	94	419	52.8	1.1	50.8	54.9	10	55.0	80
Scarlet oak	27	61	52.0	1.2	49.6	54.5	35	55.0	70
Sugar maple	123	1,093	50.7	0.8	49.2	52.2	5	50.0	80
Shagbark hickory	41	95	50.5	1.4	47.9	53.2	25	50.0	75
Bitternut hickory	30	65	50.3	2.0	46.4	54.2	15	50.0	90
Beech	19	65	50.2	2.7	44.9	55.5	25	50.0	80
Eastern hophornbeam	24	40	49.8	1.5	46.7	52.8	20	50.0	75
White oak	114	569	49.6	0.6	48.3	50.8	0	50.0	80
Hackberry	24	94	49.5	1.7	46.1	52.9	20	50.0	70
Common persimmon	8	26	49.4	1.1	47.3	51.6	20	50.0	70
Shingle oak	12	30	49.3	1.3	46.9	51.8	20	50.0	70
Sassafras	24	59	48.3	2.1	44.2	52.4	20	50.0	80
Quaking aspen	116	817	48.1	1.1	46.0	50.3	10	45.0	85
Black oak	86	396	47.7	0.8	46.1	49.2	10	50.0	85
White ash	68	213	47.6	1.1	45.4	49.8	10	45.0	80
Yellow birch	29	80	47.3	1.3	44.7	49.9	25	47.5	70
Red maple	132	725	47.1	0.9	45.4	48.8	0	45.0	75
Black willow	10	25	47.0	2.3	42.6	51.4	20	45.0	80
Green ash	33	105	46.8	1.9	43.0	50.5	0	45.0	70
Boxelder	19	108	46.7	1.8	43.1	50.2	0	45.0	80
Blackjack oak	17	34	46.5	1.3	43.9	49.0	35	45.0	65
Black walnut	31	64	46.4	1.8	42.9	49.9	10	45.0	80
Black ash	46	320	46.4	1.5	43.5	49.3	0	45.0	75

continued

Table 5—Mean crown density and other statistics[a] for all live trees ≥ 5.0 inches diameter by species for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99 (continued)

					95% confidence				
Species[b]	Plots[c]	Trees	Mean	SE	Lower	Upper	Minimum	Median	Maximum
	- - - number - - -		*- percent -*						
Hardwoods (continued)									
Black locust	11	38	45.8	2.3	41.3	50.3	5	45.0	80
Black cherry	56	120	45.6	1.4	42.9	48.4	20	45.0	70
Post oak	53	212	45.5	0.7	44.0	47.0	5	45.0	70
Balsam poplar	31	89	45.4	1.2	43.0	47.7	15	45.0	70
Northern red oak	98	389	45.3	0.9	43.6	47.0	15	45.0	70
American sycamore	17	40	45.1	2.2	40.7	49.5	25	45.0	65
Northern pin oak	13	41	45.1	1.5	42.1	48.2	30	45.0	65
Bur oak	46	182	44.8	1.7	41.5	48.1	10	45.0	80
American elm	104	269	44.8	1.1	42.6	46.9	5	45.0	80
Bigtooth aspen	37	182	44.6	1.6	41.4	47.8	10	45.0	75
Basswood	62	318	44.5	2.3	40.0	49.0	5	45.0	80
Silver maple	12	103	44.0	4.2	35.9	52.2	0	45.0	80
Slippery elm	34	76	43.1	1.6	39.9	46.3	15	45.0	70
Chinkapin oak	18	60	43.1	2.0	39.2	47.0	15	45.0	65
Honeylocust	13	25	41.2	3.4	34.5	47.9	20	45.0	65

SE = standard error.

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

[b] See appendix table A.4.

[c] Total number of forested plots on which the species was measured.

