United States
Department of
Agriculture

Forest Service

Southern
Research Station

General Technical
Report SRS–124

Descriptive Statistics of Tree Crown Condition in the Northeastern United States

KaDonna C. Randolph, Randall S. Morin, and Jim Steinman

Authors

KaDonna C. Randolph, Mathematical Statistician, USDA Forest Service, Southern Research Station, Forest Inventory and Analysis, Knoxville, TN 37919; **Randall S. Morin**, Research Forester, USDA Forest Service, Northern Research Station, Forest Inventory and Analysis, Newtown Square, PA 19073; and **Jim Steinman**, Northeast Regional Program Manager, USDA Forest Service, Forest Health Monitoring, Newtown Square, PA 19073.

Cover photo: Eastern white pine *(Pinus strobus). (*photo by Stéphen Robichaud, Trees Unlimited, Canada, Bugwood.org)

July 2010

Southern Research Station
200 W.T. Weaver Blvd.
Asheville, NC 28804

Descriptive Statistics of Tree Crown Condition in the Northeastern United States

KaDonna C. Randolph, Randall S. Morin, and Jim Steinman

Contents

Page

Descriptive Statistics of Tree Crown Condition in the Northeastern United States

KaDonna C. Randolph, Randall S. Morin, and Jim Steinman

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 Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia 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. 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. McWilliams and others 2007). The purpose of this crown condition summary is to document the species-specific crown conditions collected by FHM in the Northeastern United States (fig. 1) so that the FIA State-level summaries can be understood in their regional historical context. The Northeastern Research Station (U.S. Department of Agriculture Forest Service 2002a, 2002b, 2002c, 2002d, 2002e, 2002f, 2002g, 2002h, 2002i, 2003a, 2003b, 2003c) presented frequency statistics for three crown condition indicators (crown dieback, foliage transparency, and crown density) for the most common species groups, and by hardwood and softwood taxonomic groups, in the summaries of FHM in the Northeastern States between 1996 and 1999. Though based on the same data, this report goes beyond their summary by presenting detailed descriptive statistics at the individual species level. Similar regional summaries for the Southern (Randolph 2006), North Central (Randolph and others 2010b), Interior West (Randolph and Thompson 2010), and West Coast (Randolph and others 2010a) States are also available.

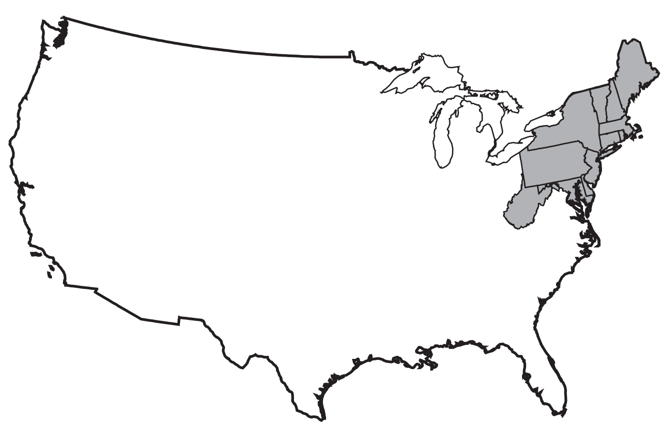

Figure 1—Northeastern States included in the crown condition summary are shaded gray.

Methods

Data Collection

In order to have complete statewide coverage for as many Northeastern 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 Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia (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 $\geq$ 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. $\geq$ 1.0 inch but $<$ 5.0 inches on a 1/300-acre microplot located 12 feet east from each subplot center.

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

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		
Connecticut	1	4	1	5	11
Delaware	1	—	—	1	2
Maine	19	24	30	55	128
Maryland[a]	2	7	6	1	16
Massachusetts	5	6	5	6	22
New Hampshire	—	—	—	34	34
New Jersey	1	3	2	7	13
New York	—	—	—	107	107
Pennsylvania	—	—	50	34	84
Rhode Island	—	1	0	1	2
Vermont	4	5	7	9	25
West Virginia	—	30	21	27	78
All States	33	80	122	287	522

FHM = Forest Health Monitoring.
— = no sample.
[a] The intensification plots measured in 1998 and 1999 are not included.

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).

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, the Maryland intensification plots measured in 1998 and 1999 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 90^{th} percentile) also were calculated for the trees. Summaries by FIA species group 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 13,007 trees on 513 of the 522 forested plots. A total of 92 species was observed, and of these, 46 species had 25 or more observations. For all trees combined, crown dieback ranged from 0 to 99 percent, though 96 percent of the trees exhibited < 15 percent crown dieback (fig. 3). Foliage transparency ranged from 5 to 99 percent and like crown dieback, the majority of observations tended to concentrate in a small portion of this range (fig. 4). Crown density values ranged from 0 to 90 percent. Unlike crown dieback and foliage transparency, the crown density values were spread across the middle of the range: 88 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 4.2 percent crown dieback, 17.0 percent foliage transparency, and 47.7 percent crown density (table 2).

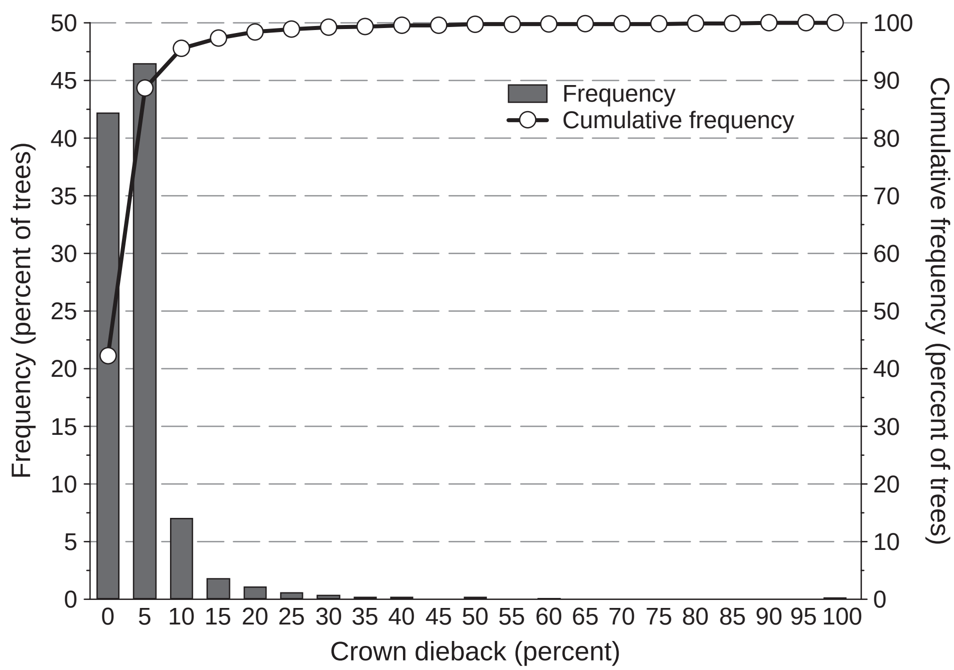

Figure 3—Crown dieback frequency histogram and cumulative frequency distribution for all trees combined in 12 Northeastern States, 1996-99.

