CHAPTER 7.

Crown Condition

KaDonna C. Randolph

INTRODUCTION

Tree crown conditions are visually assessed by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) Program as an indicator of forest health. These assessments are useful because individual tree photosynthetic capacity is dependent upon the size and condition of the crown. In general, trees with full, vigorous crowns are associated with more vigorous growth rates (Zarnoch and others 2004); when trees undergo stress, the first symptoms are often visible in the crown. Furthermore, tree crowns form the overstory structure of the forest and directly influence the composition and structure of the understory thereby making them an integral component of the forest ecosystem.

Initially implemented by the Forest Health Monitoring (FHM) Program, crown conditions have been measured in the United States since 1990 (Randolph 2013). After a series of field tests and reviews in the early 1990s, the crown condition indicator was formalized to include a set of eight variables: vigor class, uncompacted live crown ratio, crown light exposure, crown position, crown density, crown dieback, foliage transparency, and crown diameter (Schomaker and others 2007). When the FHM detection monitoring plots were incorporated into FIA in the year 2000, assessment of these and other forest health indicators was continued by FIA (Woodall and others 2011).

Due to budget uncertainties in 2011, FIA deferred collection of the forest health indicators and began reviewing its forest health monitoring protocols in light of fluctuating budgets, emergent user needs, and evolving forest health science (USDA Forest Service 2012). The review led FIA to revise the "Phase 3 (P3) Forest Health Indictors" aspect of the program into a new framework termed "Phase 2 (P2) Plus / Ecosystem Indicator Program" (USDA Forest Service 2013). When the new framework is fully implemented, FIA will collect fewer variables on a greater number of plots in an effort to improve flexibility without compromising long-term analytical capabilities. To date, updated protocols for the crown condition indicator, which, at a minimum, call for the assessment of uncompacted live crown ratio and crown dieback on all P2 Plus plots, have been implemented to varying degrees by the four FIA regions (fig 7.1).

This chapter represents the third national summary of crown condition in the United States. Previous summaries were included in *Forest Health Monitoring: 2006 National Technical Report* (Randolph 2009) and *Forest Health Monitoring: National Status, Trends, and Analysis 2013* (Randolph 2015). In like manner, the objective of this report is to summarize crown conditions for major species groups for the years 2011–2015 and evaluate changes in crown condition during the last two decades with the goal of identifying species in decline. Special attention is given to species affected by three of the top mortality agents in the Eastern United States: emerald ash borer (*Agrilus planipennis*) (EAB), beech bark disease (BBD), and hemlock woolly adelgid (*Adelges tsugae*) (HWA). Due to the transition from P3 to P2 Plus, crown dieback was the only crown condition variable evaluated.

METHODS

Data

Crown dieback is the recent mortality of branches with fine twigs, which begins at the terminal portion of a branch and proceeds toward the trunk (Schomaker and others 2007). Forest Inventory and Analysis assesses crown dieback on live trees with diameter at breast height (d.b.h.) ≥ 12.7 cm by means of ocular estimation and records the values in 5-percent classes. Prior to 2011, crown dieback was collected on FIA P3 plots in all regions. In 2011 and the years following, assessment of crown dieback varied by region (table 7.1). For this summary, I obtained all crown dieback data collected by FIA from 2000 through 2015 (O'Connell and others 2017) and utilized various subsets of the data to summarize current conditions and calculate changes over time. Crown dieback assessments made by the FHM Program from 1995 through 1999 (Randolph 2006, Randolph and others 2010a, 2010b) were also incorporated. Though little to no crown dieback data were available for the Rocky Mountain and West Coast regions after 2010, information on tree status (live, dead, or cut) in those regions was incorporated into the analysis.

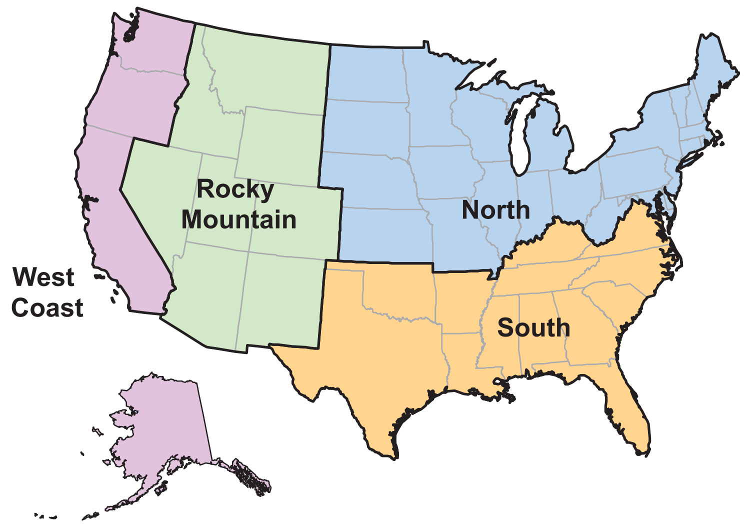

Figure 7.1—Regional breakdown of the United States for the crown dieback analysis corresponds to the administrative units of the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program.

Analysis

Survivorship—The relationship between past crown dieback and current tree status, i.e., survivorship, was evaluated for all regions. For the Rocky Mountain and West Coast regions, trees with crown dieback measured from 2001 through 2005 were matched with observations made from 2011 through 2015. For the North and South regions, observations made from 2006 through 2010 were matched with observations made from 2011 through 2015. Measurement intervals for individual trees assessed during these time periods varied from 2 to 12 years; only trees with a 5-year

Table 7.1—Year of crown dieback assessment by region and State, 2011–2015

Region[a] and measurement year	State
North	
2011–2015	Illinois, Missouri, Pennsylvania
2011–2013, 2015	Delaware
2012–2015	Connecticut, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, South Dakota, Vermont, West Virginia, Wisconsin
2013–2015	Rhode Island
Rocky Mountain	
2011–2012	Nevada, New Mexico
2012	Arizona, Colorado, Idaho, Montana, Utah, Wyoming
South	
2012–2015	Alabama, Arkansas, Florida, Georgia, Kentucky, Mississippi, North Carolina, Oklahoma, South Carolina, Texas
2012–2014	Louisiana[b], Virginia
2012–2013, 2015	Tennessee

[a] Crown dieback was not assessed in the West Coast region.
[b] Crown dieback was assessed in 2015 but the data were not available at the time of analysis.

measurement interval in the North and South regions or 10-year measurement interval in the West Coast and Rocky Mountain regions were included in the survivorship analysis. The percentage of trees by past crown dieback class (0 percent, 1–10 percent, 11–20 percent, and > 20 percent) and current tree status (live, dead, or cut) was calculated for each region. To expose any species groups potentially affected by acute stressors between the most recent and previous assessments, the percentage of trees in each current tree status class was calculated for trees with 0-percent crown dieback at the previous assessment for major species groups in each region.

