CHAPTER 9.

Crown Condition

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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 an individual tree's photosynthetic capacity is dependent upon the size and condition of its crown. In general, trees with full, vigorous crowns are associated with more vigorous growth rates (Zarnoch and others 2004), and 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 Service, 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. Due to budget uncertainties in 2011, FIA halted collection of the forest health indicators, including crown condition (USDA Forest Service 2012). Along with budget constraints, emergent user needs and evolving forest health science have led FIA to incorporate some of its forest health indicators, among them crown condition, into a new framework termed "Phase 2 Plus / Ecosystem Indicator Program" (USDA Forest Service 2013). This new framework collects fewer variables on a greater number of plots in an effort to improve flexibility without compromising long-term analytical capabilities. Specific protocols for the new framework are under development by FIA. Recent analyses suggest that at minimum FIA should continue assessing uncompacted live-crown ratio and crown dieback as part of the Phase 2 Plus / Ecosystem Indicator Program (Morin and others 2012).

The last national reporting of crown condition was included in the 2006 *Forest Health Monitoring National Technical Report* (Randolph 2009) where I summarized data collected from 2000 through 2004. Geographic areas and species groups with poor conditions were identified, and those with unknown causes were investigated further (Randolph and others 2012). In the same manner, this report summarizes crown conditions for major species groups in the United States (2006–2010) and evaluates changes in crown condition during the last decade. Also included are comparisons to the crown conditions observed by the FHM Program between 1996 and 1999 (Randolph 2006; Randolph and Thompson 2010; Randolph and others 2010a, 2010b, 2010c).

METHODS

Data

I used publicly available crown condition data collected by the FIA Program between 2000 and 2010 (table 9.1) (O'Connell and others 2013). Crown density, crown dieback, and foliage transparency for live trees with a diameter of at least 5.0 inches at breast height were summarized by FIA species groups within each FIA region (fig. 9.1). Crown condition definitions and data collection protocols are outlined by Schomaker and others (2007). Briefly, crown density is the amount of crown biomass, i.e., branches, foliage, and reproductive structures, that blocks light visibility through the projected crown outline. Foliage transparency is the amount of skylight visible through the live, normally foliated portion of the crown. 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. All three variables are assessed by means of ocular estimation and recorded in 5-percent classes. High levels of crown dieback indicate potentially serious declines in tree health, while low levels of crown density and high levels of transparency may indicate greater amounts of defoliation and signal that a tree may have a reduced capacity for growth.

Table 9.1—Years of data included in crown condition analyses by State

Measurement years	States
2000–10	Indiana, Iowa, Maine, Michigan, Minnesota, Missouri, Pennsylvania, Utah, Wisconsin
2001–10	Arizona, California, Illinois, Kansas, Nebraska, Oregon, South Dakota, Washington
2001, 2003–09	North Dakota
2001–05, 2007–10	Ohio
2002–10	Alabama, Colorado, Florida, Montana, South Carolina, Tennessee, Texas
2002–05, 2007–10	New Hampshire, New York
2002–04, 2006–10	Arkansas
2002–04, 2006, 2009–10	Georgia
2002–05, 2009–10	Louisiana
2002–06, 2008–10	Virginia
2003–10	Connecticut, Kentucky, Massachusetts, Vermont
2003–07, 2009–10	North Carolina
2004–10	Alaska, Delaware, Idaho, Maryland, New Jersey, West Virginia
2004–05	Nevada
2004–07, 2009–10	Rhode Island
2008–10	New Mexico
2009–10	Mississippi, Oklahoma

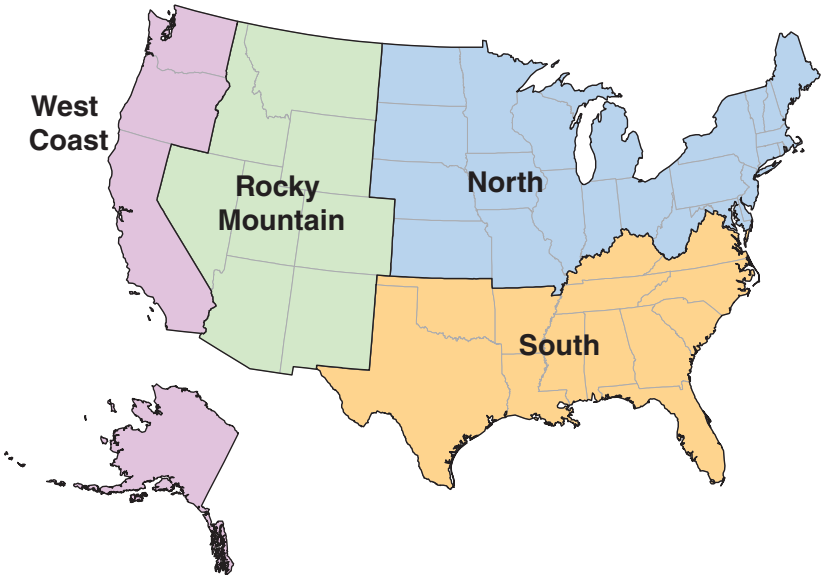

Figure 9.1— Regional breakdown of the United States for the crown condition analysis.