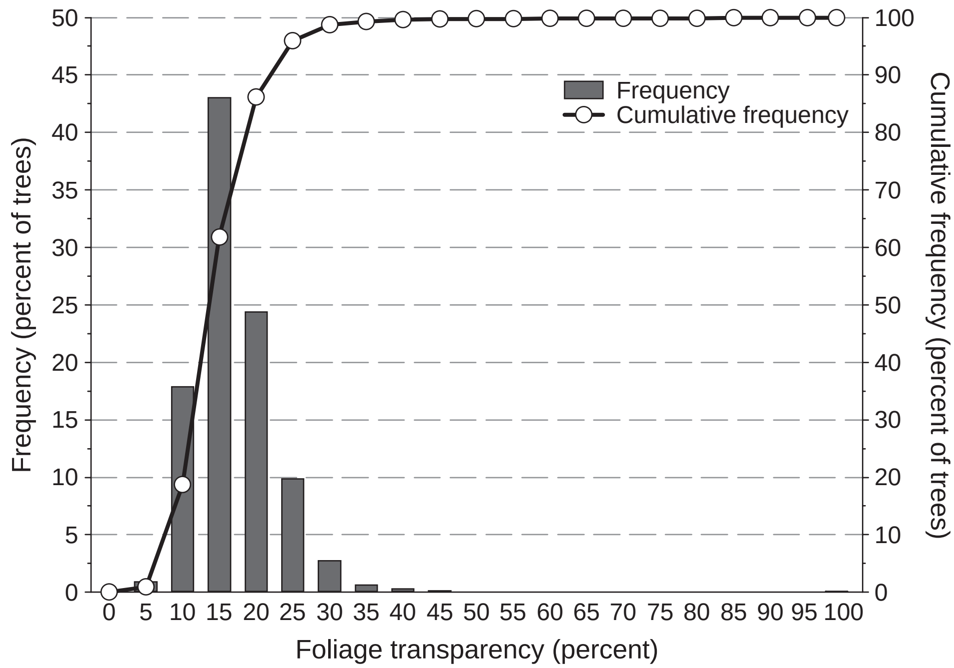

Figure 4—Foliage transparency frequency histogram and cumulative frequency distribution for all trees combined in 12 Northeastern States, 1996–99.

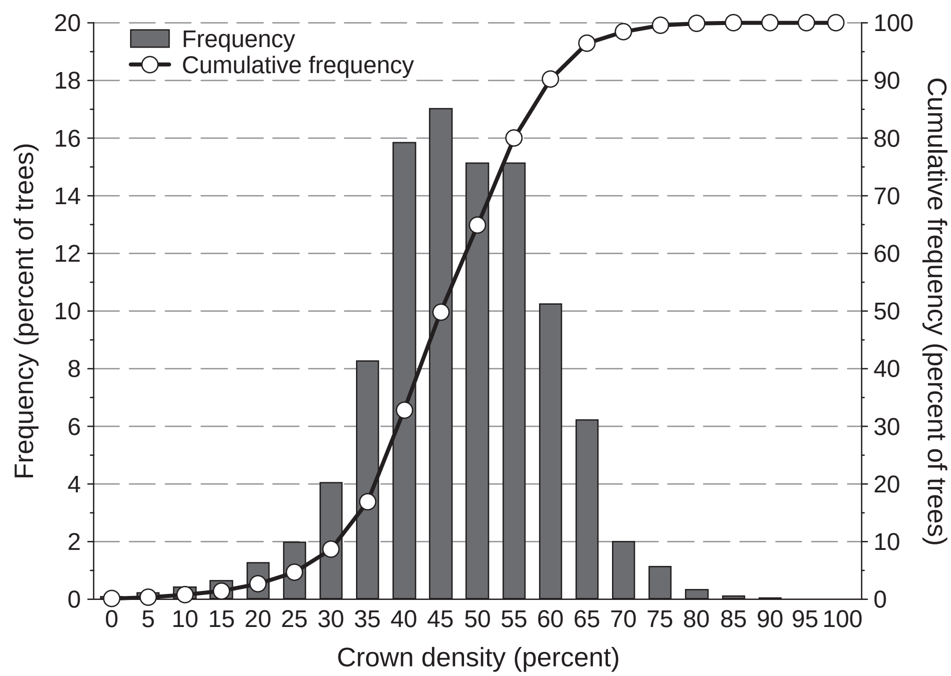

Figure 5—Crown density frequency histogram and cumulative frequency distribution for all trees combined in 12 Northeastern States, 1996–99.

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 12 Northeastern States, 1996–99

Crown condition indicator and species group	Plots[b]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - number - - -		*- - - percent - - -*						
Crown density									
Softwoods	308	3,860	47.3	0.4	46.5	48.2	5	45	90
Hardwoods	495	9,147	47.8	0.2	47.3	48.3	0	50	90
All trees	513	13,007	47.7	0.2	47.2	48.1	0	50	90
Crown dieback									
Softwoods	308	3,860	4.0	0.2	3.5	4.5	0	5	99
Hardwoods	495	9,147	4.3	0.1	4.0	4.6	0	5	99
All trees	513	13,007	4.2	0.1	3.9	4.5	0	5	99
Foliage transparency									
Softwoods	308	3,860	18.2	0.4	17.5	19.0	5	15	90
Hardwoods	495	9,147	16.5	0.2	16.2	16.8	5	15	99
All trees	513	13,007	17.0	0.2	16.7	17.4	5	15	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 1.0 percent for loblolly pine (*Pinus taeda*) and sweetgum (*Liquidambar styraciflua*) to 12.1 percent for gray birch (*Betula populifolia*) (table 3). Mean foliage transparency ranged from 10.5 percent for sweetgum to 26.9 percent for Virginia pine (*P. virginiana*) (table 4), and mean crown density ranged from 40.2 percent for pitch pine (*P. rigida*) to 57.5 percent for sweetgum (table 5).

Sapling Crown Vigor

Crown vigor was assessed for 3,384 saplings on 473 of the 522 forested plots. The percentage of saplings in each vigor category was about the same for both the softwood and hardwood groups. Overall, 76.7 percent of the sapling crowns were categorized as good (table 6). Among the softwood species groups with at least 25 observations, the other eastern softwoods group had the highest percentage of saplings in the good category (83.6 percent) and the eastern white and red pines (*P. strobus* and *P. resinosa*) group had the lowest percentage of saplings in the good category (55.6 percent). The eastern white and red pines group had the highest percentage of saplings in the poor category (3.2 percent), whereas the eastern hemlock (*Tsuga canadensis*) group had the lowest percentage of saplings in the poor category (0.0 percent) (table 6). Among the hardwood species groups with at least 25 observations, the yellow birch (*B. alleghaniensis*) group had the highest percentage of saplings in the good category (91.4 percent) and the other eastern soft hardwoods group had the lowest percentage of saplings in the good category (64.0 percent). The tupelo and blackgum (*Nyssa* spp.) group had the highest percentage of trees in the poor category (5.5 percent), whereas the select white oaks (*Quercus* spp.), hickory (*Carya* spp.), ash (*Fraxinus* spp.), and cottonwood-aspen (*Populus* spp.) 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 12 Northeastern States, 1996–99