Current conditions—Current (2011–2015) crown dieback conditions were summarized for the North and South regions by species class (hardwood or softwood) and species group. Mean crown dieback was calculated using the ratio of means estimator (Cochran 1977, Woodall and others 2011). The frequency of trees in each crown dieback class (0 percent, 1–10 percent, 11–20 percent, and > 20 percent) also was calculated by species group. Infestation data (county and date of infestation discovery) were obtained for EAB (EAB Information Network 2017); beech scale (*Cryptococcus fagisuga*), the initiating agent of BBD (Cale and Morin 2017); and HWA (USDA Forest Service, Northeastern Area 2017) (fig. 7.2). These data were used to respectively subdivide ash (*Fraxinus* spp.), beech (*Fagus grandifolia*), and eastern hemlock (*Tsuga canadensis*) trees into classes based on duration of infestation. Current mean crown dieback and the frequency of trees in each crown dieback class then were calculated for each species group by infestation class.

Trends—Changes in crown condition can be evaluated by comparing crown dieback assessments on the same set of trees over time or by examining the net change in dieback for all trees measured at multiple points in time.[1] The former uses only paired trees at two (or more points) in time and necessarily includes surviving trees only. The latter includes all trees measured at each point in time and includes trees that have survived across all time periods as well as those that died or were cut. To make the most of the crown dieback data collected to date, I made two evaluations of change in crown dieback over time. The first included only trees with crown dieback assessments made from 2006 through 2010 and 5 years later (2011–2015), i.e., surviving trees with two dieback assessments, in the North and South regions. A paired *t*-test was used to test the hypothesis that the mean change in crown dieback for the paired trees was zero. Secondly, I calculated mean crown dieback by region (North and South) for all trees assessed by FIA during three different 5-year time periods: 2001–2005, 2006–2010, and 2011–2015. Regional crown dieback means from the last FHM assessments (1995–1999 for the North region and 1996–1999 for the South region) were obtained from Randolph (2006) and Randolph and others (2010a, 2010b). The frequency of trees by crown dieback class (0 percent, 5 percent, and > 5 percent) was calculated for each time period by region.

RESULTS AND DISCUSSON

Relationship between Crown Dieback and Survivorship

Crown dieback is strongly correlated with tree survivorship such that trees with greater amounts of dieback are more likely to die within 5 years than those with little or no dieback (Morin and others 2015, Steinman 2000). Therefore, as expected, the likelihood of mortality tended to increase with increasing

[1] Bechtold, W.A.; Randolph, K.C. 2006. FIA Crown-condition indicator workshop outline and class notes. Unpublished document. 70 p. On file with: U.S. Department of Agriculture, Forest Service, Southern Forest Inventory and Analysis Program, 4700 Old Kingston Pike, Knoxville, TN 37919.

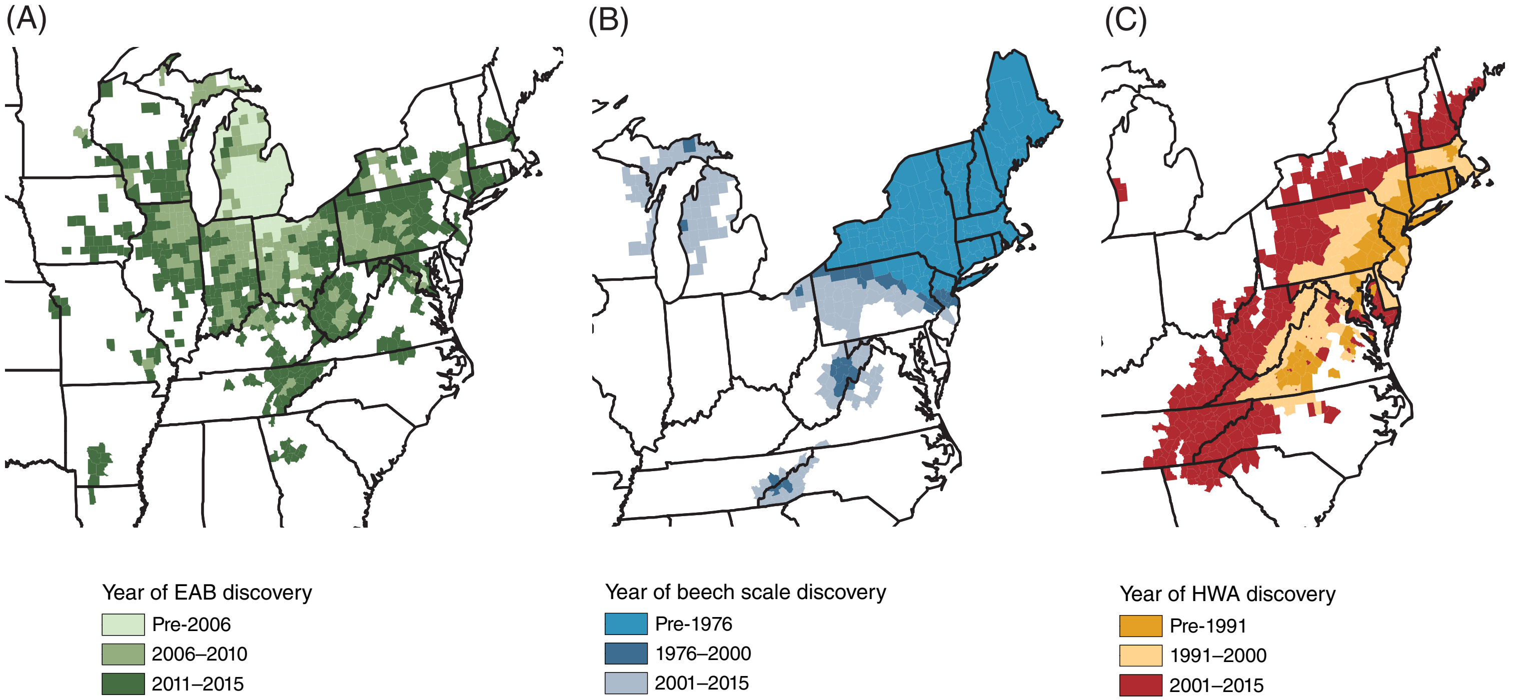

Figure 7.2—Year of discovery and distribution of (A) emerald ash borer (EAB Information Network 2017), (B) beech scale (Cale and Morin 2017), and (C) hemlock woolly adelgid (USDA Forest Service, Northeastern Area 2017) in the Eastern United States through the year 2015.

crown dieback in all regions (fig. 7.3). In the West Coast region, 50.5 percent of the trees assessed with > 20-percent crown dieback during 2001–2005 were dead by the time they were remeasured 10 years later. Likewise in the Rocky Mountain region, 43.2 percent of the trees with > 20-percent crown dieback died over the same 10-year period. Similar percentages were observed over a 5-year period in the Eastern United States where 47.2 percent and 54.0 percent of the trees assessed with > 20-percent crown dieback during 2006–2010 in the North and South regions, respectively, were dead by the time they were remeasured during 2011–2015 (fig. 7.3).

