United States
Department of
Agriculture

Forest Service

Southern
Research Station

General Technical
Report SRS–127

Descriptive Statistics of Tree Crown Condition in the United States Interior West

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Cover photo: A stand of lodgepole pine and Douglas-fir in the Rocky Mountain Region. (photo courtesy of Rocky Mountain Research Station)

July 2010
Southern Research Station
200 W.T. Weaver Blvd.
Asheville, NC 28804

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Abstract

The U.S. Forest Service Forest Inventory and Analysis (FIA) Program uses visual assessments of tree crown condition to monitor changes and trends in forest health. This report describes four crown condition indicators (crown dieback, crown density, foliage transparency, and sapling crown vigor) measured in Colorado, Idaho, Nevada, Utah, and Wyoming between 1996 and 1999. Descriptive statistics are presented by species and FIA species group. Inter- and intra-species variation, crown condition stressors, and statistical concerns 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. frost, wind, and ice storms), drought, senescence, and competition or other stand conditions (Kenk 1993), and when severe enough, may result in tree mortality (Lawrence and others 2002).

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

At the State level, the 5-year FIA reports mandated by the 1998 Farm Bill [Agricultural Research, Extension, and Education Reform Act of 1998] (Public Law 105-185) are a primary outlet for reporting tree crown condition. These reports describe the current status and trends in forest extent and condition, and typically present data summaries in tabular format by species or species group (e.g. Donnegan and others 2008). The purpose of this crown condition summary is to document the species-specific crown conditions collected by FHM in the U.S. Interior West (fig. 1) so that the FIA State-level summaries can be understood in their regional historical context. Rogers and others (2001) presented frequency histograms for three crown condition indicators (crown dieback, foliage transparency, and crown density) by hardwood and softwood taxonomic groups as an appendix of their summary of forest health monitoring in the Interior West between 1996 and 1999. Though based on the same data, this report goes beyond their summary by presenting detailed descriptive statistics at the species level. Similar regional summaries for the West Coast (Randolph and others 2010a), Southern (Randolph 2006), North Central (Randolph and others 2010b), and Northeastern (Randolph and others 2010c) States are also available.

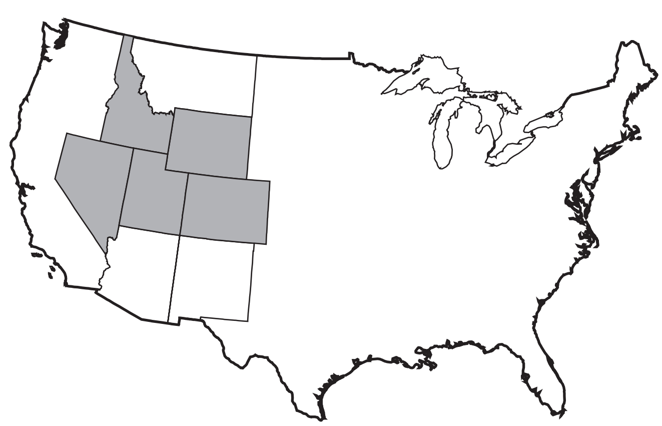

Figure 1—Interior West States included in the crown condition summary are shaded gray.

Methods

Data Collection

In order to have complete statewide coverage for as many Interior West 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 Colorado, Idaho, Nevada, Utah, and Wyoming (table 1). Each inventory plot is a cluster of four 1/24-acre circular subplots with subplot centers located 120 feet apart (U.S. Department of Agriculture Forest Service 1999). The four crown condition indicators included in this summary are: (1) crown density—the amount of crown branches, foliage, and reproductive structures that blocks light visibility through the projected crown outline; (2) crown dieback—recent mortality of branches with fine twigs, which begins at the terminal portion of a branch and proceeds inward toward the trunk; (3) foliage transparency—the amount of skylight visible through the live, normally foliated portion of the crown, excluding dieback, dead branches, and large gaps in the crown; and (4) sapling crown vigor—a visual measure designed to categorize saplings into three broad classes based on the amount and condition of the foliage present (Schomaker and others 2007). Crown density, crown dieback, and foliage transparency (fig. 2) were measured for every live tree ≥5.0 inches in diameter at breast height (d.b.h.) or, for woodland species, diameter at root collar (d.r.c.) on each subplot. Sapling crown vigor was assessed for every live tree (sapling) with d.b.h. or d.r.c. ≥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 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).

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

State	Year 1996	1997	1998	1999	Total
			number		
Colorado	23	36	37	57	153
Idaho	19	37	39	47	142
Nevada	—	—	—	67	67
Utah	—	—	—	142	142
Wyoming	—	26	16	25	67
All States	42	99	92	338	571

FHM = Forest Health Monitoring.