Table 6—Distribution of sapling crown vigor class for all live saplings 1.0 to < 5.0 inches diameter by FIA species group for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99

			Crown vigor rating					
			Good		Fair		Poor	
Species group[a]	Plots[b]	Saplings	Percent	SE[c]	Percent	SE[c]	Percent	SE[c]
	- - - *number* - - -			*percent*		*percent*		*percent*
Softwoods								
Loblolly and shortleaf pines	2	2	50.0	—	50.0	—	0.0	—
Other yellow pines	2	6	50.0	—	50.0	—	0.0	—
Eastern white and red pines	24	48	77.1	5.9	22.9	5.9	0.0	—
Jack pine	6	20	60.0	—	40.0	—	0.0	—
Spruce and balsam fir	85	348	77.0	4.0	21.0	3.7	2.0	1.1
Eastern hemlock	3	3	66.7	—	33.3	—	0.0	—
Other eastern softwoods	47	144	69.4	8.1	25.7	7.4	4.9	1.9
All softwoods	142	571	74.1	3.5	23.5	3.2	2.5	1.0
Hardwoods								
Select white oaks	53	103	84.5	3.7	15.5	3.7	0.0	—
Select red oaks	21	26	88.5	6.2	11.5	6.2	0.0	—
Other white oaks	14	22	63.6	—	31.8	—	4.5	—
Other red oaks	34	94	73.4	6.1	22.3	5.2	4.3	2.6
Hickory	62	105	85.7	4.1	13.3	3.7	1.0	0.9
Yellow birch	9	15	86.7	—	13.3	—	0.0	—
Hard maple	65	216	72.7	6.4	25.5	6.1	1.9	0.8
Soft maple	76	187	79.7	3.2	17.1	2.7	3.2	1.4
Beech	14	46	67.4	15.1	30.4	13.5	2.2	1.7
Sweetgum	2	2	50.0	—	50.0	—	0.0	—
Tupelo and blackgum	7	13	100.0	—	0.0	—	0.0	—
Ash	61	144	76.4	5.4	21.5	5.4	2.1	1.1
Cottonwood and aspen	68	503	68.8	4.7	29.2	4.4	2.0	0.6
Basswood	15	36	55.6	9.6	38.9	8.2	5.6	5.3
Yellow-poplar	4	13	76.9	—	23.1	—	0.0	—
Black walnut	5	5	60.0	—	40.0	—	0.0	—
Other eastern soft hardwoods	148	318	72.6	3.3	25.2	3.2	2.2	0.8
Other eastern hard hardwoods	53	111	63.1	6.0	28.8	5.0	8.1	3.9
Eastern noncommercial hardwoods	94	229	69.0	3.8	28.8	3.7	2.2	1.0
All hardwoods	386	2,188	72.9	1.8	24.7	1.7	2.4	0.4
All trees	439	2,759	73.1	1.6	24.4	1.5	2.4	0.4

FIA = Forest Inventory and Analysis; SE = standard error. (Standard error calculations consider the clustering of saplings on plots.); — = not presented due to insufficient sample.

[a] See appendix table A.4.

[b] Total number of forested plots on which saplings were measured. Plot totals are not cumulative because multiple species may occur on any given plot.

[c] SE is not presented for species groups with number of saplings < 25.

Discussion

A number of factors should be considered when analyzing and interpreting the crown condition data. These include variations due to species and site differences, impacts of biotic and abiotic stressors, the general statistical characteristics of the data, and the inventory sample design. We present a brief overview of each of these factors.

Variations Due to Species Differences

Average crown conditions are expected to vary by species due to differences in leaf and branch morphology and underlying shade tolerance. This expectation held true for species in this region where, for example, crown density averages ranged between 41.2 and 55.0 percent. On average, the species with the highest crown densities and lowest foliage transparencies were white spruce (*Picea glauca*), eastern hemlock (*Tsuga canadensis*), yellow-poplar, mockernut hickory, and black hickory (*C. texana*), and the species with the lowest crown densities and highest foliage transparencies were northern white-cedar (*Thuja occidentalis*), honeylocust, and silver maple. Such great variability inhibits direct comparisons of species because some species clearly tend to have denser crowns than others. For example, a yellow-poplar tree with a crown density of 40 percent may indicate that the tree is under stress; however, a honeylocust tree with the same crown density may not be under stress (table 5).

If comparisons among species or across mixed-species plots are required, Zarnoch and others (2004) propose standardizing the crown condition indicators to a mean of 0 and standard deviation of 1. This adjusts the crown indicators for species differences by expressing the indicators in terms of standard deviation units from the mean for a given species. This allows an indicator to be combined across species or for direct comparison of an indicator among species.

