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Descriptive Statistics of Tree Crown Condition in California, Oregon, and Washington

**KaDonna C. Randolph, Sally J. Campbell, and
Glenn Christensen**

Authors

KaDonna C. Randolph, Mathematical Statistician, USDA Forest Service, Southern Research Station, Forest Inventory and Analysis, Knoxville, TN 37919; **Sally J. Campbell**, Deputy Program Manager (retired), USDA Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis, Portland, OR 97205; and **Glenn Christensen**, Forester, USDA Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis, Portland, OR 97205.

Cover photo: Eastside of the Sierra Mountains in California. (photo by Andrew Hoff, Pacific Northwest Forest and Range Laboratory)

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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 tree crown condition indicators (crown dieback, crown density, foliage transparency, and sapling crown vigor) measured in California, Oregon, and Washington between 1996 and 1999. Descriptive statistics are presented by species and FIA species group. Inter- and intra-species variation, crown condition stressors, and statistical issues that should be considered when analyzing and interpreting the crown condition data are discussed.

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

Introduction

Tree crown condition is an important visual indicator of tree and forest health. A tree's crown is its principal engine for energy capture. Therefore, trees with full, vigorous crowns are generally associated with higher growth rates due to an increased capacity for photosynthesis. When crowns become degraded, photosynthetic capacity is reduced. Crown degradation is typically the result of past and present stressors such as insects, diseases, weather events (e.g. 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. Christensen and others 2008, Donnegan and others 2008). The purpose of this crown condition summary is to document the species-specific crown conditions collected by FHM in the coterminous Western United States (fig. 1) so that the FIA State-level summaries can be understood in their regional historical context. Campbell and others (2000) presented frequency tables for four crown condition indicators (crown dieback, foliage transparency, crown density, and sapling crown vigor class) by FIA species group as an appendix of their summary of forest health in west coast forests between 1997 and 1999. Though based on much of the same data, this report goes beyond their summary by presenting detailed descriptive statistics at the species level. Similar regional summaries for the Interior West (Randolph and Thompson 2010), Southern (Randolph 2006), North Central (Randolph and others 2010a), and Northeastern (Randolph and others 2010b) States are also available.

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

Methods

Data Collection

In order to have complete statewide coverage for as many West Coast 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 California, Oregon, and Washington (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.

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				
California	35	48	44	67	194
Oregon	—	68	61	66	195
Washington	—	49	36	50	135
All States	35	165	141	183	524

FHM = Forest Health Monitoring.
— = no sample.

All four indicators were visually assessed by two-person field crews. Crown density, crown dieback, and foliage transparency were measured in 5-percent increments and recorded as a two-digit code: 00, 05, 10… 99, where the code represents the upper limit of the class, e.g. 1 to 5 percent is code 05 and 96 to 100 percent is code 99. Sapling crown vigor was recorded in one of three classes: good (vigor class 1), fair (vigor class 2), and poor (vigor class 3). Though foliage transparency and crown density are similar measures, they cannot be interpreted as exact inverses. Crown density measures the amount of sunlight blocked by all biomass produced by the tree (both live and dead) in the crown, whereas foliage transparency measures the amount of sunlight penetrating only the live, foliated portion of the crown. Deductions are made from the maximum possible crown density for spaces between branches and other large openings in the crown. However, large gaps in the crown where foliage is not expected to occur are excluded from consideration when foliage transparency is rated. Within a species, higher crown density values, lower foliage transparency values, and lower crown dieback values typically are associated with better tree health. More detailed descriptions of the crown condition indicators are available in Schomaker and others (2007).

Data Summary

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

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. In addition, because the Cascade Mountain Range plays a large role in forest type and species distributions in Oregon and Washington, the crown condition indicators were summarized for the east and west sides of the range (fig. 3) for all species common to both sides of the range combined and for the Douglas-fir and true fir FIA species groups individually.