— = no sample.

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. Estimates were made with the SAS® procedure SURVEYMEANS (An and Watts 1998) and the following statement options: (1) CLUSTER—to designate the primary sampling unit of the survey, i.e., the plot; (2) RATIO—to request ROM estimates; and (3) DOMAIN—to identify the subpopulations, or domains, of interest, e.g. hardwoods and softwoods. Other descriptive statistics (minimum, maximum, and median or 90th percentile) also were

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).

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 12,361 trees on 542 of the 571 forested plots. A total of 34 species was observed, and of these, 26 species had 25 or more observations. For all trees combined, the range of possible values, from 0 to 99 percent, were observed for each of the crown condition indicators, though the majority of crown dieback and foliage transparency values tended to concentrate in a small portion of the total possible range. Ninety-six percent of the trees exhibited < 15 percent crown dieback (fig. 3) and 94 percent had foliage transparency < 25 percent (fig. 4). Crown densities were concentrated in the middle of the range; 79 percent of the trees had a crown density of 30 to 60 percent (fig. 5). Mean crown conditions were 3.3 percent crown dieback, 14.4 percent foliage transparency, and 44.1 percent crown density (table 2).

On average, the absolute difference between the softwood and hardwood crown condition means was greatest for crown density. Mean crown density was 45.3 percent for the softwoods and 37.9 percent for the hardwoods (table 2). Foliage transparency was higher for the hardwoods (18.5 percent) than for the softwoods (13.7 percent), whereas crown dieback was < 5 percent for both groups (table 2).

A broad range of average conditions was exhibited for each of the crown condition indicators among the species. Mean crown dieback ranged from 1.3 percent for corkbark fir (*Abies lasiocarpa*) to 7.3 percent for Gambel oak (*Quercus gambelli*) (table 3). Mean foliage transparency ranged from 9.9 percent for western juniper (*Juniperus occidentalis*) to 19.4 percent for quaking aspen (*Populus tremuloides*) (table 4), and mean crown density ranged from 33.0 percent for Gambel oak to 52.0 percent for grand fir (*A. grandis*) (table 5).

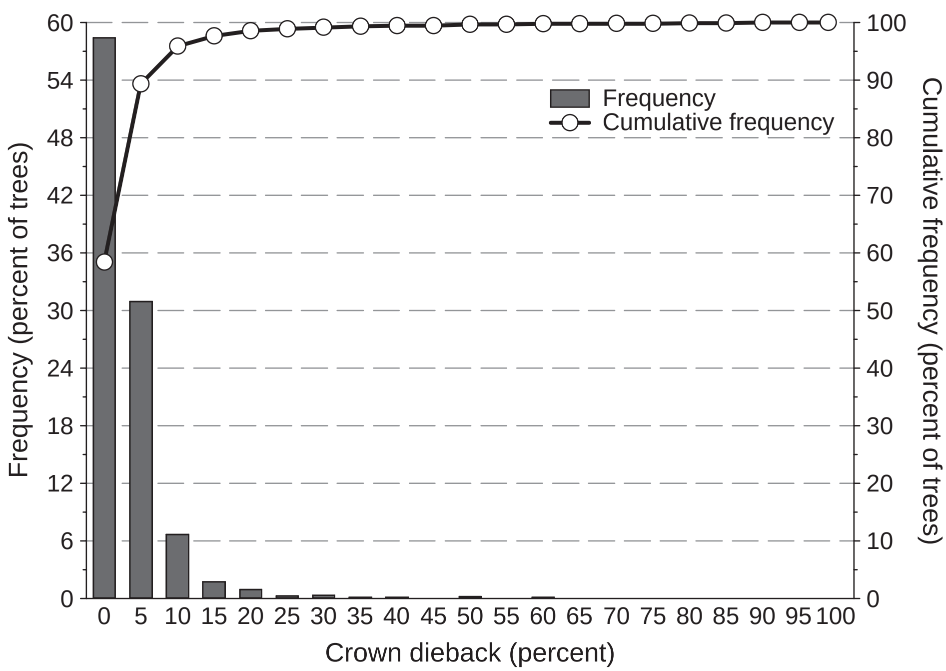

Figure 3—Crown dieback frequency histogram and cumulative frequency distribution for all trees combined for Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99.