Although high levels of crown dieback are a good indicator of impending mortality, there are instances when trees with no crown dieback will die before they are reassessed. This is most likely to happen when trees die quickly as the result of an acute stressor, e.g., wildfire, or when the effects of less acute stressors coincide with a lengthy remeasurement period. Regions or species groups with high levels of mortality among trees with 0-percent crown dieback at the previous inventory prompt further investigation. Such was the case in the Rocky Mountain region where 19.2 percent of the trees observed to have 0-percent crown dieback during 2001–2005 died within 10 years (fig. 7.3). Further investigation revealed that this group of trees was composed primarily of lodgepole pine (*Pinus contorta*), quaking aspen (*Populus tremuloides*), and subalpine fir (*Abies lasiocarpa*). Considered individually, each of these species

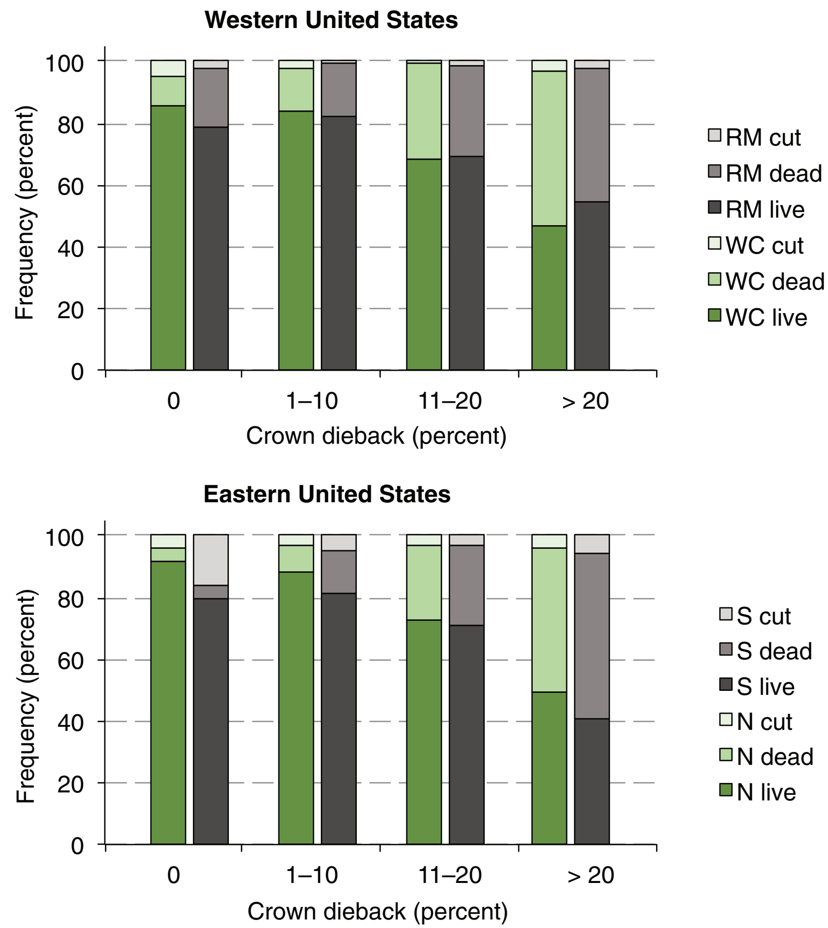

Figure 7.3—Percentage of trees remeasured after an interval of 10 years (Western United States) or 5 years (Eastern United States) by previous crown dieback, current tree status, and region. N=North. RM=Rocky Mountain. S=South. WC=West Coast. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program)

had more than 25 percent mortality among trees with 0-percent crown dieback during the 2001–2005 inventory (fig. 7.4). Lodgepole pine mortality was likely due to mountain pine beetle (*Dendroctonus ponderosae*) activity which has affected approximately 7.8 million ha of forest land in the Western United States since the year 2000 (Potter and Paschke 2016). Mountain pine beetle activity was relatively stable (< 405 000 ha annually) from 1990 through 2001 and, though increasing, remained at or below 1.2 million ha annually during the years that crown dieback was first assessed (2001–2005) (Jenkins 2015). In the intervening time period before the trees were remeasured, beetle activity increased above 1.6 million ha annually, peaking at 3.6 million ha in 2009, and incited a substantial increase in tree mortality (Jenkins 2015, Oswalt and others 2014).

The high level of quaking aspen mortality in the Rocky Mountain region among trees with 0-percent crown dieback during 2001–2005 was likely induced by a complex of interacting factors in the mid- to late-2000s termed sudden aspen decline (SAD) (Worrall and others 2013). The peak of this disease complex (2007–2008) occurred after crown dieback was first assessed during 2001–2005 (Worrall and others 2015). Similarly, mortality of subalpine fir in the Rocky Mountain region may be attributed to subalpine fir decline (SFD) which, like SAD, is a complex that involves many factors, including the western balsam bark beetle (*Dryocoetes confusus*), various fungi, and temperature and precipitation stress (Reich and others 2016).

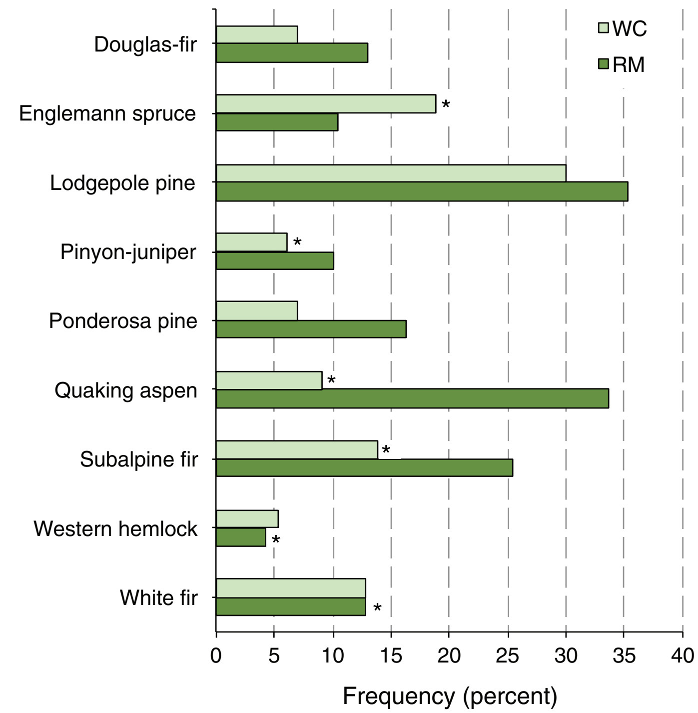

Figure 7.4—Percentage of trees in the West Coast (WC) and Rocky Mountain (RM) regions assessed with 0-percent crown dieback during 2001–2005 that were dead upon reassessment during 2011–2015, by species group. Species groups with < 200 observations are indicated with an asterisk. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program)

During 2007–2014, aerial survey data indicated that SFD mortality fluctuated yearly, affecting between 98 594 ha in 2013 (Potter and Paschke 2015) and 211 470 ha in 2007 (Potter 2012).