Variations Due to Site Factors

In addition to varying among species, average crown conditions may vary within individual species due to other factors such as stand density, stand age, or site moisture, or to the relative location of the species to its natural range. One way to accommodate stand and site influences is stratification, i.e., grouping together sets of homogenous observations and making comparisons only among those sets. Stratification, e.g. by physiographic class or stand origin, reduces variation in descriptive statistics and summaries, but it does not necessarily facilitate further inferential analyses. In broadscale surveys such as the FIA phase 3 program, complete stratification leads to small and unbalanced sample sizes that complicate analyses, limit interpretations of the results, or have both of these effects. One way to avoid these drawbacks of stratification and still account for stand influences is to “residualize” the crown condition indicators by redefining them as the residuals from a model that predicts crown condition based on tree and stand conditions (Zarnoch and others 2004). Following residualization, observations from many different plots within a given species can be combined or compared.

Crown Condition Stressors

Average crown conditions are impacted by a variety of biotic and abiotic stressors that directly or indirectly damage foliage and branches. These include insects, diseases, specific weather or disturbance events (e.g. ice storms), and other abiotic stressors (e.g. air pollution). These common stressors likely influenced a portion of the individual trees that were measured by FHM and included in this summary report, but determining the magnitude to which the average crown conditions were affected was beyond the scope of this study. We present an overview of the major stressors that have the potential to significantly impact tree crown conditions and highlight those that were active between 1996 and 1999.

Insects and diseases—Numerous insects and diseases damage trees in the forests of the North Central United States (Steinman 2004). Some directly impact the crown by actively feeding on foliage, whereas for others, foliage discoloration, crown thinning, and defoliation are secondary signs of their presence. Among the insects that directly defoliate the crown, the most damaging are the nonnative invasive gypsy moth (*Lymantria dispar* Linnaeus) and the native jack pine budworm (*Choristoneura pinus* Freeman), eastern spruce budworm (*C. fumiferana* Clemens), common pine shoot beetle (*Tomicus piniperda* Linnaeus), forest tent caterpillar (*Malacosoma disstria* Hübner), eastern tent caterpillar (*M. americanum* Fabricius), and a complex suite of other hardwood defoliators. Indirect damage of foliage and branches by obstructed flow of water and nutrients into the crown often occurs as a result of white pine blister rust (*Cronartium ribicola* J.C. Fisch. ex Rabenh.), oak wilt (*Ceratocystis fagacearum* (Bretz) Hunt), and Armillaria root rot (*Armillaria mellea* (Vahl:Fr.) Kummer). Wood-boring insects, such as the emerald ash borer (*Agrilus planipennis* Fairmaire) and Asian longhorned beetle (*Anoplophora glabripennis* Motschulsky), also disrupt water and nutrient flow and indirectly damage crowns.

Steinman (2004) reported the areas in the Northern United States with trees damaged by the most predominant insects and diseases between 1997 and 2002. Excluding the Great Plains States (North Dakota, South Dakota, Nebraska, and Kansas) oak wilt damage was observed in all of the North Central States (fig. 1); white pine blister rust damage was observed in all States except Missouri; forest tent caterpillar damage was observed in Michigan, Wisconsin, and Minnesota; eastern spruce budworm damage was observed in Michigan and Minnesota; and gypsy moth and jack pine budworm damage was observed in Michigan and Wisconsin. Thus, the crown conditions summarized here likely included some trees that were damaged by these insects and diseases.

The eastern spruce budworm is one of the most historically devastating insects in the northern spruce-fir (*Picea* spp.-*Abies* spp.) forests of the North Central United States. Although balsam fir (*A. balsamea*) is the species that suffers the most severe damage from spruce budworm, white, red (*P. rubens*), and black spruce (*P. mariana*) are also suitable hosts. Spruce, growing in mixed stands with balsam fir, is more likely to suffer budworm damage than spruce growing in pure stands (Kucera and Orr 1981). Periodic outbreaks of the eastern spruce budworm occur as a part of the natural cycle of maturing balsam fir. Historically, outbreaks of the eastern spruce budworm have returned about every 40 years (Seymour 1994). The North Central States most often affected by spruce budworm are Minnesota, Wisconsin, and Michigan. Damage by the eastern spruce budworm between 1997 and 1999 was concentrated in northern Minnesota (Steinman 2004).