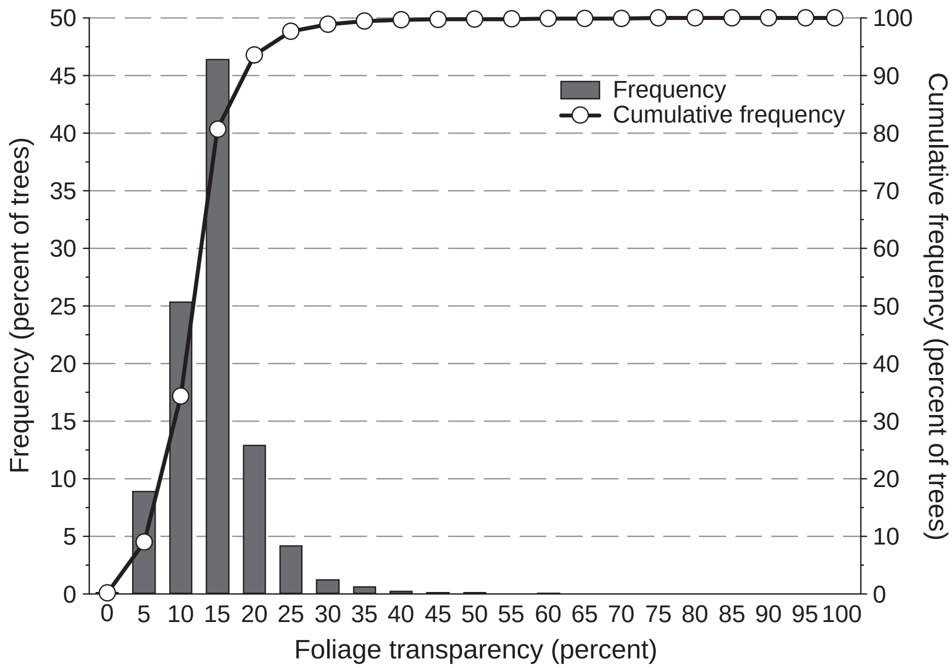

Figure 4—Foliage transparency frequency histogram and cumulative frequency distribution for all trees combined for Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99.

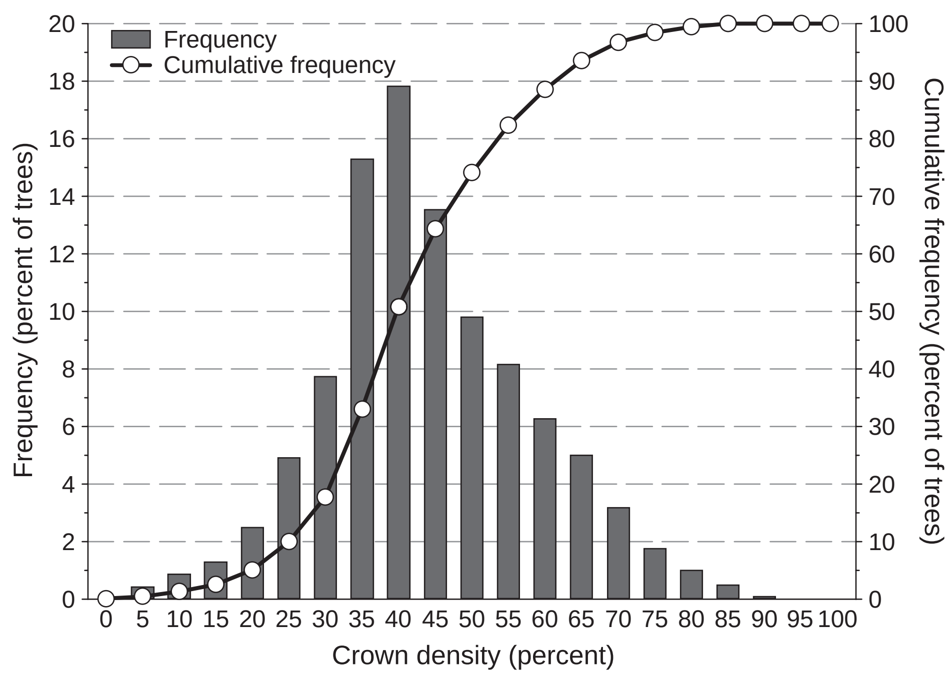

Figure 5—Crown density frequency histogram and cumulative frequency distribution for all trees combined in Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99.

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 Colorado, Idaho, Nevada, Utah, and Wyoming, 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	508	10,397	45.3	0.5	44.4	46.2	0	45	99
Hardwoods	167	1,964	37.9	1.0	35.9	39.9	5	35	85
All trees	542	12,361	44.1	0.4	43.3	45.0	0	40	99
Crown dieback									
Softwoods	508	10,397	3.1	0.2	3.0	3.7	0	0	99
Hardwoods	167	1,964	4.4	0.5	3.4	5.4	0	0	95
All trees	542	12,361	3.3	0.2	3.0	3.7	0	0	99
Foliage transparency									
Softwoods	508	10,397	13.7	0.2	13.3	14.1	0	15	99
Hardwoods	167	1,694	18.5	0.7	17.1	19.8	5	15	95
All trees	542	12,361	14.4	0.2	14.0	14.9	0	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.