Species[b]	Plots[c]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	90th percentile	Maximum
	- - - number - - -		- - - percent - - -						
Softwoods									
Loblolly pine	7	35	1.0	0.5	0.1	1.9	0	5.0	5
Black spruce	7	32	2.0	1.1	-0.2	4.2	0	5.0	30
Norway spruce	7	99	2.5	1.3	-0.1	5.0	0	5.0	5
Eastern hemlock	108	692	3.0	0.5	2.1	3.9	0	5.0	80
Red pine	10	26	3.5	0.6	2.2	4.7	0	5.0	5
White spruce	25	62	3.5	0.6	2.4	4.6	0	5.0	20
Scotch pine	6	58	3.6	2.0	-0.4	7.6	0	5.0	90
Eastern white pine	116	832	3.7	0.4	2.8	4.5	0	5.0	99
Virginia pine	12	60	4.0	0.8	2.3	5.7	0	5.0	70
Balsam fir	104	643	4.2	0.4	3.4	5.0	0	5.0	90
Red spruce	94	774	4.3	0.3	3.6	5.0	0	5.0	35
Pitch pine	14	131	5.0	0.9	3.2	6.7	0	10.0	50
Northern white-cedar	44	373	6.1	0.8	4.5	7.7	0	10.0	80
Hardwoods									
Sweetgum	11	53	1.0	0.6	-0.2	2.3	0	5.0	5
Yellow-poplar	59	223	1.4	0.3	0.9	2.0	0	5.0	15
Basswood	31	65	1.7	0.4	0.9	2.5	0	5.0	5
Shagbark hickory	27	85	1.9	0.4	1.2	2.7	0	5.0	10
Sweet birch	81	263	2.0	0.3	1.5	2.5	0	5.0	15
Bitternut hickory	20	30	2.2	0.5	1.1	3.2	0	5.0	10
Black locust	26	86	2.7	0.6	1.6	3.8	0	5.0	25
Chestnut oak	56	295	2.8	0.5	1.8	3.8	0	5.0	99
Pignut hickory	42	107	2.9	0.5	1.8	4.0	0	5.0	20
Apple spp.	16	43	2.9	1.0	1.0	4.8	0	10.0	15
Blackgum	50	112	3.1	1.0	1.1	5.2	0	5.0	99
White oak	87	284	3.5	0.3	2.8	4.1	0	5.0	25
Sugar maple	189	1,030	3.6	0.3	3.0	4.1	0	5.0	99
American hornbeam	19	28	3.6	1.1	1.4	5.8	0	10.0	15
Striped maple	14	26	3.7	1.0	1.7	5.6	0	10.0	20
Black cherry	118	414	4.0	0.4	3.3	4.7	0	5.0	50
American holly	3	42	4.2	1.8	0.7	7.6	0	10.0	10
Yellow birch	131	435	4.2	0.3	3.6	4.9	0	5.0	85
Sassafras	29	93	4.3	1.0	2.4	6.2	0	10.0	30
Beech	146	623	4.4	0.4	3.5	5.2	0	10.0	70
Black oak	56	155	4.4	0.4	3.6	5.2	0	10.0	25
Eastern hophornbeam	20	49	4.5	0.7	3.2	5.8	0	10.0	15
Northern red oak	148	520	4.7	0.3	4.1	5.4	0	10.0	99
Red maple	362	2,450	4.7	0.3	4.2	5.2	0	10.0	99
White ash	126	387	4.7	0.8	3.2	6.3	0	10.0	99
Scarlet oak	28	63	5.0	0.5	4.0	6.0	0	10.0	20
American elm	23	59	5.4	1.7	2.1	8.7	0	10.0	90
Quaking aspen	70	254	5.8	0.7	4.5	7.1	0	10.0	35
Paper birch	99	374	6.1	0.9	4.4	7.8	0	10.0	99
Bigtooth aspen	26	67	6.6	1.7	3.2	10.0	0	15.0	60
Black ash	12	33	7.0	2.0	3.1	10.9	0	20.0	30
Green ash	12	39	8.1	3.2	1.8	14.4	0	25.0	60
Gray birch	17	70	12.1	3.4	5.5	18.6	0	32.5	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 4—Mean foliage transparency and other statistics[a] for all live trees ≥ 5.0 inches diameter by species for 12 Northeastern States, 1996–99

Species[b]	Plots[c]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - *number* - - -		- - - *percent* - - -						
Softwoods									
Norway spruce	7	99	11.7	1.3	9.1	14.4	5	10	20
Black spruce	7	32	13.8	0.3	13.2	14.3	10	15	25
White spruce	25	62	15.3	0.5	14.3	16.3	10	15	25
Red spruce	94	774	15.7	0.6	14.5	16.8	5	15	40
Scotch pine	6	58	16.2	2.0	12.4	20.0	10	15	35
Loblolly pine	7	35	16.4	1.3	13.9	18.9	5	15	40
Eastern hemlock	108	692	17.2	0.7	15.9	18.5	5	15	85
Balsam fir	104	643	17.8	0.9	16.1	19.4	5	15	90
Red pine	10	26	19.6	1.2	17.2	22.0	10	20	25
Eastern white pine	116	832	20.4	0.6	19.2	21.6	5	20	50
Northern white-cedar	44	373	21.1	0.8	19.5	22.6	10	20	35
Pitch pine	14	131	23.4	1.5	20.6	26.3	10	25	70
Virginia pine	12	60	26.9	3.7	19.7	34.1	10	25	80
Hardwoods									
Sweetgum	11	53	10.5	1.6	7.4	13.5	5	10	25
Shagbark hickory	27	85	13.6	0.7	12.2	14.9	10	15	30
Striped maple	14	26	13.8	0.9	12.0	15.7	10	15	25
Pignut hickory	42	107	14.5	0.6	13.3	15.8	5	15	25
Sugar maple	189	1,030	14.8	0.3	14.3	15.3	5	15	99
American holly	3	42	15.1	0.9	13.3	16.9	10	15	30
Bitternut hickory	20	30	15.2	0.7	13.8	16.5	10	15	25
Beech	146	623	15.2	0.4	14.5	16.0	5	15	65
Yellow birch	131	435	15.5	0.5	14.6	16.4	5	15	45
Basswood	31	65	15.5	0.7	14.2	16.9	10	15	30
Apple spp.	16	43	15.6	1.6	12.5	18.7	5	15	25
Sweet birch	81	263	15.7	0.6	14.5	16.9	5	15	40
Sassafras	29	93	15.7	1.1	13.6	17.8	5	15	35
Eastern hophornbeam	20	49	15.7	0.9	14.0	17.5	10	15	25
White oak	87	284	15.8	0.6	14.7	16.9	5	15	40
Yellow-poplar	59	223	16.2	0.6	15.1	17.3	5	15	30
Northern red oak	148	520	16.2	0.4	15.3	17.1	5	15	99
Blackgum	50	112	16.2	1.1	14.1	18.3	5	15	99
Black oak	56	155	16.2	0.5	15.2	17.3	10	15	35
Red maple	362	2,450	16.6	0.2	16.1	17.1	5	15	99
American hornbeam	19	28	16.8	1.0	14.9	18.7	10	15	30
Chestnut oak	56	295	17.1	0.6	15.9	18.3	5	15	99
Paper birch	99	374	17.8	0.5	16.7	18.8	10	15	99
Black ash	12	33	18.0	0.5	17.0	19.1	10	15	30
White ash	126	387	18.5	0.8	16.9	20.0	10	15	99
Scarlet oak	28	63	18.5	1.2	16.2	20.8	10	20	45
Quaking aspen	70	254	18.5	0.5	17.5	19.6	10	20	35
Black locust	26	86	18.6	0.9	16.9	20.4	10	20	30
Green ash	12	39	18.7	1.8	15.1	22.3	10	15	35
Black cherry	118	414	18.9	0.5	17.9	19.8	5	20	45
Bigtooth aspen	26	67	20.7	1.0	18.8	22.6	10	20	40
American elm	23	59	20.8	0.9	18.9	22.6	10	20	45
Gray birch	17	70	22.3	1.3	19.8	24.7	10	20	40

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 12 Northeastern States, 1996–99