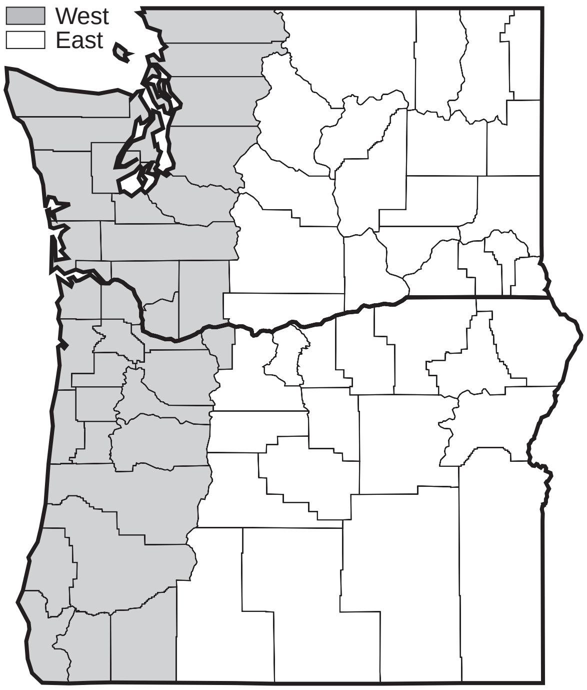

Figure 3—Areas of Washington and Oregon east and west of the Cascade Mountain Range.

Results

Tree Crown Condition

Tree crown condition was assessed for 11,135 trees on 501 of the 524 forested plots. A total of 67 species was observed, and of these, 42 species had 25 or more observations. For all trees combined, the range of possible values from 0 to 99 percent was 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-four percent of the trees exhibited <10 percent crown dieback (fig. 4) and 87 percent had foliage transparency <25 percent (fig. 5). Crown densities were concentrated in the middle of the range; 82 percent of the trees had a crown density of 30 to 65 percent (fig. 6). Mean crown conditions were 2.1 percent crown dieback, 16.6 percent foliage transparency, and 46.4 percent crown density (table 2).

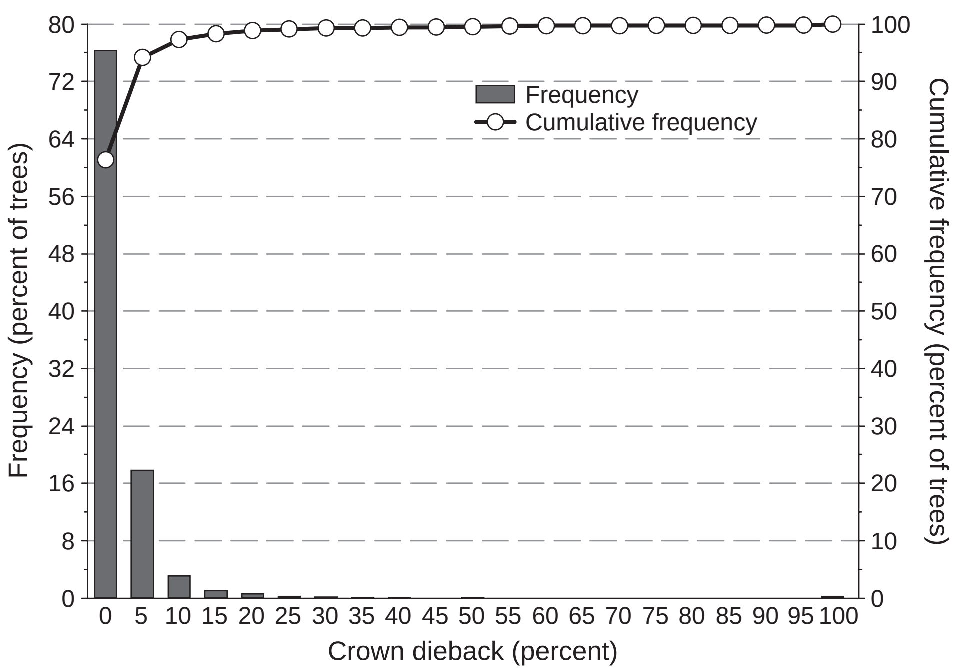

Figure 4—Crown dieback frequency histogram and cumulative frequency distribution for all trees combined for California, Oregon, and Washington, 1996–99.