Analysis

The prescribed frequency of measurement for FIA forest health plots is once every five years; however, deviations from this ideal occurred between 2000 and 2010 due to a variety of factors. For example, some States in the East transitioned from a 5-year measurement cycle to a 7-year cycle after the first State-wide inventory was completed. Such factors produced irregular remeasurement periods (i.e., more or less than the ideal 5 years) for a small portion of the data. Analyses for this report dealt with the irregular measurement patterns thusly:

- Using the ratio of means estimator (Cochran 1977, Woodall and others 2011), 5-year moving averages and associated 95-percent confidence intervals were calculated for crown density, crown dieback, and foliage transparency. The moving averages were calculated for the general hardwoods and softwoods groups and for FIA species groups within each region for the years 2004–2010. These moving averages are referenced by their ending year, e.g. the "2007 moving average" is based on data from 2003–2007. Only the most recent assessment for each 5-year time period was used for plots that happened to have two assessments within the selected timeframe. For example, if a plot was measured in 2004 and 2005, the 2005 moving average included the 2005 assessment but not the 2004 assessment.
- Tests for significant changes in crown condition during the 2000s were performed by comparing the 95-percent confidence interval of the 2004 moving average to that of the 2010 moving average. The averages were declared statistically significantly different if the two confidence intervals did not overlap. This method is a more conservative approach (i.e., significant differences may not be detected when they truly exist) than the standard method, which examines the confidence interval for the difference between two means (i.e., $mean_1$ - $mean_2$) (Schenker and Gentleman 2001). This approach was necessary because the groups being compared

included a mixture of paired and non-paired trees.[1] Only species groups measured on at least 100 plots during both time periods were included in the tests. Tests for significant differences were performed on the 2004 and 2010 moving averages for the hardwoods, softwoods, and each species group within each region. Data for the West Coast and South were not available until 2001 and 2002, respectively (table 9.1), which shortened the 2004 5-year moving average to a 4-year moving average for the West Coast and to a 3-year moving average for the South.

FIA has established measurement quality objectives (MQO) for each variable in its inventory. For crown density, crown dieback, and foliage transparency, 90 percent of the assessments by two independent field crews are expected to be within ±10 percent (two classes) of each other (Schomaker and others 2007). Quality assurance data collected between 2002 and 2004 (Westfall and others 2009) indicated that field crews in all regions met the MQO for crown dieback. Field crews in the West Coast region, Rocky Mountain region, and north-central portion of the North region met the MQO for foliage transparency. MQO for crown density were not attained in any region. Given these quality assurance results, it is evident that estimates of crown density and, depending on the region, estimates of foliage transparency include more variation due to inconsistency among observers than estimates of crown dieback. In general, statistically significant changes in crown density that approach ±10 percent from time 1 to time 2 and statistically significant changes in foliage transparency that exceed ±5 percent are worthy of further investigation. Any species or species group with statistically significant changes in more than one of the crown variables, regardless of the magnitude of change, also should be investigated further.

The 5-year moving average was used to assess trends over time and to report the current (2010) conditions. Annual means were calculated for each species group for the years 2000–2010 to shed light on the 5-year moving average trend lines. The spatial distribution of mean crown conditions were examined visually by mapping the plot means. All plots with measurement years of 2006–2010 were displayed for this analysis if the plot contained at least five trees of the species group of interest. Displays were based on the perturbed ("fuzzed") geographic coordinates (McRoberts and others 2005). Maps of the plot means showed nothing extraordinary overall; therefore, only a limited number of examples are presented in the results.

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

RESULTS AND DISCUSSION

West Coast Region

A significant increase in crown dieback was observed for the West Coast hardwood group, which consisted mostly of species from the *Quercus* genera (table 9.2). Some extreme year-to-year fluctuations in crown dieback were evident for the hardwoods; particularly notable were averages >6.0 percent in 2005 and 2006 (fig. 9.2). The effect of these years on the 5-year moving average was evident throughout the measurement period, as the moving average increased between 2005 and 2009 and then declined in 2010 when the 2005 high dropped out of the calculation. The 2010 moving average was 4.8 percent, only slightly higher than the average observed for hardwoods in California, Oregon, and Washington between 1996 and 1999 (fig. 9.2).

Significant changes in crown density, crown dieback, and foliage transparency were observed for the West Coast softwood group, which consisted mostly of species from the *Pseudotsuga, Pinus, Tsuga, Abies,* and *Picea* genera (table 9.2). The changes in all three crown variables were indicative of declining crown conditions. Crown

Table 9.2—Mean crown conditions for major species groups in the West Coast region of the United States, 2006–10

			Crown density			Crown dieback			Foliage transparency		
Species group	Plots	Trees	Mean	SE[a]	Change[b]	Mean	SE[a]	Change[b]	Mean	SE[a]	Change[b]
			%			%			%		
Softwoods	518	10,152	39.9	0.54	-	2.9	0.17	+	22.4	0.43	+
Douglas-fir	223	2,565	38.2	1.18	-	1.3	0.17	0	22.4	1.12	0
Lodgepole pine	63	693	35.3	1.45	NA	3.1	0.52	NA	22.5	1.24	NA
Ponderosa and Jeffrey pines	103	825	37.9	1.76	0	2.1	0.31	0	23.7	1.23	0
Sitka spruce	83	555	46.2	1.32	NA	4.8	1.05	NA	25.1	1.26	NA
True fir	134	1,385	40.8	1.47	-	2.8	0.42	+	18.7	0.57	+
Western hemlock	149	1,641	40.8	0.94	-	3.6	0.37	+	25.4	0.78	+
Hardwoods	211	2,739	36.8	0.69	0	4.8	0.46	+	26.2	0.74	0
Oak	92	1,199	36.0	0.92	NA	5.5	0.73	NA	25.0	1.19	NA

[a] Standard error.
[b] Test that the mean for 2006–10 is significantly different from the mean for 2000–04 based on overlapping 95-percent confidence intervals. (+) indicates the mean for 2006–10 was greater than the mean for 2000–04, (–) indicates the mean for 2006–10 was less than the mean for 2000–04, and (0) indicates no significant difference. NA indicates the test for significant difference was not performed. Only species groups measured on at least 100 plots during both time periods were included in the tests.
Source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program.