The emerald ash borer (EAB) and Asian longhorned beetle (ALB) are two forest health threats that have emerged since the FHM survey ended in 1999. The EAB is an exotic beetle from Asia that was discovered in southeastern Michigan in 2002 (McCullough and Katovich 2004). In North America, the EAB has attacked only ash (*Fraxinus* spp.) trees (McCullough and Katovich 2004). As of 2009, the EAB had been detected in 12 additional States, including Minnesota, Wisconsin, Illinois, Indiana, and Missouri (U.S. Department of Agriculture Forest Service 2009b). Likewise, the ALB is also an exotic beetle likely introduced to the U.S. in solid wood packing material from China (U.S. Department of Agriculture Forest Service 2008). The ALB was first discovered in 1996 in New York City, and as of 2009, had been detected in Massachusetts and the Chicago, Illinois area (U.S. Department of Agriculture Forest Service 2009a). The ALB prefers maple species (*Acer* spp.), but birch (*Betula* spp.), Ohio buckeye (*Aesculus glabra*), elm (*Ulmus* spp.), horsechestnut (*A. hippocastanum*), and willow (*Salix* spp.) are suitable hosts also (U.S. Department of Agriculture Forest Service 2008). Adults of both the EAB and ALB feed on foliage, though damage is usually minimal unless the infestation is extensive. The most detrimental damage results from the larvae of both beetles that feed in the phloem and cambium which disrupts translocation, girdles branches, and eventually kills the entire tree (McCullough and Katovich 2004, U.S. Department of Agriculture Forest Service 2008). State and Federal forestry agencies are establishing quarantines and promoting educational campaigns in order stop the spread of these insects. If these efforts are not successful, the EAB and ALB will have significant impacts on future crown and forest health conditions in the North Central States.

Decline complexes—In addition to specific insects and diseases, crowns can be affected by general declines resulting from the interaction of predisposing stress factors (e.g. defoliating insects, drought, frost or ice damage, poor site quality, unbalanced soil nutrition, and advanced tree age) and secondary diseases or insects (e.g. root fungi, canker fungi, and insect borers). In the North Central region, particularly in the Missouri Ozarks, oak (*Q.* spp.) decline is most noteworthy (Lawrence and others 2002). In Missouri, oak decline has affected black oak (*Q. velutina*) and scarlet oak (*Q. coccinea*) primarily (Lawrence and others 2002), but it is known to also affect northern red oak (*Q. rubra*), pin oak (*Q. palustris*), white oak (*Q. alba*), and chestnut oak (*Q. prinus*) (Wargo and others 1983). In the North Central region, these oaks made up 13 percent of the trees measured in the 1996 to 1999 FHM survey. Since symptoms of oak decline typically include branch dieback and sparse or stunted foliage (Wargo and others 1983), continued oak decline episodes could have a significant impact on future crown conditions.

Abiotic stressors—Weather events such as drought, snow and ice storms, and tornadoes or other wind events also periodically influence individual tree crown conditions across the landscape. Together with the biological stressors, these factors may have a multiplicative, rather than a simply additive, impact on crown condition. Notable events in the North Central States between 1996 and 1999 include a drought in Missouri in 1999 (U.S. Department of Agriculture Forest Service 2003) and a major storm known as the “Boundary Waters-Canadian Derecho” which blew across northern Minnesota on July 4, 1999 (Moser and others 2007). Individual-tree crown conditions likely reflect damage from those events but the impact on the overall regional averages may have been minimal due to the events’ limited geographic range and time span relative to the region’s size, timescale of the study, and FHM sampling intensity.

Statistical Characteristics and Hypothesis Testing

A statistical power analysis by Bechtold and others (2009) demonstrated the statistical rigor of the crown condition indicator and determined the spatial scale at which the indicator is functional for hypothesis testing. For most plausible scenarios, about 100 plots (or 50 paired plots) are adequate for detecting differences between two sets of observations. Given the FIA phase 3 sampling network, an area of 4.8 million acres of forest provides the necessary 50 plots (Bechtold and others 2009). Michigan, Minnesota, Missouri, Ohio, and Wisconsin each have enough forested area to supply the minimum sample size individually. When combined with the remaining seven North Central States (fig. 1), < 6 percent of the total combined forested area in these 12 States would need to be impacted in order to detect a significant change in crown condition (Bechtold and others 2009).