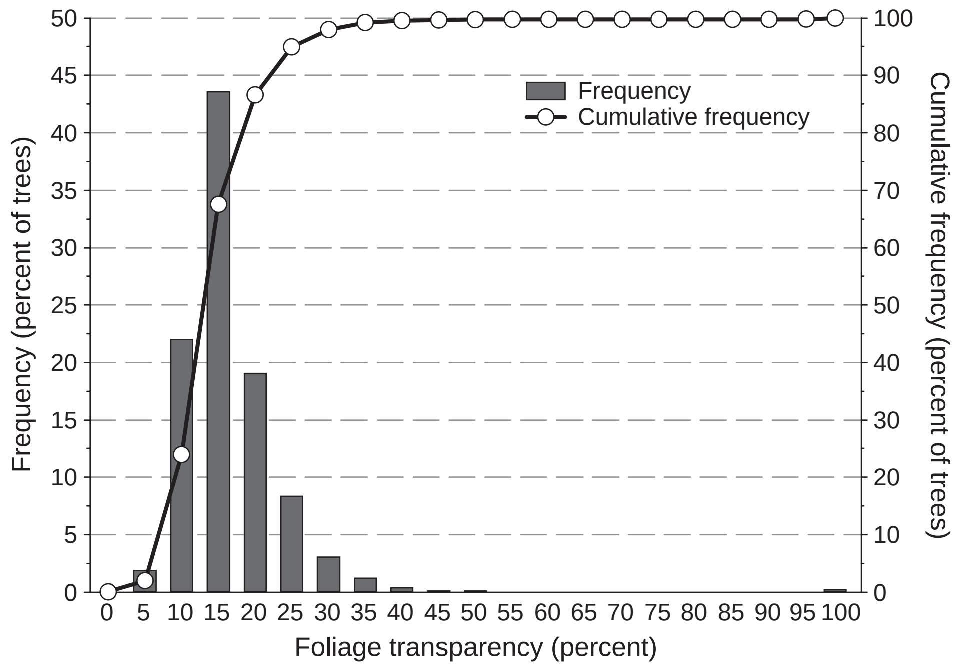

Figure 5—Foliage transparency frequency histogram and cumulative frequency distribution for all trees combined for California, Oregon, and Washington, 1996–99.

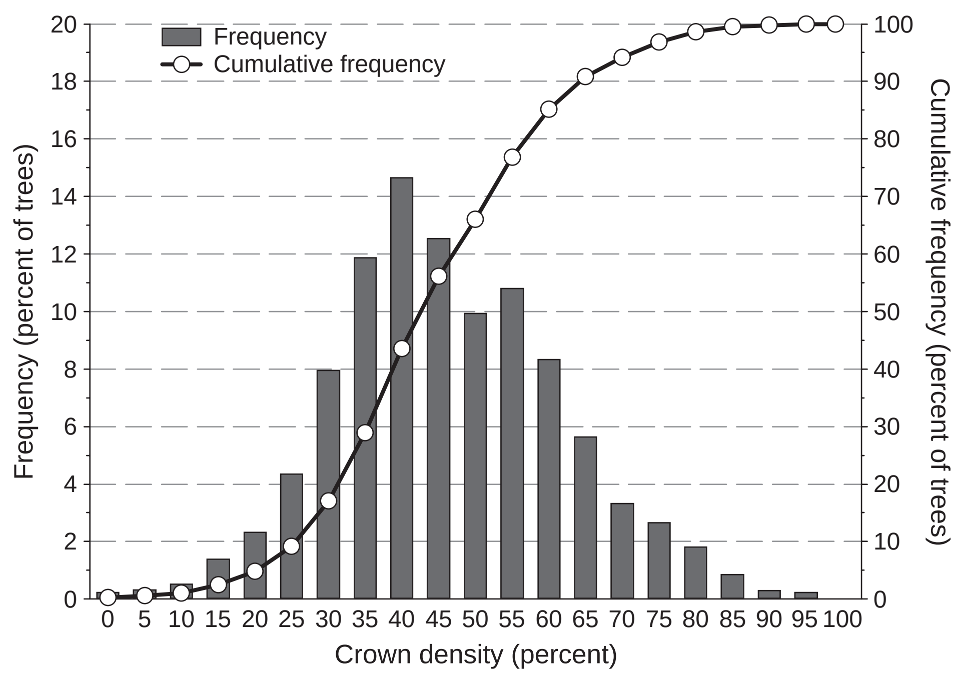

Figure 6—Crown density frequency histogram and cumulative frequency distribution for all trees combined in California, Oregon, and Washington, 1996–99.