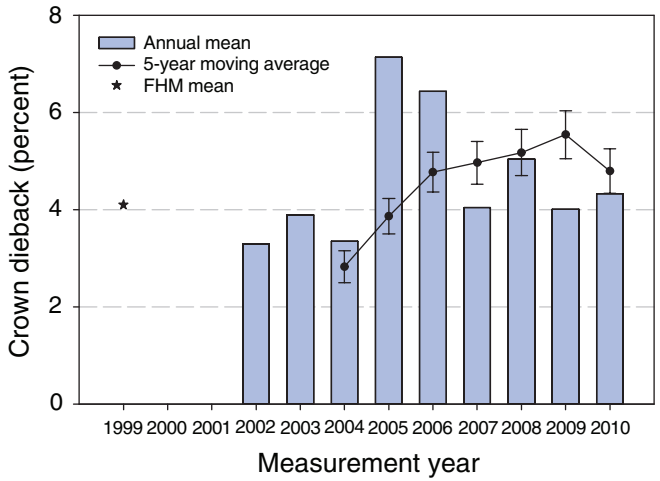

Figure 9.2—Mean crown dieback for hardwood species in the West Coast region of the United States. The annual mean in 2001 was zero percent. The 1999 mean is based on data collected in California, Oregon, and Washington by the Forest Service, Forest Health Monitoring (FHM) Program, 1996–99 (Randolph and others 2010a). Standard error bars are shown for each data point along the 5-year moving average trend line. (Additional data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

density decreased from 45.0 percent to 39.9 percent, crown dieback increased from 1.4 percent to 2.9 percent, and foliage transparency increased from 19.2 percent to 22.4 percent (fig. 9.3). All of the 2010 moving averages indicated poorer conditions than those observed by FHM between 1996 and 1999 (fig. 9.3). The changes among the softwood crown conditions generally were gradual, with few unusually high or low annual means affecting the moving average. Further examination indicated that the decline in the softwood crown conditions were concentrated in western hemlock (*Tsuga heterophylla*), true fir (*Abies* spp., predominantly *A. concolor*), and Douglas-fir (*Pseudotsuga menziesii*) (table 9.2).

Crown density—Significant declines in crown density were observed for Douglas-fir, western hemlock, and true fir in the West Coast region (table 9.2). Average crown density for all three of these species was 49 to 50 percent between 1996 and 1999 (Randolph and others 2010a). By 2004, the moving averages for all three species had dropped to about 46 percent, and by 2010 had declined to <41 percent (fig. 9.4). The decline for western hemlock was fairly steady throughout the measurement period, whereas the declines for Douglas-fir and the true firs were influenced by large decreases in 2006 (fig. 9.4).

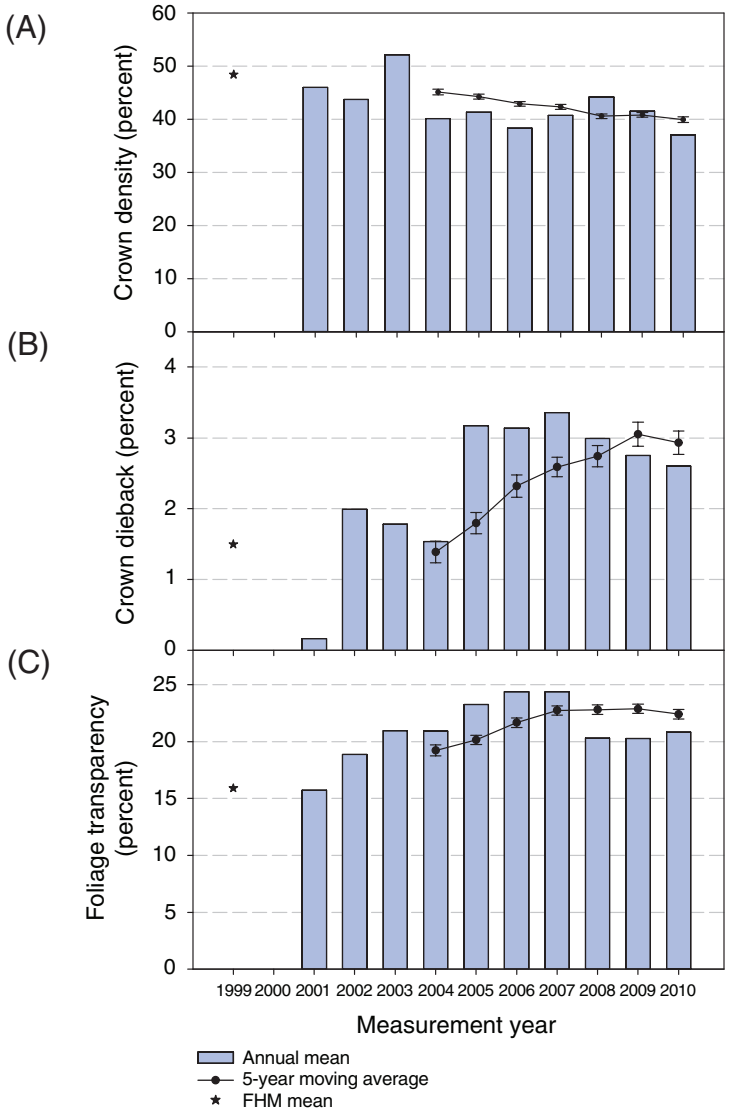

Figure 9.3— (A) Mean crown density, (B) mean crown dieback, and (C) mean foliage transparency for softwood species in the West Coast region of the United States. The 1999 mean is based on data collected in California, Oregon, and Washington by the Forest Service, Forest Health Monitoring Program (FHM), 1996–99 (Randolph and others 2010a). Standard error bars are shown for each data point along the 5-year moving average trend line. (Additional data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