In contrast to the western regions, the percentage of trees assessed with 0-percent crown dieback during 2006–2010 that died prior to reassessment during 2011–2015 was < 10 percent for most species groups in the Eastern United States (fig. 7.5). One notable exception was elm (*Ulmus* spp.) in the North region, which had 17.4 percent mortality among trees with 0-percent crown dieback (fig. 7.5). Elm trees are affected by a number of insect and disease agents (Bey 1990, Penn State Extension 2017), most notably Dutch elm disease (DED) (Haugen 1998) and elm yellows (formerly called elm phloem necrosis) (Marcone 2017). Both DED and elm yellows rapidly induce mortality and are likely contributing factors to the high level of mortality.

Current Crown Dieback

Due to morphological traits or harsh growing conditions, some tree species generally maintain more crown dieback than others. Under optimal conditions, hardwoods typically have more crown dieback than softwoods. This expectation held true for the current inventory period, 2011–2015. In the North region, mean crown dieback ranged from 0.6 percent for the eastern white pine (*Pinus strobus*) and red pine (*P. resinosa*) group to 6.1 percent for elm (table 7.2) and was 2.8 percent for all species combined. In the South region, mean crown

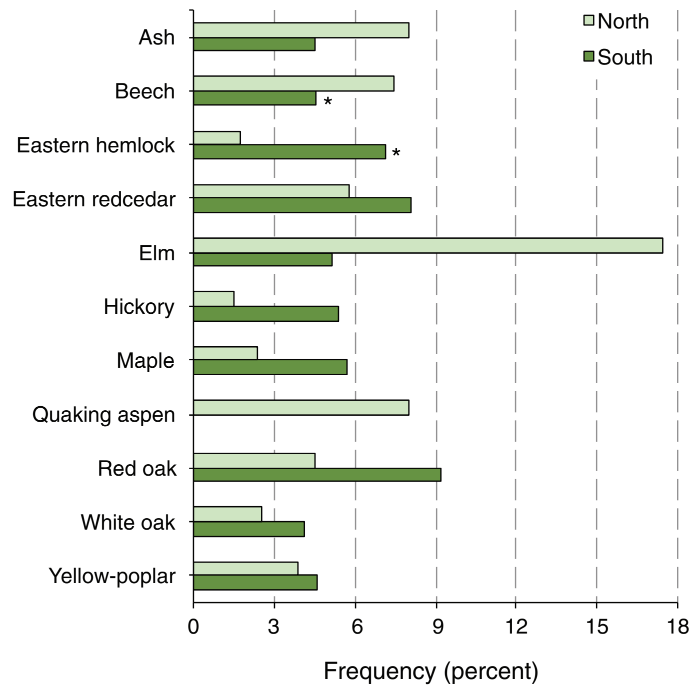

Figure 7.5—Percentage of trees in the North and South regions assessed with 0-percent crown dieback during 2006–2010 that were dead upon reassessment during 2011–2015, by species group. Species groups with < 200 observations are indicated with an asterisk. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program)

Table 7.2—Mean crown dieback and number of trees ≥ 12.7 cm d.b.h. by dieback class for major species groups in the North region, 2011–2015

Species group	Plots	Trees	Mean	SE[a]	Dieback class 0	1–10	11–20	> 20
			%		---------------- %	----------------		
Softwoods	1,364	18,662	1.7	0.1	15,361	2,863	226	212
Eastern hemlock	306	2,277	1.1	0.2	2,039	199	20	19
Eastern redcedar	154	800	2.4	0.5	572	201	11	16
Eastern white and red pines	432	3,249	0.6	0.1	2,950	281	9	9
Northern white-cedar	215	3,042	4.2	0.7	2,002	827	103	110
Spruce and balsam fir	630	6,609	1.1	0.1	5,554	971	55	29
Hardwoods	2,574	44,513	3.3	0.1	28,465	14,301	837	910
Ash	758	2,908	5.4	0.5	1,771	897	94	146
Basswood	267	986	2.4	0.4	754	212	5	15
Beech	453	1,991	3.2	0.3	1,362	524	65	40
Birch	832	3,750	2.9	0.2	2,563	1,053	64	70
Black cherry	519	1,671	3.7	0.3	946	653	40	32
Black walnut	218	487	3.6	0.5	255	217	8	7
Blackgum	177	410	1.8	0.4	317	87	3	3
Cottonwood and aspen	548	3,595	2.5	0.2	2,745	716	59	75
Elm	547	1,468	6.1	0.4	633	719	41	75
Hackberry	163	482	4.7	0.6	180	284	8	10
Hickory	531	1,878	2.4	0.2	1,217	637	6	18
Maple	1,703	13,437	2.6	0.1	9,459	3,510	246	222
Red oak	931	3,777	3.5	0.2	2,030	1,623	69	55
Sassafras	157	493	4.7	0.8	264	208	6	15
White oak	727	3,943	3.4	0.2	2,059	1,789	44	51
Yellow-poplar	177	768	2.9	0.6	548	201	7	12

[a] Standard error.

dieback ranged from 0.1 percent for the loblolly pine (*P. taeda*) and shortleaf pine (*P. echinata*) group to 4.0 percent for black cherry (*Prunus serotina*) (table 7.3) and was 1.0 percent for all species combined. Consistent with previous observations (Randolph 2015), and with the exception of black cherry, crown dieback was higher in the North region than in the South region for species groups observed in both regions. In particular, ash and elm had considerably higher means in the North than in the South: 5.4 percent vs. 2.7 percent and 6.1 percent vs. 1.6 percent, respectively. The disparity between the North and South regions for ash and elm may be due in part to the more northerly distribution of EAB (fig. 7.2), DED (USDA Forest Service 2017), and elm yellows (Marcone 2017).