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 California, Oregon, and Washington, 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	457	8,631	48.4	0.6	47.2	49.6	0	45	95
Hardwoods	207	2,504	39.6	0.7	38.2	41.0	0	40	99
All trees	501	11,135	46.4	0.6	45.3	47.5	0	45	99
Crown dieback									
Softwoods	457	8,631	1.5	0.1	1.3	1.7	0	0	99
Hardwoods	207	2,504	4.1	0.4	3.3	4.9	0	0	99
All trees	501	11,135	2.1	0.1	1.8	2.3	0	0	99
Foliage transparency									
Softwoods	457	8,631	15.9	0.2	15.4	16.3	0	15	99
Hardwoods	207	2,504	19.0	0.7	17.7	20.3	0	15	99
All trees	501	11,135	16.6	0.3	16.1	17.1	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.

On average, the absolute difference between the softwood and hardwood crown condition means was greatest for crown density. Mean crown density was 48.4 percent for the softwoods and 39.6 percent for the hardwoods (table 2). Foliage transparency was higher for the hardwoods (19.0 percent) than for the softwoods (15.9 percent), whereas mean 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 0.3 percent for Port-Orford-cedar (*Chamaecyparis lawsoniana)* to 9.2 percent for interior live oak (*Quercus wislizeni*) (table 3). Mean foliage transparency ranged from 10.9 percent for noble fir (*Abies procera*) to 27.9 percent for quaking aspen (*Populus tremuloides*) (table 4), and mean crown density ranged from 32.4 percent for California black oak (*Q. kelloggii*) to 57.9 percent for noble fir (table 5).

For all of the common species combined and for both the Douglas-fir (*Pseudotsuga menziesii*) and true fir (*A.* spp.) species groups, mean crown density was slightly higher on the west side of the Cascade Mountain Range than on the east side of the range, whereas mean crown dieback and mean foliage transparency were slightly higher on the east side (table 6).

Sapling Crown Vigor

Crown vigor was assessed for 1,653 saplings on 315 of the 524 forested plots. Overall, 59.9 percent of the sapling crowns were categorized as good (table 7). Although the percentage of hardwood and softwood saplings categorized as poor was about the same, the hardwood group had slightly more saplings in the good category (63.6 percent) than the softwood group (58.1 percent). Among the softwood species groups with at least 25 observations, the percentage of saplings in the good category ranged from 22.0 percent for the western hemlock (*Tsuga heterophylla*)

Table 3—Mean crown dieback and other statistics[a] for all live trees ≥ 5.0 inches diameter[b] by species for California, Oregon, and Washington, 1996–99

Species[c]	Plots[d]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	90th percentile	Maximum
	- - - number - - -		*- percent*	*- -*					
Softwoods									
Port-Orford-cedar	2	53	0.3	0.0	0.2	0.3	0	0.0	5
Shasta red fir	5	57	0.4	0.2	0.0	0.7	0	0.0	5
California juniper (w)	5	26	0.6	0.4	-0.3	1.4	0	5.0	5
Western redcedar	35	199	0.6	0.2	0.2	1.0	0	0.0	20
Jeffrey pine	24	113	0.8	0.3	0.1	1.4	0	5.0	20
Incense-cedar	44	212	0.8	0.2	0.3	1.2	0	5.0	25
Ponderosa pine	121	995	0.9	0.2	0.5	1.2	0	0.0	90
Sitka spruce	9	45	0.9	0.2	0.6	1.2	0	5.0	10
Sugar pine	29	106	0.9	0.4	0.1	1.7	0	5.0	25
California red fir	16	145	1.1	0.3	0.6	1.6	0	5.0	15
White fir	69	637	1.1	0.3	0.5	1.8	0	5.0	80
Douglas-fir	228	2,706	1.2	0.2	0.9	1.6	0	5.0	99
Western hemlock	77	916	1.3	0.3	0.7	1.8	0	5.0	35
Gray pine	17	39	1.3	0.5	0.3	2.2	0	5.0	5
Subalpine fir	18	114	1.4	0.4	0.6	2.1	0	5.0	20
Noble fir	14	56	1.4	0.6	0.2	2.6	0	5.0	10
Engelmann spruce	17	103	1.5	0.9	-0.2	3.2	0	5.0	70
Redwood	6	54	1.7	0.4	0.9	2.4	0	5.0	15
Lodgepole pine	61	738	2.2	0.3	1.5	2.8	0	5.0	99
Whitebark pine	7	37	2.2	0.7	0.8	3.5	0	5.0	15
Pacific silver fir	26	247	2.4	0.9	0.6	4.3	0	5.0	70
Western larch	23	100	2.5	0.7	1.2	3.7	0	7.5	40
Western juniper	51	304	2.6	0.4	1.9	3.4	0	5.0	35
Singleleaf pinyon (w)	8	47	2.7	1.4	-0.1	5.4	0	10.0	20
Mountain hemlock	20	204	3.3	0.6	2.1	4.4	0	5.0	90
Western white pine	22	69	3.5	1.0	1.6	5.4	0	5.0	60
Grand fir	43	238	4.0	0.9	2.2	5.8	0	10.0	95
Pacific yew	6	31	5.9	2.2	1.7	10.2	0	5.0	99
Hardwoods									
California-laurel	10	33	1.5	0.7	0.2	2.8	0	5.0	15
Tan oak	22	486	1.8	0.5	0.7	2.9	0	5.0	99
Red alder	44	404	3.1	1.3	0.4	5.7	0	5.0	99
California black oak	38	217	3.6	0.7	2.3	5.0	0	5.0	99
Coast live oak	7	80	3.8	1.1	1.6	6.1	0	10.0	25
Blue oak	27	168	3.9	0.6	2.8	5.0	0	10.0	15
Canyon live oak	39	395	4.4	1.1	2.4	6.5	0	10.0	90
Pacific madrone	36	159	5.8	1.1	3.7	7.8	0	10.0	99
Curlleaf mountain-mahogany (w)	8	65	6.0	0.4	5.2	6.8	0	10.0	25
Valley oak	2	26	6.9	0.1	6.7	7.1	5	10.0	30
Oregon white oak	16	124	6.9	1.9	3.2	10.6	0	15.0	99
Quaking aspen	3	36	7.5	2.3	3.0	12.0	0	15.0	60
Bigleaf maple	26	110	7.5	3.3	1.0	14.1	0	10.0	99
Interior live oak	12	80	9.2	2.6	4.1	14.4	0	17.5	99