In addition to having an adequate sample size, any data used in hypothesis testing 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) require an assumption of normality. When normality cannot be assumed, other avenues for analyzing the crown condition indicators, such as nonparametric techniques or categorical methods for ordinal data, should be explored. For instance, because the distribution of the crown dieback indicator resembles a log-normal distribution, Bechtold and others (2009) suggest using the ROM rather than the difference of the means when comparing two sets of data. Randolph (2006) examined the distributional characteristics of the crown condition data from the Southern United States and determined that the crown density indicator met the assumption of normality and that given the robustness of the *t*-test and ANOVA (analysis of variance), the assumption of normality could be applied to foliage transparency as well, as long as the sample sizes of the groups being compared are about equal and sufficiently large. Deviation from normality was determined to be too extreme, however, for such tests to be applied to crown dieback (Randolph 2006). Normality diagnostics (skewness and kurtosis values, and normal probability plots) indicated that the distributional characteristics of crown density and crown dieback in the North Central region were similar to those in the South; however, the distribution of foliage transparency was more skewed in this region than in the South.

Conclusion

With emerging threats such as the EAB and ALB and uncertainties about climate change (Solomon 2008), FHM in the North Central United States is increasingly important. 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. We have provided an overview of several factors to consider when analyzing and interpreting the crown condition data so that valid inferences can be drawn from the results. Integrating crown condition data with aerial damage surveys (e.g. Morin and others 2004), other forest health indicators (e.g. Will-Wolf and Jovan 2009), or both, may provide more powerful analyses for investigating changes in forest health. Such analyses are encouraged so that as FIA continues assessments in the North Central States, calculation of changes in the crown measurements will indicate whether crown condition—and by extension, forest health—is stable, improving, or declining.

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Appendix

Table A.1—Mean crown dieback and other statistics[a] for all live trees ≥ 5.0 inches diameter by FIA species group for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99

Species group[b]	Plots[c]	Trees	Mean	SE[d]	95% confidence Lower	95% confidence Upper	Minimum	90th percentile	Maximum
	number	*number*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*
Softwoods									
Loblolly and shortleaf pines	12	96	0.8	0.3	0.2	1.4	0	5	10
Other yellow pines	4	25	1.6	0.5	0.5	2.7	0	5	5
Eastern white and red pines	49	663	0.8	0.4	0.1	1.5	0	5	20
Jack pine	19	148	6.7	1.8	3.1	10.2	0	15	25
Spruce and balsam fir	111	826	2.9	0.4	2.1	3.8	0	5	80
Eastern hemlock	15	61	2.8	1.2	0.4	5.2	0	10	15
Other eastern softwoods	98	1,074	4.8	1.1	2.7	6.9	0	10	99
Hardwoods									
Select white oaks	164	824	3.1	0.3	2.5	3.6	0	5	99
Select red oaks	99	393	5.4	0.9	3.7	7.1	0	10	85
Other white oaks	54	215	3.7	0.9	1.9	5.6	0	5	95
Other red oaks	117	591	4.3	0.3	3.6	5.0	0	10	60
Hickory	111	310	1.8	0.3	1.2	2.4	0	5	60
Yellow birch	29	80	5.2	0.7	3.8	6.6	0	10	20
Hard maple	124	1,094	2.5	0.3	1.9	3.1	0	5	80
Soft maple	141	828	5.1	1.1	3.0	7.2	0	10	99
Beech	19	65	1.9	0.5	1.0	2.8	0	5	10
Sweetgum	4	8	5.6	—	—	—	0	20	20
Tupelo and blackgum	14	24	2.7	0.8	1.2	4.2	0	5	15
Ash	127	643	5.7	0.6	4.5	7.0	0	10	99
Cottonwood and aspen	162	1,113	3.7	0.3	3.1	4.3	0	5	50
Basswood	62	318	9.6	5.2	-0.7	19.8	0	10	95
Yellow-poplar	11	45	2.4	0.9	0.7	4.2	0	10	15
Black walnut	31	64	2.7	1.4	-0.1	5.6	0	5	90
Other eastern soft hardwoods	272	1,256	4.7	0.4	3.9	5.4	0	10	99
Other eastern hard hardwoods	55	137	2.3	0.5	1.3	3.3	0	5	40
Eastern noncommercial hardwoods	49	84	6.7	1.7	3.2	10.1	0	10	99

FIA = Forest Inventory and Analysis; SE = standard error; — = not presented due to insufficient sample.