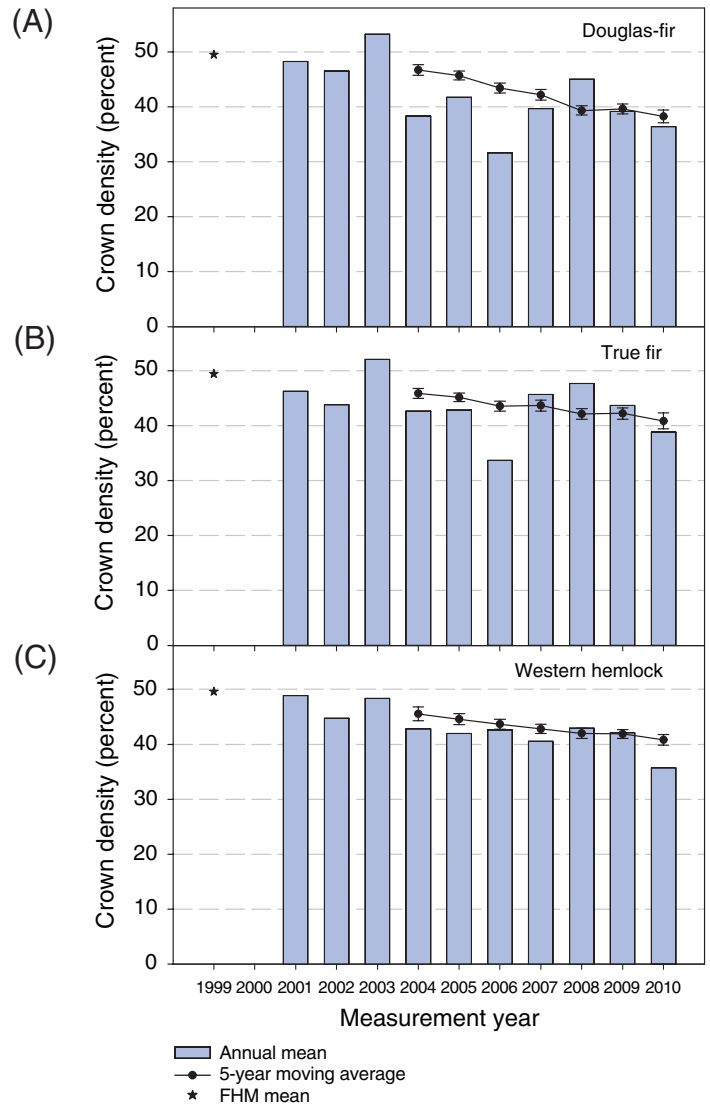

Figure 9.4—Mean crown density for (A) Douglas-fir, (B) true fir, and (C) western hemlock in the West Coast region of the United States. The 1999 mean is based on data collected in California, Oregon, and Washington by the Forest Service, Forest Health Monitoring Program (FHM), 1996–99 (Randolph and others 2010a). Standard error bars are shown for each data point along the 5-year moving average trend line. (Additional data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

Crown dieback—Significant increases in crown dieback were observed for true fir and western hemlock in the West Coast region during the 2000s (table 9.2). Between 1996 and 1999, both species groups averaged <2.0 percent crown dieback (Randolph and others 2010a), but by 2010, the moving average had risen to 2.8 percent for true fir and 3.6 percent for western hemlock (table 9.2). The pattern of increasing crown dieback was characterized by a relatively steady increase throughout the measurement period for true fir and by a peak in the middle of the measurement period for western hemlock (fig. 9.5). An examination of the 2006–2010 plot averages indicated that western hemlock crown dieback was, in general, higher in southeast Alaska than in coastal Washington and Oregon (fig. 9.6).

Foliage transparency—Significant increases in foliage transparency were observed for true fir and western hemlock in the West Coast region during the 2000s (table 9.2). The change in foliage transparency for the true fir group was steady and statistically significant, but rather small, increasing from a 2004 moving average of 16.1 percent to 18.7 percent in 2010 (fig. 9.7). The change in western hemlock foliage transparency was larger, increasing from 20.5 percent in 2004 to 25.4 percent in 2010 (fig. 9.7). The change for