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 California, Oregon, and Washington, 1996–99

Species[c]	Plots[d]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - number - - -		*- percent -*						
Softwoods									
Noble fir	14	56	10.9	0.9	9.1	12.6	5	10.0	25
California juniper (w)	5	26	12.1	1.3	9.6	14.6	5	10.0	25
Shasta red fir	5	57	12.5	1.5	9.4	15.5	0	10.0	20
Western juniper	51	304	13.0	0.5	12.1	13.9	5	15.0	30
Mountain hemlock	20	204	13.5	0.6	12.2	14.8	5	15.0	30
Subalpine fir	18	114	13.7	0.8	12.2	15.2	10	15.0	35
Western hemlock	77	916	13.7	0.5	12.7	14.7	5	15.0	30
Pacific silver fir	26	247	14.2	0.6	13.1	15.4	5	15.0	30
Sitka spruce	9	45	14.3	0.7	13.0	15.7	10	15.0	30
Engelmann spruce	17	103	14.4	1.2	12.0	16.7	5	15.0	40
California red fir	16	145	14.5	1.3	12.0	17.0	5	15.0	25
Pacific yew	6	31	14.8	2.2	10.5	19.1	5	10.0	99
White fir	69	637	14.8	0.7	13.4	16.2	5	15.0	50
Port-Orford-cedar	2	53	15.0	0.1	14.7	15.3	10	15.0	25
Douglas-fir	228	2,706	15.2	0.3	14.7	15.7	5	15.0	99
Jeffrey pine	24	113	16.6	1.6	13.5	19.8	5	15.0	60
Whitebark pine	7	37	16.8	1.0	14.7	18.8	10	15.0	25
Grand fir	43	238	17.0	0.9	15.2	18.8	5	15.0	95
Western redcedar	35	199	17.3	1.4	14.6	20.0	5	15.0	35
Incense-cedar	44	212	17.4	1.0	15.4	19.3	5	17.5	35
Western white pine	22	69	17.7	1.0	15.7	19.7	5	20.0	35
Lodgepole pine	61	738	18.3	0.8	16.7	19.9	5	15.0	99
Ponderosa pine	121	995	18.5	0.6	17.4	19.7	5	20.0	50
Redwood	6	54	18.7	1.3	16.1	21.3	10	17.5	50
Singleleaf pinyon (w)	8	47	19.4	1.0	17.3	21.4	10	20.0	30
Sugar pine	29	106	20.1	1.6	16.9	23.4	5	20.0	35
Western larch	23	100	22.5	1.1	20.4	24.6	10	20.0	40
Gray pine	17	39	27.2	3.1	21.2	33.2	10	25.0	55
Hardwoods									
Valley oak	2	26	14.4	0.2	14.0	14.9	10	15.0	25
Coast live oak	7	80	14.4	2.6	9.3	19.5	5	10.0	35
Tan oak	22	486	16.2	1.7	12.9	19.4	0	15.0	99
Blue oak	27	168	17.0	1.7	13.6	20.4	0	15.0	35
California-laurel	10	33	17.6	2.5	12.6	22.5	10	15.0	30
Curlleaf mountain-mahogany (w)	8	65	17.8	1.1	15.7	19.9	10	15.0	35
Canyon live oak	39	395	17.8	1.6	14.6	21.0	5	15.0	50
Pacific madrone	36	159	18.9	1.2	16.6	21.3	10	15.0	99
California black oak	38	217	19.7	1.1	17.6	21.9	10	20.0	99
Oregon white oak	16	124	19.8	1.7	16.4	23.1	5	20.0	99
Red alder	44	404	21.8	1.7	18.4	25.2	5	20.0	99
Bigleaf maple	26	110	23.1	2.9	17.3	28.9	5	17.5	99
Interior live oak	12	80	26.1	2.3	21.5	30.6	10	20.0	99
Quaking aspen	3	36	27.9	6.1	16.0	39.8	10	25.0	75