					95% confidence				
Species[b]	Plots[c]	Trees	Mean	SE	Lower	Upper	Minimum	Median	Maximum
	- - - number - - -		*- percent*	*- -*					
Softwoods									
White spruce	25	62	53.3	2.0	49.4	57.2	20	55.0	90
Black spruce	7	32	51.9	1.9	48.1	55.7	20	55.0	75
Red pine	10	26	50.8	2.4	46.1	55.4	30	50.0	70
Norway spruce	7	99	50.5	1.0	48.4	52.5	25	50.0	70
Balsam fir	104	643	49.7	1.2	47.3	52.2	5	50.0	85
Loblolly pine	7	35	48.9	1.8	45.3	52.5	15	50.0	70
Eastern hemlock	108	692	48.7	0.9	47.0	50.4	15	50.0	85
Red spruce	94	774	47.8	0.6	46.7	49.0	10	50.0	85
Eastern white pine	116	832	45.5	0.8	43.9	47.1	5	45.0	85
Northern white-cedar	44	373	45.0	0.8	43.4	46.6	10	45.0	80
Scotch pine	6	58	43.7	2.2	39.4	48.0	5	45.0	65
Virginia pine	12	60	41.8	2.5	36.8	46.8	15	40.0	70
Pitch pine	14	131	40.2	1.7	36.8	43.6	10	40.0	65
Hardwoods									
Sweetgum	11	53	57.5	2.7	52.2	62.7	25	60.0	90
Pignut hickory	42	107	53.0	1.8	49.5	56.5	25	55.0	80
Basswood	31	65	52.5	1.3	50.0	54.9	30	55.0	75
Blackgum	50	112	52.2	1.2	49.9	54.5	0	55.0	80
Sweet birch	81	263	52.0	1.0	50.1	53.9	25	50.0	75
Yellow-poplar	59	223	50.8	1.4	48.1	53.6	20	50.0	90
Yellow birch	131	435	50.8	0.7	49.4	52.2	5	50.0	75
Bitternut hickory	20	30	50.7	2.0	46.7	54.6	25	52.5	65
Sugar maple	189	1,030	49.9	0.6	48.8	51.1	0	50.0	80
Shagbark hickory	27	85	49.9	1.2	47.4	52.3	10	50.0	75
Striped maple	14	26	49.0	2.8	43.5	54.6	15	50.0	65
Paper birch	99	374	48.7	0.9	47.0	50.5	0	50.0	75
Sassafras	29	93	48.6	2.0	44.6	52.6	15	50.0	75
Scarlet oak	28	63	48.6	1.7	45.3	51.9	25	45.0	75
White oak	87	284	48.4	1.1	46.3	50.6	20	50.0	80
American holly	3	42	48.1	0.5	47.2	49.0	35	45.0	75
Black oak	56	155	48.0	1.1	45.8	50.2	15	50.0	75
Northern red oak	148	520	47.9	0.6	46.7	49.0	0	45.0	75
Apple spp.	16	43	47.7	1.4	44.9	50.5	20	50.0	75
Beech	146	623	47.6	1.1	45.5	49.7	5	50.0	90
Chestnut oak	56	295	47.5	1.0	45.5	49.4	0	45.0	75
Red maple	362	2,450	46.5	0.4	45.7	47.2	0	45.0	80
Black cherry	118	414	46.2	0.8	44.7	47.7	5	45.0	75
White ash	126	387	46.0	0.8	44.4	47.6	0	45.0	80
Eastern hophornbeam	20	49	45.5	2.2	41.1	49.9	20	45.0	75
Green ash	12	39	45.3	2.8	39.8	50.7	20	50.0	70
Black ash	12	33	44.1	2.0	40.2	47.9	15	45.0	65
Bigtooth aspen	26	67	43.5	2.1	39.4	47.6	5	45.0	65
Quaking aspen	70	254	43.0	1.0	41.0	44.9	5	40.0	70
Black locust	26	86	42.3	1.2	39.9	44.8	15	45.0	65
American hornbeam	19	28	42.3	2.7	37.0	47.7	10	45.0	60
Gray birch	17	70	42.3	2.3	37.8	46.7	10	40.0	65
American elm	23	59	41.9	1.3	39.4	44.4	15	40.0	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 12 Northeastern States, 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	3	12	100.0	—	0.0	—	0.0	—
Other yellow pines	6	23	47.8	—	43.5	—	8.7	—
Eastern white and red pines	35	63	55.6	8.9	41.3	9.1	3.2	2.3
Spruce and balsam fir	126	850	82.0	2.3	17.5	2.2	0.5	0.2
Eastern hemlock	41	92	84.8	4.7	15.2	4.7	0.0	—
Other eastern softwoods	22	67	83.6	5.0	13.4	4.3	3.0	2.2
All softwoods	191	1,107	80.3	2.0	18.8	1.9	0.9	0.3
Hardwoods								
Select white oaks	20	26	69.2	10.6	30.8	10.6	0.0	—
Select red oaks	24	54	79.6	5.4	18.5	4.6	1.9	1.7
Other white oaks	4	6	83.3	—	16.7	—	0.0	—
Other red oaks	15	25	76.0	7.9	20.0	7.2	4.0	4.0
Hickory	31	43	74.4	8.4	25.6	8.4	0.0	—
Yellow birch	50	105	91.4	2.5	7.6	2.5	1.0	0.9
Hard maple	101	236	85.6	3.0	12.3	2.7	2.1	1.4
Soft maple	177	473	68.5	3.2	28.8	2.9	2.7	0.9
Beech	93	224	83.9	2.8	14.7	2.7	1.3	0.8
Sweetgum	4	10	70.0	—	30.0	—	0.0	—
Tupelo and blackgum	30	55	72.7	7.5	21.8	6.0	5.5	3.0
Ash	58	125	76.0	4.9	24.0	4.9	0.0	—
Cottonwood and aspen	21	56	80.4	6.7	19.6	6.7	0.0	—
Basswood	3	5	80.0	—	20.0	—	0.0	—
Yellow-poplar	9	17	94.1	—	5.9	—	0.0	—
Black walnut	4	7	85.7	—	14.3	—	0.0	—
Other eastern soft hardwoods	117	317	64.0	4.2	32.5	3.7	3.5	1.4
Other eastern hard hardwoods	65	146	69.2	5.7	26.0	5.5	4.8	2.4
Eastern noncommercial hardwoods	150	347	75.2	3.9	22.2	3.2	2.6	1.0
All hardwoods	439	2,277	74.9	1.5	22.7	1.3	2.4	0.4
All trees	473	3,384	76.7	1.2	21.5	1.1	1.9	0.3

FIA = Forest Inventory and Analysis; SE = standard error (Standard error calculations consider the clustering of trees 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 40.2 and 57.5 percent. On average, the species with the highest crown densities and lowest foliage transparencies were the spruces (*Picea* spp.), hickories, and sweetgum, and the species with the lowest crown densities and highest foliage transparencies were Virginia pine, pitch pine, gray birch, and American elm (*Ulmus americana*). Such great variability inhibits direct comparisons of species because some species clearly tend to have denser crowns than others. For example, a sweetgum tree with a crown density of 40 percent may indicate that the tree is under stress; however, a gray birch 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 Northeastern 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 species gypsy moth (*Lymantria dispar* Linnaeus), balsam woolly adelgid (*Adelges piceae* Ratzeburg), and hemlock woolly adelgid (*A. tsugae* Annand). The most damaging native insects are the eastern spruce budworm (*Choristoneura fumiferana* Clemens), forest tent caterpillar (*Malacosoma disstria* Hübner), 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. Fish. ex Rabenh.), beech bark disease, dogwood anthracnose (*Discula destructiva* Redlin), 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: damage from white pine blister rust and dogwood anthracnose was observed in all 12 Northeastern States (fig. 1); damage from beech bark disease was observed in all States except Ohio, Maryland, and Delaware; damage by the hemlock woolly adelgid was observed in eastern West Virginia, Maryland, Delaware, southeastern Pennsylvania, New Jersey, southeastern New York, Massachusetts, Rhode Island, and Connecticut; damage from oak wilt was observed in Ohio, West Virginia, western Pennsylvania, and Maryland; and damage from the forest tent caterpillar and eastern spruce budworm were observed in two separate counties in New York. Thus, the crown conditions summarized here likely included some trees that were damaged by these insects and diseases.