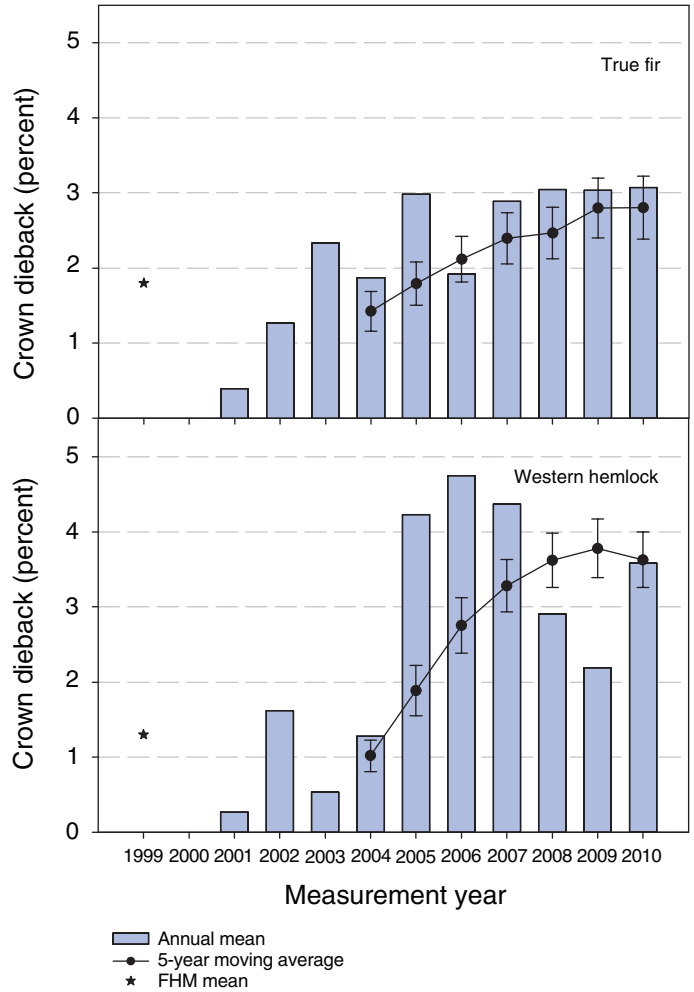

Figure 9.5—Mean crown dieback for true fir and western hemlock in the West Coast region of the United States. The 1999 mean is based on data collected in California, Oregon, and Washington by the Forest Service, Forest Health Monitoring (FHM) Program, 1996–99 (Randolph and others 2010a). Standard error bars are shown for each data point along the 5-year moving average trend line. (Additional data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

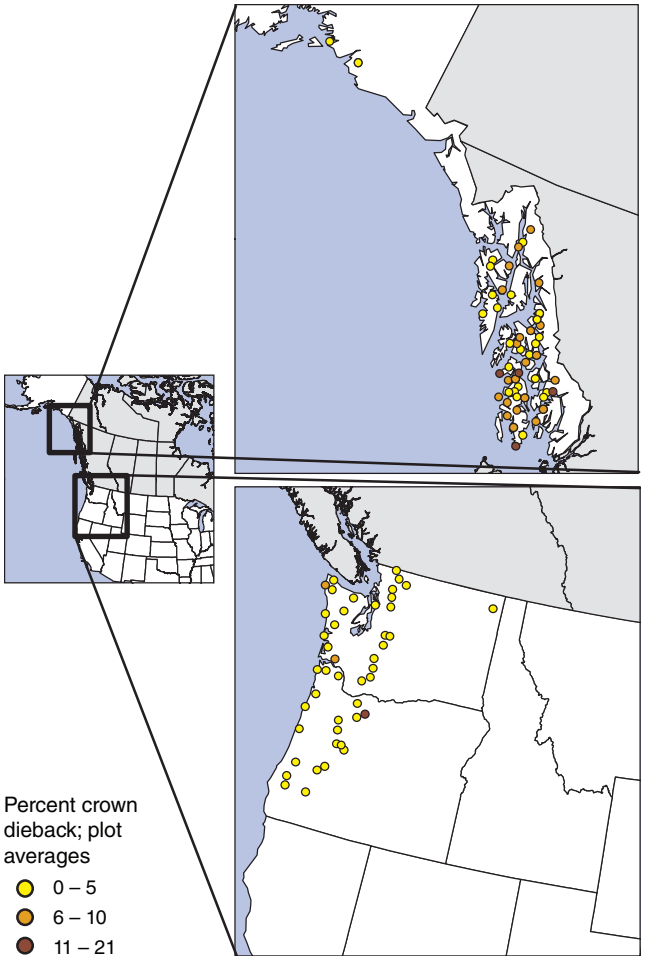

Figure 9.6—Western hemlock crown dieback plot averages, 2006–10. Plot locations are approximate. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