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

[b] See appendix table A.4.

[c] Total number of forested plots on which trees were measured.

[d] SE is not presented for species groups with number of trees < 25.

Table A.2—Mean foliage transparency and other statistics[a] for all live trees ≥ 5.0 inches diameter by FIA species group for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99

Species group[b]	Plots[c]	Trees	Mean	SE[d]	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - *number* - - -		- - - - - - - - - -	- - - - -	- - - - - -	*percent*	- - - - - -	- - - - -	- - - - - - - -
Softwoods									
Loblolly and shortleaf pines	12	96	18.2	1.3	15.6	20.8	10	20.0	45
Other yellow pines	4	25	22.0	2.8	16.6	27.4	15	20.0	40
Eastern white and red pines	49	663	19.1	0.6	17.8	20.3	10	20.0	35
Jack pine	19	148	21.7	1.7	18.4	25.0	10	20.0	40
Spruce and balsam fir	111	826	16.9	0.4	16.1	17.7	5	15.0	35
Eastern hemlock	15	61	20.8	2.5	15.9	25.8	10	20.0	35
Other eastern softwoods	98	1,074	21.5	0.9	19.8	23.2	5	20.0	99
Hardwoods									
Select white oaks	164	824	18.1	0.4	17.4	18.8	0	15.0	99
Select red oaks	99	393	21.1	0.6	19.9	22.3	10	20.0	50
Other white oaks	54	215	19.3	0.7	17.8	20.7	10	20.0	85
Other red oaks	117	591	19.1	0.4	18.3	19.8	5	20.0	55
Hickory	111	310	16.4	0.4	15.6	17.2	5	15.0	30
Yellow birch	29	80	18.5	0.9	16.7	20.3	10	17.5	30
Hard maple	124	1,094	16.3	0.5	15.4	17.3	0	15.0	35
Soft maple	141	828	19.2	0.7	17.9	20.5	10	20.0	99
Beech	19	65	16.0	0.8	14.5	17.5	5	15.0	30
Sweetgum	4	8	16.3	—	—	—	10	15.0	25
Tupelo and blackgum	14	24	19.4	1.0	17.4	21.3	10	20.0	30
Ash	127	643	20.4	0.7	19.1	21.7	10	20.0	99
Cottonwood and aspen	162	1,113	22.5	0.6	21.2	23.7	0	20.0	85
Basswood	62	318	19.0	0.7	17.6	20.4	5	20.0	45
Yellow-poplar	11	45	15.0	1.8	11.4	18.6	5	15.0	30
Black walnut	31	64	18.5	0.7	17.1	19.9	10	17.5	35
Other eastern soft hardwoods	272	1,256	20.9	0.4	20.1	21.7	0	20.0	99
Other eastern hard hardwoods	55	137	21.5	1.2	19.2	23.7	5	20.0	60
Eastern noncommercial hardwoods	49	84	21.4	1.4	18.6	24.2	10	20.0	99

FIA = Forest Inventory and Analysis; SE = standard error; — = not presented due to insufficient sample.

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

[b] See appendix table A.4.

[c] Total number of forested plots on which trees were measured.

[d] SE is not presented for species groups with number of trees < 25.

Table A.3—Mean crown density and other statistics[a] for all live trees ≥ 5.0 inches diameter by FIA species group for Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99