Sapling Crown Vigor

Crown vigor was assessed for 2,142 saplings on 361 of the 571 forested plots. Overall, 59.2 percent of the sapling crowns were categorized as good (table 6). Although the percentage of hardwood and softwood saplings categorized as poor was about the same, 65.8 percent of the softwoods were in the good category, compared to only 52.5 percent of the hardwoods. Among the softwood species groups with at least 25 observations, the ponderosa and Jeffrey pines (*Pinus ponderosa* and *P. jeffreyi*) group had the highest percentage of saplings in the good category (79.5 percent) and the western redcedar (*Thuja plicata*) group had the lowest percentage of saplings in the good category (52.9 percent). The Engelmann and other spruces (*Picea engelmannii* and *P.* spp.) group had the lowest percentage of saplings in the poor category (2.9 percent), whereas the western redcedar group had the highest percentage of saplings in the poor category (11.8 percent). Among the hardwood species groups, only the cottonwood-aspen (*Populus* spp.) and western woodland hardwoods groups had 25 observations or more. Both of these groups had about the same percentage of trees in the good category, but more of the western woodland hardwoods were categorized as poor (7.1 percent) (table 6).

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 factor.

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 33.0 and 52.0 percent. On average, the species with the highest crown densities and lowest

Table 3—Mean crown dieback and other statistics[a] for all live trees ≥ 5.0 inches diameter[b] by species for Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99

Species[c]	Plots[d]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	90th percentile	Maximum
	- - - *number* - - -		- - - *percent* - - -						
Softwoods									
Corkbark fir	10	64	1.3	0.7	0.0	2.5	0	5	10
Western larch	15	64	1.6	0.8	0.2	3.1	0	5	10
Western hemlock	12	96	1.8	1.1	-0.5	4.0	0	5	10
Bristlecone pine	8	29	1.9	0.4	1.1	2.7	0	5	10
Douglas-fir	162	1,283	2.0	0.3	1.5	2.5	0	5	99
Engelmann spruce	109	1,104	2.2	0.3	1.5	2.9	0	5	99
Ponderosa pine	56	404	2.3	0.7	0.9	3.6	0	5	60
Grand fir	43	323	2.6	0.4	1.8	3.3	0	5	70
Lodgepole pine	111	2,096	2.7	0.5	1.7	3.7	0	10	80
White fir	17	171	3.0	1.4	0.3	5.7	0	10	95
Subalpine fir	112	1,157	3.1	0.4	2.3	3.9	0	10	99
Singleleaf pinyon (w)	62	760	3.2	0.6	2.0	4.4	0	5	80
Western redcedar	17	187	3.2	1.1	1.1	5.3	0	5	60
Limber pine	40	122	3.4	0.9	1.6	5.2	0	5	60
Rocky Mountain juniper (w)	48	202	3.7	1.0	1.8	5.7	0	10	70
Common pinyon (w)	96	597	3.8	0.4	2.9	4.7	0	5	99
Whitebark pine	18	90	4.2	2.1	0.1	8.2	0	5	90
Western juniper	3	39	4.4	0.9	2.6	6.1	0	10	25
Oneseed juniper (w)	8	102	4.7	0.9	3.0	6.4	0	10	30
Utah juniper (w)	154	1,467	5.4	0.3	4.8	6.1	0	10	90
Hardwoods									
Narrowleaf cottonwood	5	46	2.9	0.4	2.2	3.7	0	10	35
Quaking aspen	84	1,233	3.1	0.5	2.1	4.0	0	5	95
Rocky Mountain maple (w)	24	65	4.2	1.0	2.3	6.2	0	10	30
Bigtooth maple (w)	6	49	6.6	2.0	2.8	10.5	0	10	75
Curlleaf mountain-mahogany (w)	38	289	7.0	1.4	4.2	9.9	0	15	85
Gambel oak (w)	22	250	7.3	1.8	3.9	10.8	0	10	80

SE = standard error.

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

[b] Diameter measured at root collar for woodland species, designated with a (w), and at breast height for all other species.

[c] See appendix table A.4.