Table 7.3—Mean crown dieback and number of trees ≥ 12.7 cm d.b.h. by dieback class for major species groups in the South region, 2011–2015

					Dieback class			
Species group	Plots	Trees	Mean	SE[a]	0	1–10	11–20	> 20
			%		----------------	%	----------------	
Softwoods	1,570	23,305	0.3	0.1	22,822	345	41	97
Eastern redcedar	245	1,010	0.7	0.2	980	17	3	10
Loblolly and shortleaf pines	1,099	17,068	0.1	0.0[b]	16,902	126	15	25
Longleaf and slash pines	218	3,028	0.3	0.2	2,943	71	2	12
Virginia pine	113	632	1.1	0.4	603	18	2	9
Hardwoods	2,041	27,686	1.6	0.1	25,302	1,492	391	501
Ash	308	914	2.7	0.5	798	70	15	31
Beech	122	273	1.3	0.7	257	10	2	4
Black cherry	275	529	4.0	1.0	449	39	14	27
Elm	528	1,226	1.6	0.3	1,128	53	16	29
Hickory	616	1,779	1.4	0.3	1,635	92	24	28
Maple	713	2,611	1.3	0.2	2,462	73	29	47
Red oak	1,214	4,714	1.6	0.1	4,287	281	58	88
Sugarberry	107	325	1.5	0.5	307	10	2	6
Sweetgum	828	3,339	1.0	0.1	3,148	110	44	37
Tupelo and blackgum	483	1,768	0.6	0.1	1,697	52	11	8
White oak	949	4,297	1.8	0.2	3,787	357	74	79
Yellow-poplar	398	1,626	0.7	0.2	1,569	33	13	11

[a] Standard error.

[b] Value is >0.0 but <0.1.

Ash, beech, and hemlock—Among the ash, beech, and hemlock trees, crown dieback was greatest in counties with the known stressors (EAB, BBD, and HWA) and was highest for ash and hemlock in areas where the stressors have persisted the longest. However, the difference among the lowest and highest crown dieback means for hemlock was only 2.1 percentage points (fig. 7.6). The reason for the lack of separation among the means in counties with and without HWA may be due in part to the way hemlock trees are affected by the insect. HWA feeds at the base of the needles causing their desiccation. Defoliation follows, typically beginning at the base of the crown and moving upward even when HWA is distributed throughout the crown (McClure and others 1996). FIA procedural definitions require crown dieback to be in the "upper and outer portions of the tree" in order to be recorded (Schomaker and others 2007: 23). Therefore, full evidence of HWA infestation may not be manifested in the crown dieback assessments made by FIA. Other measures of crown condition, e.g., crown density and foliage transparency (Schomaker and others 2007), have proven useful for predicting hemlock decline individually and together with crown dieback (Eschtruth and others 2013, Rentch and others 2009).

For beech, crown dieback means and the percentage of trees with > 10-percent dieback (fig. 7.7) mirrored what might be expected in the three stages of BBD known as the advance front, killing front, and aftermath (Cale and others 2017). Counties with the latest beech

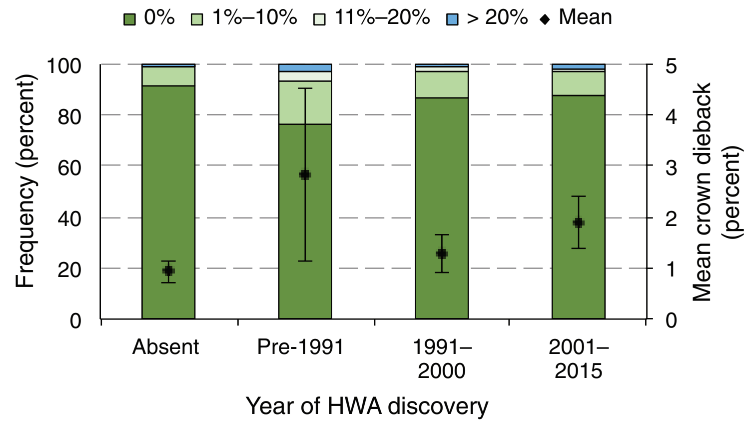

Figure 7.6—Mean crown dieback by duration of hemlock woolly adelgid (HWA) infestation and percentage of trees observed in each infestation class, by crown dieback class, for eastern hemlock trees assessed in the Eastern United States during 2011–2015. Bars around the mean represent one standard error. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program)

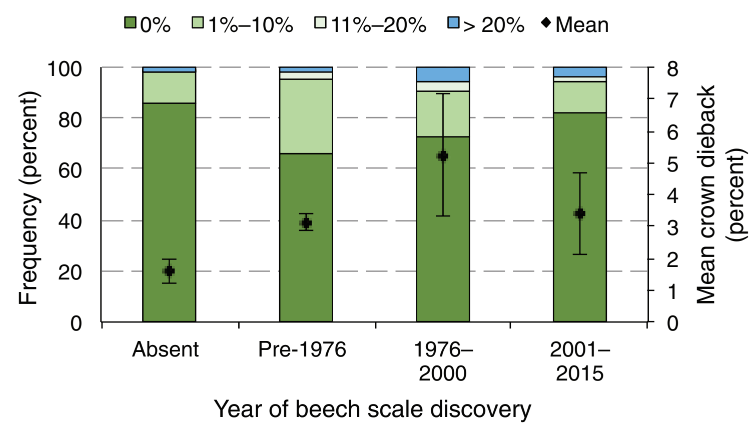

Figure 7.7—Mean crown dieback by duration of beech scale infestation and percentage of trees observed in each infestation class, by crown dieback class, for beech trees assessed in the Eastern United States during 2011–2015. Bars around the mean represent one standard error. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program)

scale detections (post-2000) are most likely in the advance front stage where beech scale populations are steadily increasing. This stage may last up to 10 years before follow-on fungal infections of *Neonectria* spp. begin to induce high levels of beech mortality, i.e, the killing front stage (Cale and others 2017). Mean crown dieback was highest (5.2 percent) in the counties presumably in the killing front stage, i.e, where beech scale was detected during 1976–2000 (fig. 7.2). Counties with the earliest beech scale detections (pre-1976) represent the aftermath stage of BBD wherein beech mortality is typically reduced due to fewer host trees and lower numbers of beech scale insects. Trees there are subject to chronic stress from BBD (Cale and others 2017), and therefore it is reasonable that mean crown dieback in these counties remains elevated above areas yet to be affected by BBD. The relatively large standard errors associated with the means for trees in counties with beech scale detections since 1976 reflect in part the degree to which stands are moving into or out of the killing front stage.