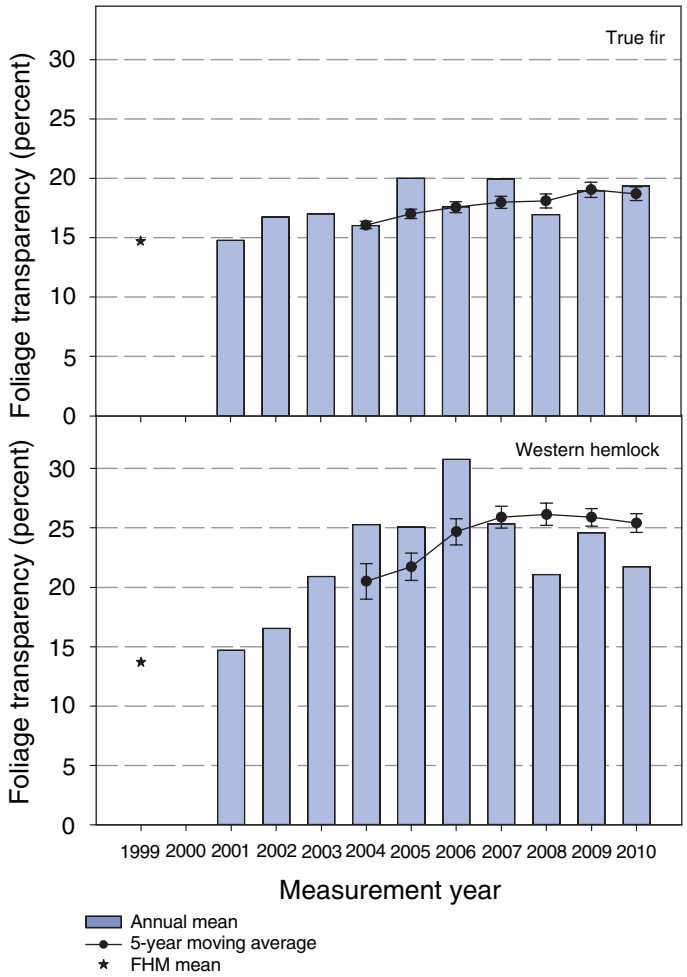

Figure 9.7—Mean foliage transparency for true fir and western hemlock in the West Coast region of the United States. The 1999 mean is based on data collected in California, Oregon, and Washington by the Forest Service, Forest Health Monitoring (FHM) Program, 1996–99 (Randolph and others 2010a). Standard error bars are shown for each data point along the 5-year moving average trend line. (Additional data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

western hemlock is especially concerning given that the mean observed between 1996 and 1999 was 13.7 percent (Randolph and others 2010a). An examination of the 2006–10 plot averages indicated that western hemlock foliage transparency was poorer in Alaska and the Olympic Peninsula of Washington than farther south along the Pacific Coast and elsewhere in the region (fig. 9.8).

Rocky Mountain Region

A significant increase in crown density was observed for the Rocky Mountain softwood group (table 9.3). This is likely due to the pinyon-juniper group, the only group with a significant change in crown condition (table 9.3). Increases in mean crown density are considered improvements in condition and typically result from added biomass in the crowns. However, increases in the mean also could result from trees with poor conditions at time 1 dying and dropping out of the crown assessments before time 2, which causes an increase in the mean of the remaining trees.

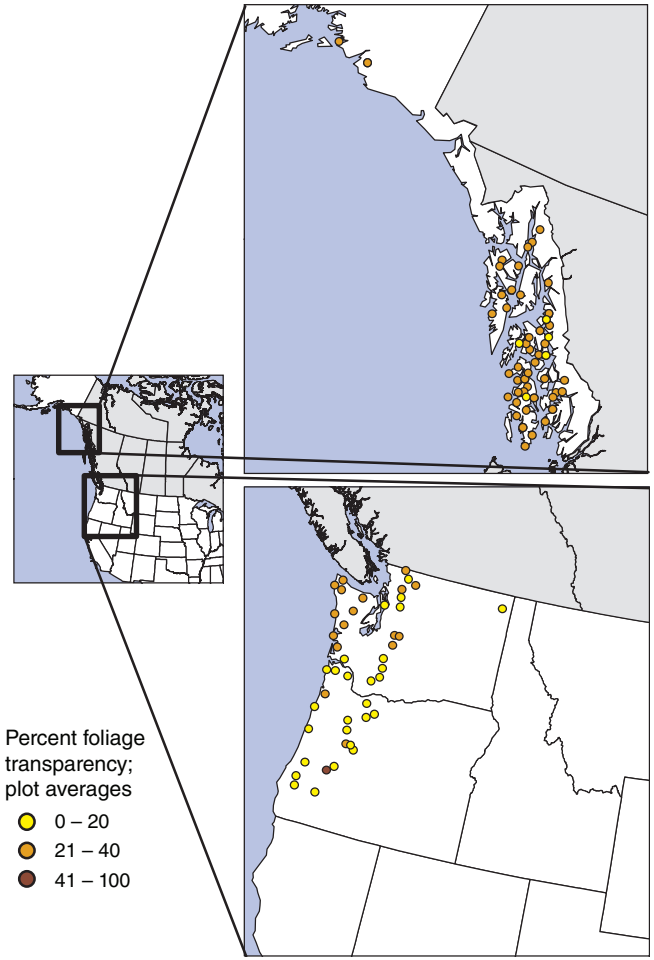

Figure 9.8—Western hemlock foliage transparency plot averages, 2006–10. Plot locations are approximate. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

Table 9.3—Mean crown conditions for major species groups in the Rocky Mountain region of the United States, 2006–10

Species group	Plots	Trees	Crown density			Crown dieback			Foliage transparency		
			Mean	SE[a]	Change[b]	Mean	SE[a]	Change[b]	Mean	SE[a]	Change[b]
			%			%			%		
Softwoods	574	10,824	45.8	0.47	+	3.6	0.20	0	15.9	0.17	0
Douglas-fir	191	1,720	44.1	0.89	0	2.4	0.46	0	16.0	0.36	0
Engelmann and other spruces	105	1,003	48.4	1.16	0	1.9	0.38	0	14.3	0.37	0
Lodgepole pine	94	1,530	38.7	1.02	NA	3.5	0.61	NA	16.9	0.54	NA
Pinyon-juniper	266	3,381	50.4	0.84	+	5.9	0.32	0	15.7	0.29	0
Ponderosa and Jeffrey pines	118	1,041	40.2	1.09	0	2.1	0.32	0	18.1	0.43	0
True fir	163	1,514	48.3	0.98	0	2.6	0.35	0	14.4	0.34	0
Hardwoods	163	1,660	39.1	1.66	0	6.0	0.66	0	20.2	0.48	0
Cottonwood and aspen	69	888	33.9	1.58	NA	3.4	0.56	NA	19.8	0.61	NA

[a] Standard error.
[b] Test that the mean for 2006–10 is significantly different from the mean for 2000–04 based on overlapping 95-percent confidence intervals. (+) indicates the mean for 2006–10 was greater than the mean for 2000–04, (–) indicates the mean for 2006–10 was less than the mean for 2000–04, and (0) indicates no significant difference. NA indicates the test for significant difference was not performed. Only species groups measured on at least 100 plots during both time periods were included in the tests.
Source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program.