[d] 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[b] by species for Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99

Species[c]	Plots[d]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - *number* - - -		- - - - - - - - - -	- - - - - - - - - -	- - - - - *percent*	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -
Softwoods									
Western juniper	3	39	9.9	0.2	9.5	10.3	5	10	15
Bristlecone pine	8	29	10.3	0.3	9.8	10.9	5	10	15
Corkbark fir	10	64	10.5	0.8	9.0	12.1	5	10	20
Utah juniper (w)	154	1,467	11.6	0.4	10.9	12.4	0	10	30
Subalpine fir	112	1,157	11.7	0.5	10.8	12.6	0	10	99
Engelmann spruce	109	1,104	11.8	0.5	10.7	12.8	5	10	40
Rocky Mountain juniper (w)	48	202	12.8	0.8	11.2	14.5	5	10	65
Common pinyon (w)	96	597	12.9	0.3	12.2	13.5	0	15	50
White fir	17	171	12.9	1.0	10.9	14.9	5	15	25
Singleleaf pinyon (w)	62	760	13.0	0.4	12.2	13.8	0	15	45
Oneseed juniper (w)	8	102	13.5	1.3	11.1	16.0	5	15	20
Ponderosa pine	56	404	14.9	0.6	13.7	16.0	5	15	55
Douglas-fir	162	1,283	14.9	0.4	14.1	15.6	0	15	99
Grand fir	43	323	15.0	0.4	14.3	15.8	5	15	35
Limber pine	40	122	15.2	0.8	13.6	16.8	0	15	25
Lodgepole pine	111	2,096	15.7	0.3	15.1	16.4	0	15	75
Western hemlock	12	96	17.2	2.0	13.3	21.1	5	15	35
Western larch	15	64	17.6	1.1	15.3	19.8	10	15	40
Whitebark pine	18	90	17.9	0.9	16.0	19.7	5	15	50
Western redcedar	17	187	18.3	1.0	16.4	20.3	5	20	40
Hardwoods									
Bigtooth maple (w)	6	49	14.5	0.7	13.2	15.8	10	15	25
Curlleaf mountain-mahogany (w)	38	289	14.7	0.7	13.4	16.0	5	15	95
Narrowleaf cottonwood	5	46	16.8	1.2	14.6	19.1	15	15	30
Gambel oak (w)	22	250	18.8	2.4	14.1	23.6	10	15	90
Rocky Mountain maple (w)	24	65	19.0	0.9	17.3	20.7	10	20	50
Quaking aspen	84	1,233	19.4	0.9	17.6	21.3	5	20	90

SE = standard error.

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

[b] Diameter measured at root collar for woodland species, designated with a (w), and at breast height for all other species.

[c] See appendix table A.4.

[d] 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[b] by species for Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99

Species[c]	Plots[d]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - *number* - - -		- - - *percent* - - -						
Softwoods									
Grand fir	43	323	52.0	1.8	48.4	55.5	10	50	90
Western hemlock	12	96	51.6	6.6	38.6	64.6	10	55	85
Western larch	15	64	50.7	3.4	44.0	57.4	15	45	80
Rocky Mountain juniper (w)	48	202	50.7	2.0	46.7	54.6	10	50	90
Subalpine fir	112	1,157	49.3	1.0	47.3	51.3	0	50	90
Western juniper	3	39	48.6	1.0	46.7	50.5	5	55	80
Common pinyon (w)	96	597	48.4	0.9	46.5	50.2	5	50	90
Douglas-fir	162	1,283	47.2	0.8	45.6	48.8	0	45	85
Corkbark fir	10	64	47.0	2.0	43.1	51.0	30	45	80
Singleleaf pinyon (w)	62	760	46.8	1.2	44.5	49.1	5	45	85
Western redcedar	17	187	46.8	2.8	41.3	52.3	5	45	85
Utah juniper (w)	154	1,467	46.2	1.0	44.4	48.1	5	45	95
Engelmann spruce	109	1,104	45.2	1.1	43.1	47.4	5	45	99
White fir	17	171	44.2	2.9	38.5	49.9	5	40	80
Ponderosa pine	56	404	42.1	1.2	39.8	44.3	10	40	85
Oneseed juniper (w)	8	102	41.7	2.6	36.6	46.7	5	45	75
Limber pine	40	122	40.5	2.6	35.4	45.7	5	40	80
Lodgepole pine	111	2,096	39.1	0.7	37.8	40.5	5	40	80
Bristlecone pine	8	29	38.8	2.4	34.2	43.4	25	35	70
Whitebark pine	18	90	34.2	2.3	29.6	38.7	10	35	50
Hardwoods									
Rocky Mountain maple (w)	24	65	50.9	3.0	45.0	56.9	25	50	85
Curlleaf mountain-mahogany (w)	38	289	45.2	2.6	40.1	50.3	5	45	80
Bigtooth maple (w)	6	49	37.1	0.7	35.8	38.5	10	40	50
Narrowleaf cottonwood	5	46	36.5	3.7	29.3	43.8	15	35	70
Quaking aspen	84	1,233	36.4	1.1	34.2	38.6	5	35	80
Gambel oak (w)	22	250	33.0	1.9	29.1	36.8	5	35	70

SE = standard error.

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

[b] Diameter measured at root collar for woodland species, designated with a (w), and at breast height for all other species.