For ash, mean crown dieback increased as duration of EAB infestation increased (fig. 7.8). Mean crown dieback was highest (15.7 percent) in the counties where EAB has been present since before 2006 and lowest (3.8 percent) in counties where EAB is absent. Standard errors of the means also increased as duration of EAB infestation increased (fig. 7.8), in part reflecting variations in the distribution of the insect within the infested counties and susceptibility of individual trees. Small sample size also

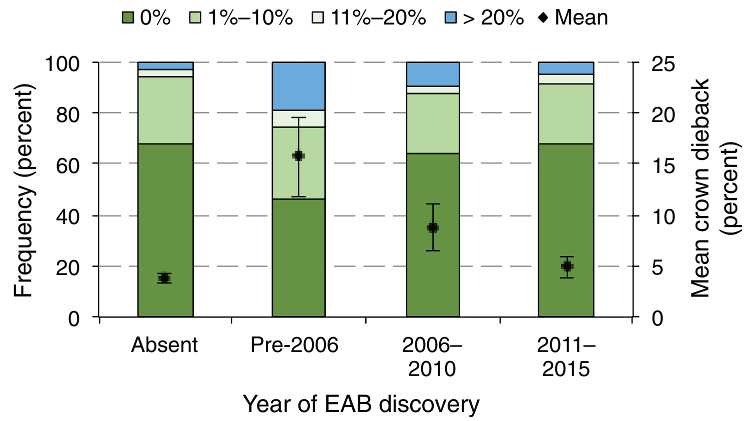

Figure 7.8—Mean crown dieback by duration of emerald ash borer (EAB) infestation and percentage of trees observed in each infestation class, by crown dieback class, for ash trees assessed in the Eastern United States during 2011–2015. Bars around the mean represent one standard error. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program)

contributed to the variability, especially in the counties where EAB was discovered prior to 2006 (only 119 trees on 25 plots).

Trends in Crown Dieback

Overall there has been a downward trend, i.e., improvement, in mean crown dieback in both the North and South regions since the late 1990s (fig. 7.9). Although the changes in mean crown dieback are small, only 1.3 percentage points in the North and 0.9 percentage points in the South, more and more trees have been observed to have 0-percent crown dieback over the last two decades, particularly in the North region (fig. 7.10). Given that the protocol for

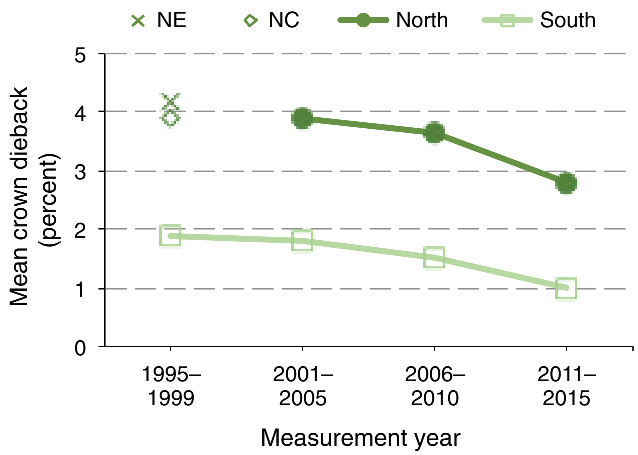

Figure 7.9—Mean crown dieback for trees ≥ 12.7 cm d.b.h. in the Eastern United States, by region and inventory period. Crown dieback in the 1990s was collected by the Forest Service Forest Health Monitoring Program and reported by Randolph (2006) for the South region and Randolph and others (2010a, 2010b) for the Northeast (NE) and North Central (NC) subregions. (Additional data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program)

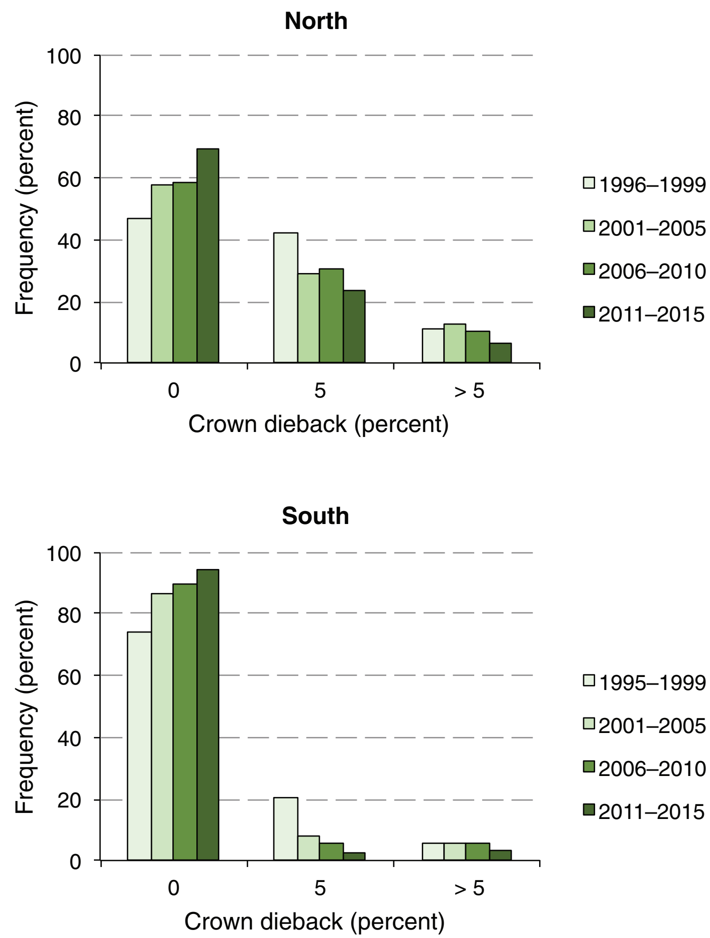

Figure 7.10—Distribution of crown dieback for trees ≥ 12.7 cm d.b.h. in the Eastern United States, by region and inventory period. (Data source: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program)

assessing crown dieback has not changed over time (Randolph 2013) and that measurement quality objectives for crown dieback historically have been met (Westfall and others 2009), this small downward trend may represent an actual change in condition rather than measurement variability. Nevertheless, because the mean was < 5 percent at all time periods, the biological significance of this decrease, i.e., the effect on growth rates, is likely negligible.