Species group[b]	Plots[c]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - number - - -		- percent	- -					
Softwoods									
Loblolly and shortleaf pines	12	96	45.6	2.0	41.6	49.6	20	45.0	70
Other yellow pines	4	25	43.6	1.1	41.4	45.8	30	45.0	55
Eastern white and red pines	49	663	48.0	1.8	44.4	51.5	10	45.0	85
Jack pine	19	148	45.1	1.8	41.5	48.7	15	45.0	75
Spruce and balsam fir	111	826	49.9	0.9	48.1	51.6	15	50.0	90
Eastern hemlock	15	61	44.3	2.7	39.0	49.7	25	45.0	65
Other eastern softwoods	98	1,074	44.8	1.3	42.3	47.4	0	45.0	95
Hardwoods									
Select white oaks	164	824	48.1	0.6	46.8	49.4	0	50.0	80
Select red oaks	99	393	45.4	0.9	43.7	47.0	15	45.0	70
Other white oaks	54	215	45.5	0.7	44.0	46.9	5	45.0	70
Other red oaks	117	591	48.2	0.6	47.0	49.4	10	50.0	85
Hickory	111	310	52.0	0.7	50.5	53.4	15	55.0	90
Yellow birch	29	80	47.3	1.3	44.7	49.9	25	47.5	70
Hard maple	124	1,094	50.7	0.8	49.2	52.2	5	50.0	80
Soft maple	141	828	46.7	0.9	44.9	48.6	0	45.0	80
Beech	19	65	50.2	2.7	44.9	55.5	25	50.0	80
Sweetgum	4	8	55.6	3.7	48.4	62.9	45	52.5	75
Tupelo and blackgum	14	24	46.9	2.5	41.9	51.9	30	45.0	65
Ash	127	643	46.8	0.9	45.0	48.6	0	45.0	80
Cottonwood and aspen	162	1,113	47.3	0.9	45.6	49.0	10	45.0	85
Basswood	62	318	44.5	2.3	40.0	49.0	5	45.0	80
Yellow-poplar	11	45	55.0	1.9	51.3	58.7	30	55.0	80
Black walnut	31	64	46.4	1.8	42.9	49.9	10	45.0	80
Other eastern soft hardwoods	272	1,256	48.3	0.6	47.1	49.6	0	50.0	80
Other eastern hard hardwoods	55	137	45.8	1.2	43.4	48.1	5	45.0	80
Eastern noncommercial hardwoods	49	84	44.9	1.7	41.6	48.3	0	47.5	75

FIA = Forest Inventory and Analysis; SE = standard error; — = not presented due to insufficient sample.

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

[b] See appendix table A.4.

[c] Total number of forested plots on which trees were measured.

Table A.4—Common and scientific name for tree species included in the FHM survey in Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99[a]

Species group and common name	Scientific name[b]	Species group and common name	Scientific name[b]
Loblolly and shortleaf pines		Hickory (continued)	
Shortleaf pine	*Pinus echinata*	Bitternut hickory	*C. cordiformis*
Other yellow pines		Pignut hickory	*C. glabra*
Table Mountain pine[d]	*Pinus pungens*	Pecan[c]	*C. illinoensis*
Scotch pine	*P. sylvestris*	Shellbark hickory[c]	*C. laciniosa*
Virginia pine[c]	*P. virginiana*	Shagbark hickory	*C. ovata*
Eastern white and red pines		Black hickory	*C. texana*
Red pine	*Pinus resinosa*	Yellow birch	*Betula alleghaniensis*
Eastern white pine	*P. strobus*	Hard maple	
Jack pine	*P. banksiana*	Black maple	*Acer nigrum*
Spruce and balsam fir		Sugar maple	*A. saccharum*
Balsam fir	*Abies balsamea*	Soft maple	
White spruce	*Picea glauca*	Red maple	*Acer rubrum*
Black spruce	*P. mariana*	Silver maple	*A. saccharinum*
Eastern hemlock	*Tsuga canadensis*	Beech	*Fagus grandifolia*
Other eastern softwoods		Sweetgum	*Liquidambar styraciflua*
Redcedar/Juniper spp.	*Juniperus* spp.	Tupelo and blackgum	
Eastern redcedar	*J. virginiana*	Water tupelo	*Nyssa aquatica*
Northern white-cedar	*Thuja occidentalis*	Blackgum	*N. sylvatica*
Tamarack	*Larix laricina*	Ash	
Select white oaks		White ash	*Fraxinus americana*
White oak	*Quercus alba*	Black ash	*F. nigra*
Swamp white oak	*Q. bicolor*	Green ash	*F. pennsylvanica*
Bur oak	*Q. macrocarpa*	Blue ash[c]	*F. quadrangulata*
Chinkapin oak	*Q. muehlenbergii*	Cottonwood and aspen	
Select red oaks		Cottonwood spp.[c]	*Populus* spp.
Cherrybark oak[d]	*Quercus pagoda*	Balsam poplar	*P. balsamifera*
Northern red oak	*Q. rubra*	Eastern cottonwood[c]	*P. deltoides*
Shumard oak[c]	*Q. shumardii*	Bigtooth aspen	*P. grandidentata*
Other white oaks		Quaking aspen	*P. tremuloides*
Chestnut oak[c]	*Quercus prinus*	Basswood	
Post oak	*Q. stellata*	Basswood spp.	*Tilia* spp.
Other red oaks		American basswood	*T. americana*
Scarlet oak	*Quercus coccinea*	Yellow-poplar	*Liriodendron tulipifera*
Northern pin oak	*Q. ellipsoidalis*	Black walnut	*Juglans nigra*
Southern red oak	*Q. falcata*	Other eastern soft hardwoods	
Shingle oak	*Q. imbricaria*	Boxelder	*Acer negundo*
Blackjack oak	*Q. marilandica*	Ohio buckeye	*Aesculus glabra*
Pin oak[c]	*Q. palustris*	River birch[c]	*Betula nigra*
Black oak	*Q. velutina*	Paper birch	*B. papyrifera*
Hickory		Northern catalpa[c]	*Catalpa speciosa*
Hickory spp.	*Carya* spp.	Hackberry spp.	*Celtis* spp.
Mockernut hickory	*C. alba*	Sugarberry	*C. laevigata*