[c] See appendix table A.4.

[d] 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[a] by FIA species group, Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99

			Crown vigor rating					
			Good		Fair		Poor	
Species group	Plots[c]	Saplings	Percent	SE[d]	Percent	SE[d]	Percent	SE[d]
	- - - number - - -			*percent*		*percent*		*percent*
Softwoods								
Douglas-fir	45	108	62.0	7.2	27.8	6.0	10.2	3.1
Ponderosa and Jeffrey pines	19	44	79.5	7.3	20.5	7.3	0.0	—
True fir	101	349	67.3	3.5	26.6	3.2	6.0	1.9
Western hemlock	3	12	58.3	—	25.0	—	16.7	—
Western white pine	1	7	71.4	—	14.3	—	14.3	—
Engelmann and other spruces	49	104	55.8	6.9	41.3	6.8	2.9	1.5
Western larch	1	1	100.0	—	0.0	—	0.0	—
Lodgepole pine	42	160	56.3	5.8	36.3	5.1	7.5	2.2
Western redcedar	7	34	52.9	9.7	35.3	6.4	11.8	4.1
Western woodland softwoods	98	222	74.8	3.9	21.6	3.6	3.6	1.2
Other western softwoods	21	51	70.6	9.3	23.5	8.1	5.9	2.6
All softwoods	285	1,092	65.8	2.3	28.3	2.1	6.0	0.9
Hardwoods								
Cottonwood and aspen	55	183	56.8	5.1	39.9	4.9	3.3	2.3
Other western hardwoods	2	9	11.1	—	88.9	—	0.0	—
Western woodland hardwoods	81	858	52.0	4.7	40.9	4.3	7.1	1.1
All hardwoods	132	1,050	52.5	4.0	41.1	3.6	6.4	1.0
All trees	361	2,142	59.2	2.4	34.6	2.2	6.2	0.7

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

[a] Diameter measured at root collar for woodland species groups and at breast height for all other species groups.

[b] See appendix table A.4.

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

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

foliage transparencies were those of the firs (*Abies* spp.) and junipers (*Juniperus* spp.), species which tend to have reasonably symmetrical growth forms with closely- or many-branched stems. The species with the least dense and most transparent crowns were those of the hardwoods, whose crowns tend to be more broad-spreading and open. Such great variability inhibits direct comparisons of species because some species clearly tend to have denser crowns than others. For example, a western hemlock (*Tsuga heteropyhlla*) tree with a crown density of 35 percent may indicate that the tree is under stress; however, a bristlecone pine (*Pinus aristata*) 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. Numerous insects and diseases damage trees in the forests of the U.S. Interior West. These include a variety of mistletoes, root diseases, and bark beetles, as well as defoliators like the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough), western spruce budworm (*Choristoneura occidentalis* Freeman), and the fall cankerworm (*Alsophila pometaria* Harris).

Between 1997 and 1999, increasing mountain pine beetle (*Dendroctonus ponderosae* Hopkins), western spruce budworm (*Choristoneura occidentalis* Freeman), and Douglas-fir beetle (*D. pseudotsugae* Hopkins) activity was observed in Colorado, Nebraska, South Dakota, and Wyoming (Forest Health Monitoring Staff 2001); but in general, insects and diseases were at endemic levels between 1996 and 1999. Since the 1990s, however, there has been an increase in damage to species vulnerable to the mountain pine beetle, particularly lodgepole pine (*P. contorta*) (U.S. Department of Agriculture Forest Service 2004), and an increase in mortality among many forest types including aspen stands (Worrall and others 2008), pinyon-juniper woodlands (Shaw and others 2005), and subalpine fir forests (Rogers and others 2001). These increases in mortality are likely due to 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) (Thompson 2009). As a result of these ongoing declines, crown conditions observed in the affected forest types after 1999 may differ significantly from those reported here.

In addition to these biotic stressors, tree crown conditions are influenced by fire, drought, and periodic weather events such as snow storms, ice storms, and tornadoes. Together with the biological stressors, these factors may have a multiplicative, rather than a simply additive, impact on crown condition. On a regional level, drought undoubtedly has been the most notable stressor. Coulston (2007) noted that compared to historical records the 1995 to 2004 decade was more droughty than expected for several ecoregion sections in the Western United States.

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). The eight States in the Interior West region (fig. 1), each have enough forested area to supply the minimum sample size individually, and when combined to the regional level, <4 percent of the total forested area 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. Many 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 dieback and crown density in the Interior West were similar to those in the South; however, the distribution of foliage transparency was more skewed in this region than in the South.

Conclusion

With continued damage by the mountain pine beetle, increasing mortality in several forest types, and uncertainties about climate change (Solomon 2008), forest health monitoring in the Interior West 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 Interior West, 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 William Bechtold and Sally Campbell 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.