Two of the most historically devastating insects in the forests of the Northeast are the gypsy moth (in hardwood forests) and the eastern spruce budworm (in softwood forests). The gypsy moth was introduced accidentally about 1868 near Boston, Massachusetts, and has been acknowledged as the most destructive defoliating forest insect in the U.S. (Davidson and others 1999, Sharov and others 2002). The range of gypsy moth now covers the entire Northeastern United States. In North America, the gypsy moth feeds on over 300 species of trees and shrubs, though there is considerable variation in susceptibility to defoliation among tree species. The most preferred tree species are in the *Quercus*, *Populus*, and *Larix* genera (Liebhold and others 1995). The largest areas of concentrated gypsy moth defoliation during 1996 through 1999 were in Pennsylvania (U.S. Department of Agriculture Forest Service 2009c). Scattered defoliation also occurred in Massachusetts, New Jersey, Ohio, and West Virginia, though in general, defoliation was minimal throughout most of the northeastern region during this time period (U.S. Department of Agriculture Forest Service 2009c).

Periodic outbreaks of the eastern spruce budworm occur as a part of the natural cycle of maturing balsam fir (*Abies balsamea*). The last major outbreak occurred in 1972-1984; historically, outbreaks of the eastern spruce budworm have returned about every 40 years (Seymour 1994). Although balsam fir is the species that suffers the most severe damage from spruce budworm, white, red, and black spruce (*P. glauca*, *P. rubens*, and *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). Observed damage by the eastern spruce budworm between 1997 and 1999 was minimal in the 12 Northeastern States (Steinman 2004).

First reported in the U.S. in 1951, the hemlock woolly adelgid is a growing threat to the survival and sustainability of eastern hemlock and Carolina hemlock (*Tsuga caroliniana*) (U.S. Department of Agriculture Forest Service 2005). Adult adelgids feed on nutrients stored at the base of the hemlock needles. This depletes the tree's energy reserves and results in needle discoloration, premature needle drop, branch tip dieback, and foliage thinning (Rentch and others 2009). Mortality follows, sometimes as quickly as 3 to 4 years after infestation (U.S. Department of Agriculture Forest Service 2005). In 2000, hemlock woolly adelgid infestations were present in 11 States (U.S. Department of Agriculture Forest Service 2000). The hemlock woolly adelgid has spread at a rate of 12.5 km per year (Onken and Keena 2008) and by 2008, infestations were detected in 18 States, including all 12 of the States in the northeastern region (fig. 1) plus Virginia, Kentucky, Tennessee, North Carolina, South Carolina, and Georgia (U.S. Department of Agriculture Forest Service 2008a). During 1996 through 1999, damage by the adelgid was observed in eastern West Virginia, Maryland, Delaware, southeastern Pennsylvania, New Jersey, southeastern New York, Massachusetts, Rhode Island, and Connecticut (Steinman 2004). As the insect spreads throughout the natural range of hemlock, a decline in hemlock crown conditions should be observed.

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 trees (McCullough and Katovich 2004). As of 2009, the EAB had been detected in 12 additional States, including New York, Pennsylvania, Ohio, West Virginia, and Maryland (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 2008b). 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 birches (*Betula* spp.), Ohio buckeye (*Aesculus glabra*), elms (*Ulmus* spp.), horsechestnut (*A. hippocastanum*), and willows (*Salix* spp.) are suitable hosts also (U.S. Department of Agriculture Forest Service 2008b). 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 2008b). State and Federal forestry agencies are establishing quarantines and promoting educational campaigns in order to 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 Northeastern United 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). Several species in the Northeastern United States have suffered from declines in recent decades, most notably oak (*Quercus* spp.) and ash (Wargo and others 1983, Manion 1991, Thomas and Boza 1984), and sugar maple (*Acer saccharum*) in particular (Horsley and others 2000, Houston 1999, Long and others 1997). Episodes of sugar maple decline have been observed in Massachusetts in the 1960s, New York and Vermont in the 1980s, and Pennsylvania in the 1980s and 1990s (Horsley and others 2002).

Symptoms of these declines typically include branch dieback and sparse or stunted foliage. Among the oaks, episodes have been most frequent in northern red oak (*Q. rubra*), scarlet oak (*Q. coccinea*), pin oak (*Q. palustris*), black oak (*Q. velutina*), white oak (*Q. alba*), and chestnut oak (*Q. prinus*) (Wargo and others 1983). These oaks, along with sugar maple and ashes, made up 21.6 percent of the trees measured in the 1996 to 1999 FHM survey. Thus, future decline episodes among these species 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. Between 1996 and 1999 in the Northeast, the most notable of such events was the January 1998 ice storm that blanketed 17 million acres of forest land in New York, Vermont, New Hampshire, and Maine with up to 3 inches of ice (Miller-Weeks and Eager 1999). The crown condition averages reported here likely reflect some damage by this storm. Post-storm assessments of the FHM plots in Vermont, New Hampshire, and Maine showed that the percentage of trees with foliage transparency ratings > 30 percent was slightly higher in 1998 than in 1994 (Miller-Weeks and Eager 1999).

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). Maine, New Hampshire, New York, Pennsylvania, and West Virginia each have enough forested area to supply the minimum sample size individually. When combined with the remaining seven Northeastern 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 in the Northeast were similar to those in the South; however, the distributions of crown dieback and foliage transparency were more skewed in this region than in the South.

Conclusion

With the continued spread of the hemlock woolly adelgid, emerging threats such as the EAB and ALB, and uncertainties about climate change (Solomon 2008), FHM in the Northeast 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 Northeast, calculation of changes in the crown measurements will indicate whether crown condition—and by extension, forest health—is stable, improving, or declining.

Acknowledgments

Appreciation is extended to Susan Crocker and Susan Will-Wolf for their comments on the initial draft of the manuscript that helped improve the quality of this report.

Literature Cited

An, A.; Watts, D. 1998. New SAS procedures for analysis of sample survey data. In: Proceedings of the twenty-third annual SAS users group international conference. Pap. 247. Cary, NC: SAS Institute Inc. http://www2.sas.com/proceedings/sugi23/Stats/p247.pdf. [Date accessed: July 23, 2008].

Anderson, R.L.; Belanger, R.P. 1987. A crown rating method for assessing tree vigor of loblolly and shortleaf pines. In: Phillips, D.R., comp. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE–42. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 538–543.

Bechtold, W.A.; Randolph, K.C.; Zarnoch, S.J. 2009. The power of FIA phase 3 crown-indicator variables to detect change. In: McWilliams, W.; Moisen, G.; Czaplewski, R., comps. 2008 Forest Inventory and Analysis (FIA) symposium. RMRS–P–56CD. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 1 CD.

Cochran, W.G. 1977. Sampling techniques. 3rd ed. New York: John Wiley. 428 p.

Davidson, C.B.; Gottschalk, K.W.; Johnson, J.E. 1999. Tree mortality following defoliation by the European gypsy moth (*Lymantria dispar* L.) in the United States: a review. Forest Science. 45: 74–84.

Horsley, S.B.; Long, R.P.; Bailey, S.W. [and others]. 2000. Factors associated with the decline disease of sugar maple on the Allegheny plateau. Canadian Journal of Forest Research. 30(9): 1–14.

Horsley, S.B.; Long, R.P.; Bailey, S.W. [and others]. 2002. Health of eastern north American sugar maple forests and factors affecting decline. Northern Journal of Applied Forestry. 19(1): 34–44.