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 California, Oregon, and Washington, 1996–99

Species[c]	Plots[d]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - *number* - - -		- - - *percent* - - -						
Softwoods									
Noble fir	14	56	57.9	2.0	53.9	61.8	25	60	90
Western juniper	51	304	56.2	2.5	51.2	61.2	5	55	95
Subalpine fir	18	114	54.4	1.7	51.1	57.6	20	55	90
Pacific silver fir	26	247	53.3	2.0	49.4	57.3	5	55	85
California juniper (w)	5	26	52.3	4.2	44.0	60.6	5	50	85
Shasta red fir	5	57	52.3	5.2	42.2	62.4	20	55	85
Engelmann spruce	17	103	51.6	1.4	48.9	54.2	15	50	85
California red fir	16	145	51.0	1.8	47.5	54.5	20	50	85
Pacific yew	6	31	50.3	7.1	36.3	64.3	0	50	95
Western hemlock	77	916	49.6	2.8	44.1	55.1	10	50	90
Douglas-fir	228	2,706	49.5	1.0	47.7	51.4	0	50	95
Sitka spruce	9	45	48.4	2.2	44.1	52.8	20	50	70
White fir	69	637	47.6	1.7	44.2	51.0	5	45	95
Western larch	23	100	47.6	1.6	44.5	50.6	15	50	80
Western white pine	22	69	47.5	2.8	42.1	52.9	20	45	85
Ponderosa pine	121	995	47.4	1.5	44.5	50.4	5	45	95
Mountain hemlock	20	204	47.4	2.2	43.2	51.6	5	50	80
Incense-cedar	44	212	46.7	2.2	42.5	51.0	15	45	95
Sugar pine	29	106	46.3	1.7	43.0	49.6	5	45	75
Singleleaf pinyon (w)	8	47	46.0	3.5	39.0	52.9	20	45	80
Port-Orford-cedar	2	53	45.6	0.3	44.9	46.2	20	45	70
Western redcedar	35	199	45.0	1.4	42.3	47.7	15	45	80
Jeffrey pine	24	113	44.8	2.4	40.0	49.6	10	45	85
Grand fir	43	238	44.0	2.0	40.0	48.0	10	40	85
Whitebark pine	7	37	43.9	2.5	39.1	48.7	10	45	70
Lodgepole pine	61	738	43.3	1.4	40.5	46.2	0	45	85
Gray pine	17	39	41.0	3.4	34.4	47.6	15	40	75
Redwood	6	54	34.8	3.2	28.5	41.1	10	35	80
Hardwoods									
Red alder	44	404	48.1	1.7	44.8	51.4	0	50	90
California-laurel	10	33	42.0	3.1	36.0	48.0	25	40	70
Tan oak	22	486	40.9	1.5	37.9	44.0	0	40	80
Bigleaf maple	26	110	39.6	2.7	34.2	45.0	0	40	75
Blue oak	27	168	39.3	1.6	36.1	42.4	15	40	80
Pacific madrone	36	159	38.3	1.9	34.6	42.0	0	35	80
Interior live oak	12	80	37.5	2.1	33.4	41.5	0	35	99
Canyon live oak	39	395	37.3	1.1	35.2	39.4	5	35	80
Valley oak	2	26	37.3	0.9	35.5	39.2	20	40	55
Coast live oak	7	80	36.1	4.0	28.2	44.0	10	35	75
Quaking aspen	3	36	35.6	1.3	33.0	38.1	5	35	65
Oregon white oak	16	124	34.8	0.9	33.0	36.6	0	35	60
Curlleaf mountain-mahogany (w)	8	65	34.0	1.1	31.8	36.2	15	35	60
California black oak	38	217	32.4	1.1	30.2	34.5	0	35	65