Coulston, J.W. 2007. Drought occurrence. In: Ambrose, M.J.; Conkling, B.L., eds. Forest health monitoring: 2005 national technical report. Gen. Tech. Rep. SRS–104. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 17–21.

Donnegan, J.; Campbell, S.; Azuma, D., tech. eds. 2008. Oregon's forest resources, 2001–2005: five-year Forest Inventory and Analysis report. Gen. Tech. Rep. PNW–GTR–765. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 186 p.

Forest Health Monitoring Staff. 2001. Forest insect and disease conditions in the Rocky Mountain region 1997–1999. Harris, J.L.; Frank, M.; Johnson, S., eds. Lakewood, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Region, Renewable Resources, Forest Health Management. 39 p. http://www.fs.fed.us/r2/fhm/reports/r2cond_97-99.pdf. [Date accessed: January 15, 2009].

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.

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

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.

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.

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.; Morin, R.S.; Steinman, J. 2010c. 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.

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.

Rogers, P.; Atkins, D.; Frank, M.; Parker, D. 2001. Forest health monitoring in the Interior West: a baseline summary of forest issues, 1996–1999. Gen. Tech. Rep. RMRS–GTR–75. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 40 p.

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.

Shaw, J.D.; Steed, B.E.; DeBlander, L.T. 2005. Forest Inventory and Analysis (FIA) annual inventory answers the question: what is happening to pinyon-juniper woodlands? Journal of Forestry. 103(6): 280–285.

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

Thompson, M.T. 2009. Analysis of conifer mortality in Colorado using Forest Inventory and Analysis's annual forest inventory. Western Journal of Applied Forestry. 24(4): 193–197.

U.S. Department of Agriculture Forest Service. 2004. Forest insect and disease conditions in the United States 2003. Washington, DC: Forest Health Protection. 142 p.

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].

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. 18 p.

Worrall, J.J.; Egeland, L.; Eager, T. [and others]. 2008. Rapid mortality of *Populus tremuloides* in southwestern Colorado, USA. Forest Ecology and Management. 255: 686–696.

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[b] by FIA species group for Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99

Species group[c]	Plots[d]	Trees	Mean	SE[e]	95% confidence Lower	95% confidence Upper	Minimum	90th percentile	Maximum
	- - - *number* - - -		- - - *percent* - - -						
Softwoods									
Douglas-fir	162	1,283	2.0	0.3	1.5	2.5	0	5	99
Ponderosa and Jeffrey pines	57	407	2.2	0.7	0.9	3.6	0	5	60
True fir	170	1,715	2.9	0.3	2.3	3.6	0	5	99
Western hemlock	12	96	1.8	1.1	-0.5	4.0	0	5	10
Western white pine	8	15	6.0	—	—	—	0	10	50
Engelmann and other spruces	112	1,118	2.2	0.3	1.5	2.8	0	5	99
Western larch	15	64	1.6	0.8	0.2	3.1	0	5	10
Lodgepole pine	111	2,096	2.7	0.5	1.7	3.7	0	10	80
Western redcedar	17	187	3.2	1.1	1.1	5.3	0	5	60
Western woodland softwoods	227	3,128	4.5	0.3	3.9	5.0	0	10	99
Other western softwoods	66	288	3.6	0.8	2.0	5.2	0	5	90
Hardwoods									
Cottonwood and aspen	89	1,288	3.1	0.5	2.2	4.0	0	5	95
Other western hardwoods	8	21	9.0	—	—	—	0	10	95
Western woodland hardwoods	84	655	6.8	1.0	4.9	8.7	0	15	85

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] Diameter measured at root collar for woodland species groups and at breast height for all other species groups.

[c] See appendix table A.4.

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

[e] 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[b] by FIA species group for Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99

Species group[c]	Plots[d]	Trees	Mean	SE[e]	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	number	*number*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*
Softwoods									
Douglas-fir	162	1,283	14.9	0.4	14.1	15.6	0	15	99
Ponderosa and Jeffrey pines	57	407	14.8	0.6	13.7	16.0	5	15	55
True fir	170	1,715	12.4	0.4	11.7	13.2	0	10	99
Western hemlock	12	96	17.2	2.0	13.3	21.1	5	15	35
Western white pine	8	15	19.3	—	—	—	15	20	30
Engelmann and other spruces	112	1,118	11.9	0.5	10.9	12.9	5	10	40
Western larch	15	64	17.6	1.1	15.3	19.8	10	15	40
Lodgepole pine	111	2,096	15.7	0.3	15.1	16.4	0	15	75
Western redcedar	17	187	18.3	1.0	16.4	20.3	5	20	40
Western woodland softwoods	227	3,128	12.3	0.3	11.8	12.9	0	15	65
Other western softwoods	66	288	14.7	1.1	12.5	16.8	0	15	50
Hardwoods									
Cottonwood and aspen	89	1,288	19.3	0.9	17.6	21.1	5	20	90
Other western hardwoods	8	21	20.7	—	—	—	10	20	85
Western woodland hardwoods	84	655	16.7	1.0	14.7	18.7	5	15	95

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] Diameter measured at root collar for woodland species groups and at breast height for all other species groups.