Houston, D.R. 1999. History of sugar maple decline. In: Horsley, S.B.; Long, R.P., eds. Sugar maple ecology and health: Proceedings international symposium. Gen. Tech. Rep. GTR–NE–261. Radnor, PA: U.S. Department of Agriculture Forest Service, Northeastern Research Station: 19–26.

Innes, J.L. 1993. Forest health: its assessment and status. Oxon, UK: CAB International. 677 p.

Kenk, G. 1993. Growth in “declining” forests of Baden-Wurttemberg (Southwestern Germany). In: Huettl, R.F.; Mueller-Dombois, D., eds. Forest decline in the Atlantic and Pacific region. New York: Springer-Verlag: 202–215.

Kucera, D.R.; Orr, P.W. 1981. Spruce budworm in the Eastern United States. Forest Insect and Disease Leaflet 160 (revised). Washington, DC: U.S. Department of Agriculture Forest Service. 7 p.

Lawrence, R.; Moltzan, B.; Moser, W.K. 2002. Oak decline and the future of Missouri's forests. Missouri Conservationist. 63(7): 11–18.

Liebhold, A.M.; Gottschalk, K.W.; Muzika, R. [and others]. 1995. Suitability of North American tree species to the gypsy moth: a summary of field and laboratory tests. Gen. Tech. Rep. NE–211. Radnor, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 34 p.

Little, E.L., Jr. 1979. Checklist of United States trees (native and naturalized). Agric. Handb. 541. Washington, DC: U.S. Department of Agriculture. 375 p.

Long, R.P.; Horsley, S.B.; Lilja, P.R. 1997. Impact of forest liming on growth and crown vigor of sugar maple and associated hardwoods. Canadian Journal of Forest Research. 27: 1560–1573.

Manion, P.D. 1991. Tree disease concepts, 2d ed. Upper Saddle River, NJ: Prentice Hall. 416 p.

McCullough, D.G; Katovich, S.A. 2004. Pest alert: emerald ash borer. NA–PR–02–04. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area State and Private Forestry. 2 p.

McWilliams, W.H.; Cassell, S.P.; Alerich, C.L. [and others]. 2007. Pennsylvania's forest, 2004. Resour. Bull. NRS–20. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 86 p.

Miller-Weeks, M.; Eager, C. 1999. The Northeastern ice storm 1998: a forest damage assessment. Concord, NH: North East State Foresters Association. 32 p.

Millers, I.; Anderson, R.; Burkman, W.; Hoffard, W. 1992. Crown condition rating guide. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area State and Private Forestry; Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. 37 p.

Morin, R.S., Jr.; Liebhold, A.M.; Gottschalk, K.W. 2004. Area-wide analysis of hardwood defoliator effects on tree conditions in the Allegheny plateau. Northern Journal of Applied Forestry. 21(1): 31–39.

Onken, B.; Keena, M. 2008. Hemlock woolly adelgid initiative: progress and future direction. In: Onken, B.; Reardon, R., comps. Fourth symposium on hemlock woolly adelgid in the Eastern United States. FHTET–2008–01. Morgantown, WV: Forest Health Technology Enterprise Team: 214–220.

Randolph, K.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.

Randolph, K.C.; Campbell, S.; Christensen, G. 2010a. Descriptive statistics of tree crown condition in California, Oregon, and Washington. Gen. Tech. Rep. SRS–126. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 19 p.

Randolph, K.C.; Morin, R.S.; Steinman, J. 2010b. Descriptive statistics of tree crown condition in the North Central United States. Gen. Tech. Rep. SRS–125. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 21 p.

Randolph, K.C.; Thompson, M.T. 2010. Descriptive statistics of tree crown condition in the United States Interior West. Gen. Tech. Rep. SRS–127. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

Rentch, J.; Fajvan, M.A.; Evans, R.A.; Onken, B. 2009. Using dendrochronology to model hemlock woolly adelgid effects on eastern hemlock growth and vulnerability. Biological Invasions. 11: 551–563.

Riitters, K.; Tkacz, B. 2004. The U.S. forest health monitoring program. In: Wiersma, B., ed. Environmental Monitoring. Boca Raton, FL: CRC Press: 669–683.

Schomaker, M.E.; Zarnoch, S.J.; Bechtold, W.A. [and others]. 2007. Crown-condition classification: a guide to data collection and analysis. Gen. Tech. Rep. SRS–102. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 78 p.

Seymour, R.S. 1994. The northeastern region. In: Barrett, J.W., ed. Regional silviculture of the United States. 3rd ed. New York: John Wiley: 31–79.

Sharov, A.A.; Leonard, D.; Leibhold, A.M. [and others]. 2002. “Slow the spread”: a national program to contain the gypsy moth. Journal of Forestry. 100: 30–35.

Solomon, A. 2008. Forests and global climate change. Compass. 10:1–2.

Steinman, J. 2004. Forest health monitoring in the Northeastern United States: disturbances and conditions during 1993-2002. NA–TP–01–04. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area State and Private Forestry. 50 p.

Thomas, W.D., Jr.; Boza, C.A. 1984. The oak decline complex. Journal of Arboriculture. 10(6): 170–177.

U.S. Department of Agriculture Forest Service. 1999. Forest health monitoring 1999 field methods guide. Research Triangle Park, NC: Forest Health Monitoring Program. [Not paged].

U.S. Department of Agriculture Forest Service. 2000. Hemlock woolly adelgid distribution 1991-2000. http://na.fs.fed.us/fhp/hwa/maps/1991_2000.pdf. [Date accessed: October 2009].

U.S. Department of Agriculture Forest Service. 2002a. Forest health monitoring in Connecticut, 1996-1999. NE–INF–153. Newtown Square, PA: Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2002b. Forest health monitoring in Maine, 1996-1999. NE–INF–145. Newtown Square, PA: Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2002c. Forest health monitoring in Massachusetts, 1996-1999. NE–INF–149. Newtown Square, PA: Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2002d. Forest health monitoring in New Hampshire, 1996-1999. NE–INF–146. Newtown Square, PA: Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2002e. Forest health monitoring in New York, 1996-1999. NE–INF–151. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2002f. Forest health monitoring in Pennsylvania, 1998-1999. NE–INF–158. Newtown Square, PA: Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2002g. Forest health monitoring in Rhode Island, 1996-1999. NE–INF–156. Newtown Square, PA: Northeastern Research Station. 5 p.

U.S. Department of Agriculture Forest Service. 2002h. Forest health monitoring in Vermont, 1996-1999. NE–INF–147. Newtown Square, PA: Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2002i. Forest health monitoring in West Virginia, 1996-1999. NE–INF–159. Newtown Square, PA: Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2003a. Forest health monitoring in Delaware, 1996-1999. NE–INF–162. Newtown Square, PA: Northeastern Research Station. 4 p.

U.S. Department of Agriculture Forest Service. 2003b. Forest health monitoring in Maryland, 1996-1999. NE–INF–196. Newtown Square, PA: Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2003c. Forest health monitoring in New Jersey, 1996-1999. NE–INF–161. Newtown Square, PA: Northeastern Research Station. 8 p.

U.S. Department of Agriculture Forest Service. 2005. Pest alert: Hemlock woolly adelgid. NA–PR–09–05. Newtown Square, PA: Northeastern Area State and Private Forestry. 2 p.

U.S. Department of Agriculture Forest Service. 2008a. Hemlock woolly adelgid infestations 2008. http://na.fs.fed.us/fhp/hwa/maps/2008.pdf. [Date accessed: October 2009].

U.S. Department of Agriculture Forest Service. 2008b. Pest alert: Asian longhorned beetle (*Anoplophora glabripennis*). NA–PR–01–99GEN. Newtown Square, PA: Northeastern Area State and Private Forestry. 2 p.