Crown dieback for trees measured in the years 2006–2010 and again in 2011–2015 was stable for most species groups across the Eastern United States (tables 7.4 and 7.5). Notable exceptions were ash, elm, and yellow-poplar. In the North region, the overall increase in mean crown dieback for these three groups ranged between 1.8 and 2.9 percentage points (table 7.4). In the South region, crown dieback for ash and yellow-poplar was stable, but the mean for elm increased 2.2 percentage points (table 7.5). Further examination of the data revealed that the increase in crown dieback for yellow-poplar in the North region was largely driven by a small number of trees with changes in crown dieback from ≤ 5 percent to 99 percent. Similarly large changes in crown dieback were more common for ash trees in the North region and elm trees in both regions. Though ash yellows (Sinclair and Griffiths 1994) may play a role, EAB was likely the driving factor for the change among ash as the mean change in crown dieback was higher for ash in counties with EAB (mean = 5.4 percent, standard error = 1.8) than in counties without EAB (mean < 0.1 percent,

Table 7.4—Mean crown dieback and other statistics for paired trees measured 5 years apart for major species groups in the North region, 2006–2010 vs. 2011–2015

Species group	Plots	Trees	2006–2010 Mean	2006–2010 SE[a]	2011–2015 Mean	2011–2015 SE[a]	P-value[b]
			%		%		
Softwoods	577	6,797	2.1	0.2	1.9	0.2	0.25
Eastern hemlock	126	768	0.9	0.2	1.1	0.3	0.60
Eastern redcedar	64	308	2.2	0.3	2.4	0.5	0.65
Eastern white and red pines	164	1,252	0.9	0.2	0.8	0.2	0.54
Northern white-cedar	106	1,199	4.8	0.7	4.6	1.0	0.87
Spruce and balsam fir	270	2,361	2.0	0.2	1.5	0.2	0.04
Hardwoods	1,097	17,040	3.2	0.1	3.6	0.1	<0.01
Ash	299	1,140	4.3	0.4	6.1	0.8	0.01
Basswood	108	383	2.9	0.5	2.5	0.5	0.55
Beech	188	688	3.5	0.4	3.4	0.4	0.91
Birch	343	1,385	2.9	0.2	3.3	0.4	0.29
Black cherry	190	572	3.6	0.3	3.8	0.4	0.79
Black walnut	83	190	4.2	0.7	4.4	0.8	0.71
Blackgum	77	159	1.1	0.2	1.8	0.5	0.15
Cottonwood and aspen	227	1,200	2.6	0.3	3.2	0.4	0.10
Elm	211	463	3.6	0.3	6.5	0.8	<0.01
Hackberry	78	198	4.1	0.8	5.1	1.1	0.13
Hickory	214	691	2.1	0.2	2.3	0.3	0.52
Maple	714	5,452	2.8	0.1	2.8	0.2	0.65
Red oak	384	1,428	4.0	0.2	4.0	0.3	0.98
Sassafras	68	208	5.3	0.9	4.5	1.1	0.55
White oak	317	1,733	3.3	0.2	3.5	0.3	0.48
Yellow-poplar	67	288	1.7	0.3	3.5	1.0	0.03

[a] Standard error.
[b] The probability of obtaining a larger *t*-value under the null hypothesis that the difference between the two means equals zero.

Table 7.5—Mean crown dieback and other statistics for paired trees measured 5 years apart for major species groups in the South region, 2006–2010 vs. 2011–2015

Species group	Plots	Trees	2006–2010 Mean	2006–2010 SE[a]	2011–2015 Mean	2011–2015 SE[a]	P-value[b]
			%		%		
Softwoods	368	4,730	0.2	0.0[c]	0.4	0.1	0.06
Eastern redcedar	58	258	0.6	0.3	0.4	0.2	0.52
Loblolly and shortleaf pines	255	3,242	0.1	0.0[c]	0.1	0.1	0.16
Longleaf and slash pines	74	730	0.3	0.2	0.8	0.6	0.18
Virginia pine	28	224	0.2	0.1	0.4	0.2	0.57
Hardwoods	509	6,170	1.4	0.1	1.5	0.1	0.57
Ash	77	248	2.0	0.4	2.0	0.6	0.96
Beech	30	57	0.1	0.1	0.6	0.5	0.24
Black cherry	70	131	1.9	0.9	2.7	1.0	0.56
Elm	104	225	1.3	0.4	3.5	1.1	0.04
Hickory	159	430	1.3	0.3	1.2	0.3	0.73
Maple	175	610	1.4	0.3	1.4	0.4	0.95
Red oak	311	1,144	1.3	0.2	1.7	0.3	0.17
Sugarberry	17	35	0.3	0.3	2.9	2.8	0.37
Sweetgum	190	649	1.3	0.3	1.5	0.3	0.56
Tupelo and blackgum	135	351	2.0	1.0	0.4	0.1	0.11
White oak	248	1,065	1.6	0.3	1.1	0.2	0.03
Yellow-poplar	105	370	0.6	0.2	0.3	0.1	0.14

[a] Standard error.
[b] The probability of obtaining a larger *t*-value under the null hypothesis that the difference between the two means equals zero.
[c] Value is >0.0 but <0.1.

standard error = 0.5). Individual-tree damage agent codes (O'Connell and others 2017) for the elm trees were examined but no single factor appeared to be driving the changes.

SUMMARY

Given the backdrop of assessments made over the last two decades, current crown dieback conditions appear to be within expected norms for most species in the Eastern United States As expected, elevated levels of crown dieback were observed for ash, beech, and hemlock trees in areas affected by EAB, BBD, and HWA, respectively. Crown dieback was not only elevated, but also increasing for ash trees in the East, evidence of EAB's continued spread and devastation. Crown dieback was also elevated and increasing for elm trees. This is likely due to DED and elm yellows, although followup study may be warranted to isolate any hot spots of decline and determine if there are other active causal agents, e.g., bacterial leaf scorch caused by *Xylella fastidiosa*.

In the Western United States, reduced P3 data collection prohibited an analysis of crown condition for the years 2011–2015. Previous crown dieback combined with current tree status revealed high mortality among trees previously assessed as having no crown dieback. This was particularly true for lodgepole pine, quaking aspen, and subalpine fir trees in the Rocky Mountain region, and is likely the result of stressors emerging during the intervening 10-year remeasurement period.

LITERATURE CITED

Bey, C.F. 1990. *Ulmus americana* L. American Elm. In: Burns, R.M; Honkala, B.H., tech. coords. Agriculture Handbook 654. Silvics of North America: Volume 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 801–807.

Cale, J.A.; Garrison-Johnston, M.T.; Teale, S.A.; Castello, J.D. 2017. Beech bark disease in North America: over a century of research revisited. Forest Ecology and Management. 394: 86–103.

Cale, J.A; Morin, R.S. 2017. County-level detection dates for beech scale in Canada and the United States. UAL Dataverse V1. http://dx.doi.org/10.7939/DVN/10835. [Date accessed: May 25, 2017].

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

EAB Information Network. 2017. Emerald ash borer detection map by county and year. http://www.emeraldashborer.info/timeline/by_county/index.html. [Date accessed: May 15, 2017].