[c] See appendix table A.4.

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

[e] 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[b] by FIA species group for Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99

Species group[c]	Plots[d]	Trees	Mean	SE[e]	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - *number* - - -		- - -	- - -	- - - *percent*	- - -	- - -	- - -	- - -
Softwoods									
Douglas-fir	162	1,283	47.2	0.8	45.6	48.8	0	45	85
Ponderosa and Jeffrey pines	57	407	42.2	1.2	39.9	44.5	10	40	85
True fir	170	1,715	49.2	0.9	47.5	50.9	0	50	90
Western hemlock	12	96	51.6	6.6	38.6	64.6	10	55	85
Western white pine	8	15	47.7	—	—	—	20	45	70
Engelmann and other spruces	112	1,118	45.3	1.1	43.2	47.4	5	45	99
Western larch	15	64	50.7	3.4	44.0	57.4	15	45	80
Lodgepole pine	111	2,096	39.1	0.7	37.8	40.5	5	40	80
Western redcedar	17	187	46.8	2.8	41.3	52.3	5	45	85
Western woodland softwoods	227	3,128	46.9	0.7	45.6	48.2	5	45	95
Other western softwoods	66	288	40.1	2.3	35.5	44.7	5	40	80
Hardwoods									
Cottonwood and aspen	89	1,288	36.5	1.1	34.3	38.6	5	35	80
Other western hardwoods	8	21	46.2	—	—	—	5	45	65
Western woodland hardwoods	84	655	40.5	2.0	36.6	44.4	5	40	85

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] Diameter measured at root collar for woodland species groups and at breast height for all other species groups.

[c] See appendix table A.4.

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

[e] 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 Colorado, Idaho, Nevada, Utah, and Wyoming, 1996–99[a]

Species group and common name	Scientific name[b]	Species group and common name	Scientific name[b]
Douglas-fir	*Pseudotsuga menziesii*	Other western softwoods	
Ponderosa and Jeffrey pines		Western juniper	*Juniperus occidentalis*
Jeffrey pine[c]	*Pinus jeffreyi*	Whitebark pine	*Pinus albicaulis*
Ponderosa pine	*P. ponderosa*	Bristlecone pine	*P. aristata*
True fir		Coulter pine[c]	*P. coulteri*
White fir	*Abies concolor*	Limber pine	*P. flexilis*
Grand fir	*A. grandis*	Pacific yew	*Taxus brevifolia*
Subalpine fir, corkbark fir	*A. lasiocarpa*	Mountain hemlock[c]	*Tsuga mertensiana*
Western hemlock	*Tsuga heterophylla*	Cottonwood and aspen	
Western white pine	*Pinus monticola*	Narrowleaf cottonwood[c]	*Populus angustifolia*
Engelmann and other spruces		Black cottonwood[c]	*P. balsamifera*
Engelmann spruce	*Picea engelmannii*	Plains cottonwood	*P. deltoides* ssp. *monilifera*
Blue spruce	*P. pungens*	Quaking aspen	*P. tremuloides*
Western larch	*Larix occidentalis*	Other western hardwoods	
Lodgepole pine	*Pinus contorta*	Paper birch	*Betula papyrifera*
Western redcedar	*Thuja plicata*	Bur oak	*Quercus macrocarpa*
Western woodland softwoods		Western woodland hardwoods	
Oneseed juniper	*Juniperus monosperma*	Rocky Mountain maple	*Acer glabrum*
Utah juniper	*J. osteosperma*	Bigtooth maple	*A. grandidentatum*
Rocky Mountain juniper	*J. scopulorum*	Curlleaf mountain-mahogany	*Cercocarpus ledifolius*
Common pinyon	*Pinus edulis*	Alderleaf mountain-mahogany	*C. montanus*
Singleleaf pinyon	*P. monophylla*	Gambel oak	*Quercus gambelli*

FHM = Forest Health Monitoring.

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

[b] Little (1979).

[c] Tree only.

Randolph, KaDonna C.; Thompson, Mike 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.

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 Colorado, Idaho, Nevada, Utah, and Wyoming between 1996 and 1999. Descriptive statistics are presented by species and FIA species group. Inter- and intra-species variation, crown condition stressors, and statistical concerns 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.