U.S. Department of Agriculture Forest Service. 2009a. Alien forest pest explorer: Asian longhorned beetle. http://www.fs.fed.us/ne/morgantown/4557/AFPE. [Date accessed: October].

U.S. Department of Agriculture Forest Service. 2009b. Alien forest pest explorer: emerald ash borer. http://www.fs.fed.us/ne/morgantown/4557/AFPE. [Date accessed: October].

U.S. Department of Agriculture Forest Service. 2009c. An atlas of historical gypsy moth defoliation and quarantined areas in the US. http://www.fs.fed.us/ne/morgantown/4557/gmoth/atlas/#defoliation. [Date accessed: October].

Wargo, P.M.; Houston, D.R.; LaMadeleine, L.A. 1983. Oak decline. Forest Insect and Disease Leaflet 165. Broomall, PA: U.S. Department of Agriculture Forest Service, Northern Area State and Private Forestry. 7 p.

Will-Wolf, S.; Jovan, S. 2009. Lichens, ozone, and forest health—exploring cross-indicator analyses with FIA data. In: McWilliams, W.; Moisen, G.; Czaplewski, R., comps. Forest inventory and analysis (FIA) symposium 2008. RMRS–P–56CD. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station.

Zarnoch, S.J.; Bechtold, W.A.; Stolte, K.W. 2004. Using crown condition variables as indicators of forest health. Canadian Journal of Forest Research. 34: 1057–1070.

Appendix

Table A.1—Mean crown dieback and other statistics[a] for all live trees ≥ 5.0 inches diameter by FIA species group for 12 Northeastern States, 1996–99

Species group[b]	Plots[c]	Trees	Mean	SE[d]	95% confidence Lower	95% confidence Upper	Mini-mum	90th percentile	Maxi-mum
	- - - number - - -		*- percent -*						
Softwoods									
Loblolly and shortleaf pines	10	43	1.4	0.5	0.4	2.4	0	5.0	5
Other yellow pines	29	249	4.4	0.7	3.0	5.9	0	10.0	90
Eastern white and jack pines	120	858	3.7	0.4	2.8	4.5	0	5.0	99
Spruce and balsam fir	139	1,511	4.2	0.3	3.6	4.7	0	5.0	90
Eastern hemlock	108	692	3.0	0.5	2.1	3.9	0	5.0	80
Baldcypress	1	5	0.0	—	—	—	0	0.0	0
Other eastern softwoods	62	502	5.5	0.8	3.9	7.1	0	10.0	80
Hardwoods									
Select white oaks	89	289	3.5	0.3	2.8	4.1	0	5.0	25
Select red oaks	148	520	4.7	0.3	4.1	5.4	0	10.0	99
Other white oaks	59	299	2.7	0.5	1.7	3.7	0	5.0	99
Other red oaks	79	243	4.5	0.3	3.9	5.1	0	10.0	25
Hickory	83	260	2.5	0.3	1.8	3.1	0	5.0	20
Yellow birch	131	435	4.2	0.3	3.6	4.9	0	5.0	85
Hard maple	190	1,033	3.6	0.3	3.0	4.1	0	5.0	99
Soft maple	364	2,458	4.7	0.3	4.2	5.2	0	10.0	99
Beech	146	623	4.4	0.4	3.5	5.2	0	10.0	70
Sweetgum	11	53	1.0	0.6	-0.2	2.3	0	5.0	5
Tupelo and blackgum	50	112	3.1	1.0	1.1	5.2	0	5.0	99
Ash	141	461	5.3	0.8	3.8	6.9	0	10.0	99
Cottonwood and aspen	98	346	5.9	0.6	4.7	7.1	0	10.0	60
Basswood	31	65	1.7	0.4	0.9	2.5	0	5.0	5
Yellow-poplar	59	223	1.4	0.3	0.9	2.0	0	5.0	15
Black walnut	9	20	3.3	—	—	—	0	7.5	20
Other eastern soft hardwoods	261	1,072	5.3	0.4	4.5	6.2	0	10.0	99
Other eastern hard hardwoods	117	407	2.6	0.3	2.0	3.3	0	5.0	40
Eastern noncommercial hardwoods	101	228	4.2	0.4	3.3	5.1	0	10.0	40

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 12 Northeastern States, 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	10	43	18.1	1.9	14.4	21.9	5	15	40
Other yellow pines	29	249	22.6	1.6	19.5	25.7	10	20	80
Eastern white and jack pine	120	858	20.4	0.6	19.2	21.6	5	20	50
Spruce and balsam fir	139	1,511	16.5	0.6	15.4	17.6	5	15	90
Eastern hemlock	108	692	17.2	0.7	15.9	18.5	5	15	85
Baldcypress	1	5	13.0	—	—	—	10	15	15
Other eastern softwoods	62	502	19.2	1.2	16.8	21.5	5	20	70
Hardwoods									
Select white oaks	89	289	15.7	0.6	14.6	16.8	5	15	40
Select red oaks	148	520	16.2	0.4	15.3	17.1	5	15	99
Other white oaks	59	299	17.1	0.6	15.9	18.3	5	15	99
Other red oaks	79	243	16.7	0.5	15.7	17.7	10	15	45
Hickory	83	260	14.6	0.4	13.8	15.5	5	15	30
Yellow birch	131	435	15.5	0.5	14.6	16.4	5	15	45
Hard maple	190	1,033	14.8	0.3	14.3	15.3	5	15	99
Soft maple	364	2,458	16.6	0.2	16.1	17.1	5	15	99
Beech	146	623	15.2	0.4	14.5	16.0	5	15	65
Sweetgum	11	53	10.5	1.6	7.4	13.5	5	10	25
Tupelo and blackgum	50	112	16.2	1.1	14.1	18.3	5	15	99
Ash	141	461	18.5	0.7	17.1	19.8	10	15	99
Cottonwood and aspen	98	346	19.0	0.5	18.0	19.9	10	20	40
Basswood	31	65	15.5	0.7	14.2	16.9	10	15	30
Yellow-poplar	59	223	16.2	0.6	15.1	17.3	5	15	30
Black walnut	9	20	15.8	—	—	—	10	15	25
Other eastern soft hardwoods	261	1,072	18.5	0.3	17.9	19.2	5	20	99
Other eastern hard hardwoods	117	407	16.5	0.5	15.6	17.5	5	15	50
Eastern noncommercial hardwoods	101	228	16.4	0.5	15.4	17.4	5	15	35

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 12 Northeastern States, 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	10	43	47.6	1.9	43.8	51.3	15	50	70
Other yellow pines	29	249	41.4	1.3	38.8	44.0	5	40	70
Eastern white and jack pine	120	858	45.6	0.8	44.0	47.2	5	45	85
Spruce and balsam fir	139	1511	49.0	0.7	47.5	50.4	5	50	90
Eastern hemlock	108	692	48.7	0.9	47.0	50.4	15	50	85
Baldcypress	1	5	75.0	—	—	—	70	75	80
Other eastern softwoods	62	502	46.3	0.9	44.4	48.1	10	45	80
Hardwoods									
Select white oaks	89	289	48.5	1.1	46.4	50.6	20	50	80
Select red oaks	148	520	47.9	0.6	46.7	49.0	0	45	75
Other white oaks	59	299	47.4	1.0	45.5	49.4	0	45	75
Other red oaks	79	243	48.5	0.9	46.8	50.3	15	50	80
Hickory	83	260	51.3	1.0	49.4	53.3	10	50	80
Yellow birch	131	435	50.8	0.7	49.4	52.2	5	50	75
Hard maple	190	1,033	49.9	0.6	48.8	51.1	0	50	80
Soft maple	364	2,458	46.5	0.4	45.7	47.2	0	45	80
Beech	146	623	47.6	1.1	45.5	49.7	5	50	90
Sweetgum	11	53	57.5	2.7	52.2	62.7	25	60	90
Tupelo and blackgum	50	112	52.2	1.2	49.9	54.5	0	55	80
Ash	141	461	45.7	0.8	44.2	47.2	0	45	80
Cottonwood and aspen	98	346	43.2	0.9	41.4	44.9	5	45	70
Basswood	31	65	52.5	1.3	50.0	54.9	30	55	75
Yellow-poplar	59	223	50.8	1.4	48.1	53.6	20	50	90
Black walnut	9	20	49.8	—	—	—	35	50	65
Other eastern soft hardwoods	261	1,072	46.9	0.5	45.9	48.0	0	45	80
Other eastern hard hardwoods	117	407	49.2	0.9	47.4	50.9	15	50	80
Eastern noncommercial hardwoods	101	228	45.8	1.0	43.9	47.8	10	45	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.
[d] SE is not presented for species groups with number of trees < 25.