North Region

In the North region, no changes were observed in crown density, whereas two species groups, beech (*Fagus grandifolia*) and maples (*Acer* spp.), displayed decreases in crown dieback, and five individual species groups, in addition to the general hardwood and softwood groups, displayed increases in foliage transparency (table 9.4). Though decreases in crown dieback are considered improvements in crown condition, the improvement for beech was much more dramatic than that for the maples (fig. 9.9). Although they were statistically significant, the increases in foliage transparency for black walnut (*Juglans nigra*), hickory (*Carya* spp.), maples, northern white-cedar (*Thuja occidentalis*), and spruce (*Picea* spp.) and balsam fir (*Abies balsamea*) were all <4.0 percent, and therefore likely biologically unimportant.

Table 9.4—Mean crown conditions for major species groups in the North region of the United States, 2006–10

Species group	Plots	Trees	Crown density			Crown dieback			Foliage transparency		
			Mean	SE[a]	Change[b]	Mean	SE[a]	Change[b]	Mean	SE[a]	Change[b]
			%			%			%		
Softwoods	952	12,055	48.6	0.33	0	2.4	0.14	0	19.4	0.22	0
Eastern hemlock	207	1,316	47.7	0.91	0	1.5	0.20	0	18.1	0.35	0
Eastern white and red pines	262	2,081	48.5	0.65	0	1.3	0.17	0	20.5	0.50	0
Northern white-cedar	160	2,060	44.3	0.96	0	4.8	0.60	0	22.3	0.79	+
Spruce and balsam fir	426	3,978	52.0	0.51	0	2.2	0.17	0	17.7	0.22	+
Hardwoods	1,874	32,772	47.3	0.16	0	4.1	0.10	0	21.1	0.12	0
Ash	550	2,176	44.7	0.60	0	6.3	0.84	0	23.0	0.39	0
Basswood	172	659	47.0	0.89	0	2.9	0.41	0	19.9	0.37	0
Beech	304	1,208	46.7	0.60	0	4.1	0.36	-	19.7	0.37	0
Black walnut	152	402	46.8	0.61	0	4.4	0.60	0	23.5	0.69	+
Cottonwood and aspen	390	2,270	45.9	0.63	0	3.7	0.35	0	23.4	0.47	0
Hickory	419	1,407	49.7	0.43	0	2.7	0.24	0	20.1	0.29	+
Maples	1,176	9,708	48.2	0.24	0	3.0	0.11	-	19.7	0.19	+
Red oaks	708	2,781	47.8	0.33	0	4.6	0.28	0	21.1	0.26	0
Tupelo and blackgum	150	331	49.9	0.77	NA	2.6	0.73	NA	19.6	0.69	NA
White oaks	578	3,327	46.6	0.36	0	3.9	0.18	0	21.0	0.27	0
Yellow birch	257	845	49.6	0.58	0	3.3	0.34	0	19.4	0.30	0
Yellow-poplar	158	616	52.1	0.72	NA	3.0	0.62	NA	20.3	0.74	NA

[a] Standard error.
[b] Test that the mean for 2006–10 is significantly different from the mean for 2000–04 based on overlapping 95-percent confidence intervals. (+) indicates the mean for 2006–10 was greater than the mean for 2000–04, (–) indicates the mean for 2006–10 was less than the mean for 2000–04, and (0) indicates no significant difference. NA indicates the test for significant difference was not performed. Only species groups measured on at least 100 plots during both time periods were included in the tests.
Source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program.

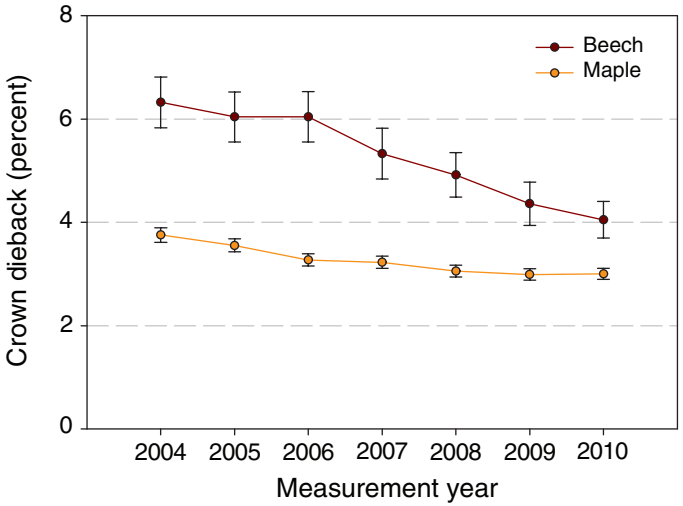

Figure 9.9—Five-year moving average trend line for beech and maple crown dieback in the North region of the United States, 2004–10. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

South Region

Significant increases in foliage transparency were observed for both the hardwood and softwood groups in the South region of the United States (table 9.5). At the species level, all but one species group (ash, *Fraxinus* spp.) displayed increases in foliage transparency, but as in the North, all changes were <4.0 percent. One species group, loblolly and shortleaf pine (*Pinus taeda* and *P. echinata*), displayed a decrease in crown dieback; however, the decrease was negligible (from 0.3 percent to 0.2 percent). No changes were observed in crown density.