Eschtruth, A.K.; Evans, R.A.; Battles, J.J. 2013. Patterns and predictors of survival in *Tsuga canadensis* populations infested by the exotic pest *Adelges tsugae*: 20 years of monitoring. Forest Ecology and Management. 305: 195–203.

Haugen, L. 1998. How to identify and manage Dutch elm disease. NA-PR-07-98. Radnor, PA: U.S. Department of Agriculture Forest Service, Northeastern Area, State and Private Forestry. https://www.na.fs.fed.us/spfo/pubs/howtos/ht_ded/ht_ded.htm. [Date accessed: May 31, 2017].

Jenkins, M.L., comp. 2015. Major forest insect and disease conditions in the United States: 2013. FS-1054. Washington, DC: U.S. Department of Agriculture, Forest Service. 44 p. https://www.fs.fed.us/foresthealth/publications/ConditionsReport_2013.pdf. [Date accessed: May 2, 2017].

Marcone, C. 2017. Elm yellows: a phytoplasma disease of concern in forest and landscape ecosystems. Forest Pathology. 47(1): e12324.

McClure, M.S.; Salom, S.M.; Shields, K.S. 1996. Hemlock woolly adelgid. FHTET-96-35. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 18 p.

Morin, R.S.; Randolph, K.C.; Steinman, J. 2015. Mortality rates associated with crown health for eastern forest tree species. Environmental Monitoring and Assessment. 187: 87.

O'Connell, B.M.; Conkling, B.L.; Wilson, A.M. [and others]. 2017. The Forest Inventory and Analysis database: database description and user guide for phase 2 (version 7.0). U.S. Department of Agriculture, Forest Service. 830 p. https://www.fia.fs.fed.us/library/database-documentation/current/ver70/FIADB%20User%20Guide%20P2_7-0_ntc.final.pdf. [Date accessed: May 3, 2017].

Oswalt, S.N.; Smith, W.B.; Miles, P.D.; Pugh, S.A. 2014. Forest resources of the United States, 2012: a technical document supporting the Forest Service update of the 2010 RPA assessment. Gen. Tech. Rep. WO-91. Washington, DC: U.S. Department of Agriculture, Forest Service. 218 p.

Penn State Extension. 2017. Elm diseases. http://extension.psu.edu/pests/plant-diseases/all-fact-sheets/elm-diseases. [Date accessed: May 30, 2017].

Potter, K.M. 2012. Large-scale patterns of insect and disease activity in the conterminous United States and Alaska from the national insect and disease detection survey database, 2007 and 2008. In: Potter, K.M.; Conkling, B.L., eds. Forest Health Monitoring: 2009 national technical report. Gen. Tech. Rep. SRS-167. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 63–78.

Potter, K.M.; Paschke, J.L. 2015. Large-scale patterns of insect and disease activity in the conterminous United States, Alaska, and Hawaii from the national insect and disease survey, 2013. In: Potter, K.M.; Conkling, B.M., eds. Forest Health Monitoring: national status, trends, and analysis 2014. Gen. Tech. Rep. SRS-209. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 19–38.

Potter, K.M.; Paschke, J.L. 2016. Large-scale patterns of insect and disease activity in the conterminous United States and Alaska from the national insect and disease survey, 2014. In: Potter, K.M.; Conkling, B.L., eds. Forest Health Monitoring: national status, trends, and analysis 2015. Gen. Tech. Rep. SRS-213. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 21–40.

Randolph, K. 2015. Crown condition. In: Potter, K.M.; Conkling, B.L., eds. Gen. Tech. Rep. SRS-207. Forest Health Monitoring: national status, trends, and analysis 2013. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 135–151.

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. 2009. Crown condition. In: Ambrose, M.J.; Conkling, B.L., eds. Gen Tech. Rep. SRS-117. Forest Health Monitoring: 2006 national technical report. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 65–110.

Randolph, K.C. 2013. Development history and bibliography of the U.S. Forest Service crown-condition indicator for forest health monitoring. Environmental Monitoring and Assessment. 185(6): 4977–4993. DOI: 10.1007/s10661-012-2919-z.

Randolph, K.C.; Morin, R.S.; Steinman, J. 2010a. 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.; Morin, R.S.; Steinman, J. 2010b. 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.

Reich, R.M.; Lundquist, J.E.; Hughes, K. 2016. Host-environment mismatches associated with subalpine fir decline in Colorado. Journal of Forestry Research. 27(5): 1177–1189.

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.

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.

Sinclair, W.A.; Griffiths, H.M. 1994. Ash yellows and its relationship to dieback and decline of ash. Annual Review of Phytopathology. 32: 49–60.

Steinman, J. 2000. Tracking the health of trees over time on forest health monitoring plots. In: Hansen, M.; Burk, T., eds. Gen. Tech. Rep. NC-212. Integrated tools for natural resources inventories in the 21st century, proceedings of the IUFRO conference; 1998 August 16–20; Boise, ID. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 334–339.

U.S. Department of Agriculture (USDA) Forest Service. 2012. Forest inventory and analysis fiscal year 2011 business report. FS-999. Washington, DC: U.S. Department of Agriculture, Forest Service. 72 p.

U.S. Department of Agriculture (USDA) Forest Service. 2013. Forest inventory and analysis fiscal year 2012 business report. FS-1020. Washington, DC: U.S. Department of Agriculture, Forest Service. 72 p.

U.S. Department of Agriculture (USDA) Forest Service. 2017. Alien forest pest explorer. https://foresthealth.fs.usda.gov/portal/Flex/APE. [Date accessed: May 4, 2017].

U.S. Department of Agriculture (USDA) Forest Service, Northeastern Area. 2017. Forest Health Protection—Hemlock woolly adelgid. Distribution maps. https://www.na.fs.fed.us/fhp/hwa/maps/distribution.shtm. [Date accessed: May 24, 2017].

Westfall, J.A.; Bechtold, W.A.; Randolph, K.C. 2009. Section 1: Tree crown indicator. In: Westfall, J.A., ed. Gen. Tech. Rep. NRS-53. FIA national assessment of data quality of forest health indicators. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 3–15.

Woodall, C.W.; Amacher, M.; Bechtold, W. [and others]. 2011. Status and future of the forest health indicators program of the United States. Environmental Monitoring and Assessment. 177: 419–436.

Worrall, J.J.; Keck, A.G.; Marchetti, S.B. 2015. *Populus tremuloides* stands continue to deteriorate after drought-incited sudden aspen decline. Canadian Journal of Forest Research. 45: 1768–1774.

Worrall, J.; Rehfeldt, G.E.; Hamann, A. [and others]. 2013. Recent declines of *Populus tremuloides* in North America linked to climate. Forest Ecology and Management. 299: 35–51.

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.