continued

Table A.4—Common and scientific name for tree species included in the FHM survey in Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin, 1996–99[a] (continued)

Species group and common name	Scientific name[b]	Species group and common name	Scientific name[b]
Other eastern soft hardwoods (continued)		Eastern noncommercial hardwoods	
Hackberry	*C. occidentalis*	Striped maple	*Acer pensylvanicum*
Butternut[c]	*Juglans cinerea*	Mountain maple[d]	*A. spicatum*
Sycamore	*Platanus occidentalis*	Serviceberry spp.	*Amelanchier* spp.
Black cherry	*Prunus serotina*	Pawpaw	*Asimina triloba*
Black willow	*Salix nigra*	American hornbeam, musclewood[d]	*Carpinus caroliniana*
Sassafras	*Sassafras albidum*	Eastern redbud[c]	*Cercis canadensis*
Winged elm	*Ulmus alata*	Hawthorn spp.	*Crataegus* spp.
American elm	*U. americana*	Cockspur hawthorn[d]	*C. crus-galli*
Siberian elm[c]	*U. pumila*	Osage-orange	*Maclura pomifera*
Slippery elm	*U. rubra*	Apple spp.	*Malus* spp.
Other eastern hard hardwoods		Eastern hophornbeam, ironwood	*Ostrya virginiana*
Sweet birch[d]	*Betula lenta*	American plum[d]	*Prunus americana*
Flowering dogwood	*Cornus florida*	Pin cherry	*P. pensylvanica*
Common persimmon	*Diospyros virginiana*	Chokecherry[d]	*P. virginiana*
Honeylocust[c]	*Gleditsia triacanthos*	Willow spp.	*Salix* spp.
Kentucky coffeetree[c]	*Gymnocladus dioicus*	Chittamwood, gum bumelia[d]	*Sideroxylon lanuginosum*
American holly[c]	*Ilex opaca*	American mountain-ash	*Sorbus americana*
Mulberry spp.[c]	*Morus* spp.		
White mulberry[c]	*M. alba*		
Red mulberry	*M. rubra*		
Black locust	*Robinia pseudoacacia*		
Rock elm[c]	*Ulmus thomasii*		

FHM = Forest Health Monitoring.

[a] Species group, common, and scientific names of species occurring in the FHM sample as saplings (1.0 to < 5.0 inches diameter) and trees (≥ 5.0 inches diameter) unless otherwise noted by footnote *c* or *d.*

[b] Little (1979).

[c] Tree only.

[d] Sapling only.

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The U.S. Forest Service Forest Inventory and Analysis (FIA) Program uses visual assessments of tree crown condition to monitor changes and trends in forest health. This report describes four crown condition indicators (crown dieback, crown density, foliage transparency, and sapling crown vigor) measured in Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin between 1996 and 1999. Descriptive statistics are presented by species and FIA species group. Inter- and intra-species variation, crown condition stressors, and statistical issues that should be considered when analyzing and interpreting the crown condition data are discussed.

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