National Observations

In general, crown conditions across the United States were stable during the last decade. Though some changes in crown condition were observed, many of the statistically significant changes were relatively small and likely biologically unimportant. Notable exceptions to this were the declining crown conditions among the hardwoods, western hemlock, and true firs in the West Coast region. These declines may be the result of Sudden Oak Death (*Phytophthora ramorum*) among oaks in California and Oregon, western black-headed budworm (*Acleris gloverana*) on hemlocks in Alaska, and western spruce budworm (*Choristoneura occidentalis*) and fir engraver beetle (*Scolytus ventralis*) on the true firs (Man 2009, Snyder and others 2008). However, the increases in western hemlock and hardwood crown dieback between 2005

Table 9.5—Mean crown conditions for major species groups in the South region of the United States, 2006–10

Species group	Plots	Trees	Crown density			Crown dieback			Foliage transparency		
			Mean	SE[a]	Change[b]	Mean	SE[a]	Change[b]	Mean	SE[a]	Change[b]
			%			%			%		
Softwoods	1,164	17,385	41.5	0.28	0	0.4	0.05	0	23.7	0.27	+
Loblolly and shortleaf pines	783	11,830	41.4	0.35	0	0.2	0.03	-	23.5	0.33	+
Longleaf and slash pines	168	2,636	41.1	0.60	NA	0.3	0.10	NA	22.8	0.61	NA
Virginia pine	119	673	39.4	0.79	NA	1.1	0.28	NA	27.6	1.35	NA
Hardwoods	1,631	23,116	43.6	0.21	0	2.4	0.10	0	22.9	0.18	+
Ash	247	759	42.1	0.69	0	2.9	0.46	0	23.1	0.57	0
Beech	106	239	48.5	1.2	NA	1.6	0.55	NA	19.6	0.54	NA
Hickory	525	1,622	46.2	0.43	0	1.4	0.19	0	21.2	0.40	+
Maples	640	2,453	41.9	0.37	0	2.2	0.23	0	22.4	0.32	+
Red oaks	951	3,564	44.7	0.34	0	2.7	0.21	0	22.9	0.27	+
Sweetgum	598	2,389	44.4	0.38	0	2.0	0.24	0	21.1	0.36	+
Tupelo and blackgum	418	1,533	41.1	0.88	0	1.6	0.41	0	23.7	0.61	+
White oaks	771	3,699	44.6	0.39	0	2.1	0.18	0	22.6	0.37	+
Yellow-poplar	404	1,613	44.1	0.53	0	1.4	0.26	0	20.7	0.42	+

[a] Standard error.
[b] Test that the mean for 2006–10 is significantly different from the mean for 2000–04 based on overlapping 95-percent confidence intervals. (+) indicates the mean for 2006–10 was greater than the mean for 2000–04, (–) indicates the mean for 2006–10 was less than the mean for 2000–04, and (0) indicates no significant difference. NA indicates the test for significant difference was not performed. Only species groups measured on at least 100 plots during both time periods were included in the tests.
Source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program.

and 2007 coincided with an increase in western hemlock foliage transparency and decreases in Douglas-fir and true fir crown density in 2006. This coincident pulse of degraded crown conditions may suggest a stressor event other than the insects and diseases known to be present in the West Coast region.

Regional differences were observed in the crown condition means for several of the species groups that crossed the FIA unit boundaries by which the data were summarized (fig. 9.1) (though no formal tests were performed to determine statistical differences). Four species groups were summarized in both the West Coast and Rocky Mountain regions. With the exception of Douglas-fir and lodgepole pine (*Pinus contorta*) crown dieback, crown conditions in the Rocky Mountain region were better or approximately equal to the crown conditions in the West Coast region (tables 9.2 and 9.3). Eight species groups were summarized for both the North and South regions. Crown density and foliage transparency in the North were approximately equal to or better than the conditions in the South; however, crown dieback was better (i.e., lower) in the South, and sometimes substantially so, e.g., ash, beech, and red oaks (*Quercus* spp.) (tables 9.4 and 9.5). One species group, cottonwood-aspen, spanned the Rocky Mountain and North regions. Crown dieback and foliage transparency conditions in the Rocky Mountain region for this species group were approximately equal to those in the North region; however, crown density was much lower in the Rocky Mountain region than in the North (tables 9.3 and 9.4). The differences within species across regions may signify actual differences in the condition, i.e., health, of the trees, but also potentially reflect differences in climate and other factors that affect growing conditions, e.g., forest management practices.

During the last decade, several species throughout the United States were imperiled by insect and disease outbreaks. Among these were the western pines (*Pinus* spp.), endangered by a host of bark beetles, particularly the mountain pine beetle (*Dendroctonus ponderosae*), and the eastern ashes, threatened by the emerald ash borer (*Agrilus planipennis*). Although no changes in crown condition were observed for either species group during the 2000s, the 2010 crown density moving averages for lodgepole pine, ponderosa pine (*Pinus ponderosa*), and Jeffrey pine (*Pinus jeffreyi*) in the West Coast region were substantially lower than the average conditions observed between 1996 and 1999. Mean crown density for lodgepole pine was 43.3 percent in 1999 (Randolph and others 2010a) and 35.3 percent in 2010 (table 9.2). Mean crown density for the ponderosa and Jeffrey pines was 47.2 percent in 1999 (Randolph and others 2010a) and 37.9 percent in 2010 (table 9.2). The ash group has maintained a high mean level of crown dieback in the Northern United States since the late 1990s, averaging 5.3 percent in the Northeast and 5.7 percent in the North Central States between 1996 and 1999 (Randolph and others 2010b, 2010c) and 6.3 percent across the entire northern region in 2010 (table 9.4).

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