Table A.4—Common and scientific name for tree species included in the FHM survey in 12 Northeastern States, 1996–99[a]

Species group and common name	Scientific name[b]	Species group and common name	Scientific name[b]
Loblolly and shortleaf pines		Hickory	
Shortleaf pine[c]	*Pinus echinata*	Hickory spp.	*Carya* spp.
Loblolly pine	*P. taeda*	Mockernut hickory	*C. alba*
Other yellow pines		Bitternut hickory	*C. cordiformis*
Pitch pine	*Pinus rigida*	Pignut hickory	*C. glabra*
Scotch pine[c]	*P. sylvestris*	Pecan[c]	*C. illinoensis*
Virginia pine	*P. virginiana*	Shagbark hickory	*C. ovata*
Eastern white and red pines		Yellow birch	*Betula alleghaniensis*
Red pine[c]	*Pinus resinosa*	Hard maple	
Eastern white pine	*P. strobus*	Florida maple[c]	*Acer barbatum*
Spruce and balsam fir		Black maple[c]	*A. nigrum*
Balsam fir	*Abies balsamea*	Norway maple[d]	*A. platanoides*
White spruce	*Picea glauca*	Sugar maple	*A. saccharum*
Black spruce	*P. mariana*	Soft maple	
Red spruce	*P. rubens*	Red maple	*Acer rubrum*
Eastern hemlock	*Tsuga candensis*	Silver maple	*A. saccharinum*
Cypress		Beech	*Fagus grandifolia*
Baldcypress[c]	*Taxodium distichum*	Sweetgum	*Liquidambar styraciflua*
Other eastern softwoods		Tupelo and blackgum	
Redcedar/Juniper spp.[d]	*Juniperus* spp.	Blackgum	*Nyssa sylvatica*
Eastern redcedar	*J. virginiana*	Ash	
Norway spruce	*Picea abies*	Ash spp.[c]	*Fraxinus* spp.
Northern white-cedar	*Thuja occidentalis*	White ash	*F. americana*
Tamarack	*Larix laricina*	Black ash	*F. nigra*
Select white oaks		Green ash	*F. pennsylvanica*
White oak	*Quercus alba*	Cottonwood and aspen	
Swamp white oak[c]	*Q. bicolor*	Cottonwood spp.[c]	*Populus* spp.
Bur oak[c]	*Q. macrocarpa*	Balsam poplar	*P. balsamifera*
Select red oaks		Eastern cottonwood[c]	*P. deltoides*
Northern red oak	*Quercus rubra*	Bigtooth aspen	*P. grandidentata*
Other white oaks		Quaking aspen	*P. tremuloides*
Chestnut oak	*Quercus prinus*	Basswood	
Post oak[c]	*Q. stellata*	Basswood spp.	*Tilia* spp.
Other red oaks		American basswood	*T. americana*
Scarlet oak[c]	*Quercus coccinea*	Yellow-poplar	*Liriodendron tulipifera*
Southern red oak[c]	*Q. falcata*	Black walnut	*Juglans nigra*
Shingle oak[c]	*Q. imbricaria*	Other eastern soft hardwoods	
Blackjack oak	*Q. marilandica*		
Water oak	*Q. nigra*	Boxelder	*Acer negundo*
Pin oak[c]	*Q. palustris*	Ohio buckeye	*Aesculus glabra*
Willow oak	*Q. phellos*	European alder[d]	*Alnus glutinosa*
Black oak	*Q. velutina*	Birch spp.	*Betula* spp.

continued

Table A.4—Common and scientific name for tree species included in the FHM survey in 12 Northeastern States, 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)		Other eastern hard hardwoods (continued)	
River birch[c]	*Betula nigra*	Black locust	*Robinia pseudoacacia*
Paper birch	*B. papyrifera*	Eastern noncommercial hardwoods	
Western paper birch[c]	*B. papyrifera* var. *commutata*		
Gray birch	*B. populifolia*	Striped maple	*Acer pensylvanicum*
Northern catalpa[d]	*Catalpa speciosa*	Mountain maple	*A. spicatum*
Hackberry spp.[c]	*Celtis* spp.	Yellow buckeye[d]	*Aesculus flava*
Hackberry	*C. occidentalis*	Ailanthus	*Ailanthus altissima*
Butternut	*Juglans cinerea*	Red alder[d]	*Alnus rubra*
Cucumbertree	*Magnolia acuminata L*	Serviceberry spp.	*Amelanchier* spp.
Mountain magnolia	*M. fraseri*	Pawpaw[d]	*Asimina triloba*
Paulownia, empress tree[c]	*Paulownia tomentosa*	American hornbeam, musclewood	*Carpinus caroliniana*
Sycamore	*Platanus occidentalis*		
Black cherry	*Prunus serotina*	American chestnut	*Castanea dentata*
Black willow[d]	*Salix nigra*	Eastern redbud	*Cercis canadensis*
Sassafras	*Sassafras albidum*	Hawthorn spp.	*Crataegus* spp.
Elm spp.[c]	*Ulmus* spp.	Hawthorn (crus-galli)	*C. crus-galli*
American elm	*U. americana*	Osage-orange[c]	*Maclura pomifera*
Slippery elm	*U. rubra*	Sweetbay	*Magnolia virginiana*
Other eastern hard hardwoods		Apple spp.	*Malus* spp.
Sweet birch	*Betula lenta*	Eastern hophornbeam, ironwood	*Ostrya virginiana*
Catalpa spp.[c]	*Catalpa* spp.		
Flowering dogwood	*Cornus florida*	Sourwood	*Oxydendrum arboreum*
Common persimmon[c]	*Diospyros virginiana*	Pin cherry	*Prunus pensylvanica*
Waterlocust[c]	*Gleditsia aquatica*	Chokecherry	*P. virginiana*
Honeylocust[d]	*G. triacanthos*	Bear oak, scrub oak	*Quercus ilicifolia*
American holly	*Ilex opaca*	Willow spp.[d]	*Salix* spp.
Red mulberry[c]	*Morus rubra*	American mountain-ash[d]	*Sorbus americana*
Oak spp. (deciduous)[c]	*Quercus* spp.		

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 d.b.h.) and trees (≥ 5.0 inches d.b.h.) unless otherwise noted by footnote *c* or *d*.

[b] Little (1979).

[c] Tree only.

[d] Sapling only.

Randolph, KaDonna C.; Morin, Randall S.; Steinman, Jim. 2010. Descriptive statistics of tree crown condition in the Northeastern United States. Gen. Tech. Rep. SRS–124. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 21 p.

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 Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia 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.