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—Mean[a] crown attributes for live trees ≥ 5.0 inches diameter by species group and crown condition indicator, Washington and Oregon, 1996–99, area west of the Cascade Mountain Range vs. area east of the Cascade Mountain Range

Species group[b] and crown condition indicator	West				East			
	Plots[c]	Trees	Mean	SE	Plots[c]	Trees	Mean	SE
	- - - number - - -		*- - percent - -*		*- - - number - - -*		*- - percent - -*	
All species[d]								
Crown density	159	3,908	50.0	1.0	136	2,608	47.9	0.9
Crown dieback	159	3,908	1.7	0.2	136	2,608	1.8	0.2
Foliage transparency	159	3,908	15.3	0.3	136	2,608	16.7	0.3
Douglas-fir								
Crown density	120	1,813	51.2	1.3	66	519	48.8	1.2
Crown dieback	120	1,813	1.3	0.2	66	519	1.4	0.3
Foliage transparency	120	1,813	14.8	0.3	66	519	15.5	0.6
True fir[e]								
Crown density	43	328	51.9	2.0	56	527	49.8	1.5
Crown dieback	43	328	2.3	0.8	56	527	2.8	0.7
Foliage transparency	43	328	13.6	0.7	56	527	15.0	0.6

SE = standard error.

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

[b] See appendix table A.4.

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

[d] Includes 23 species common to both sides of the Cascade Mountain Range.

[e] Includes five *Abies* species common to both sides of the Cascade Mountain Range: *A. amabilis, A. concolor, A. grandis, A. lasiocarpa, A. procera.*

group to 73.7 percent for the incense-cedar (*Calocedrus decurrens*) group. The western redcedar (*Thuja plicata*) group had the highest percentage of saplings in the poor category (17.9 percent) (table 7). Among the hardwood species groups with at least 25 observations, the oak (*Q.* spp.) group had the highest percentage of saplings in the good category (67.3 percent) and the lowest percentage of saplings in the poor category (4.2 percent). Similarly, the red alder (*Alnus rubra*) group had the lowest percentage of saplings in the good category (52.7 percent) and the highest percentage of saplings in the poor category (9.1 percent) (table 7).

For all species combined, the percentages of saplings in the good and poor categories were higher on the east side of the Cascades than on the west side. However, the percentage of saplings in the fair category was higher on the west side of the Cascades than on the east side (table 8). For the two species groups examined individually, both the Douglas-fir and true fir groups had higher percentages of saplings in the good category, and correspondingly lower percentages of saplings in the fair and poor categories, on the west side of the Cascades (table 8).

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, and the general statistical characteristics of the data. We present a brief overview of each factor.

Table 7—Distribution of sapling crown vigor class for all live saplings 1.0 to < 5.0 inches diameter[a] by FIA species group, California, Oregon, and Washington, 1996–99

			Crown vigor rating					
			Good		Fair		Poor	
Species group[b]	Plots[c]	Saplings	Percent	SE[d]	Percent	SE[d]	Percent	SE[d]
	- - - - *number* - - - -			*percent*		*percent*		*percent*
Softwoods								
Douglas-fir	91	266	62.8	4.8	33.5	4.6	3.8	1.2
Ponderosa and Jeffrey pines	50	165	69.7	4.5	28.5	4.0	1.8	1.6
True fir	84	233	60.1	5.1	33.9	4.7	6.0	1.7
Western hemlock	28	173	22.0	10.2	74.0	11.5	4.0	3.1
Sugar pine	8	14	71.4	—	28.6	—	0.0	—
Western white pine	5	7	100.0	—	0.0	—	0.0	—
Sitka spruce	2	2	100.0	—	0.0	—	0.0	—
Engelmann and other spruces	5	13	53.8	—	23.1	—	23.1	—
Western larch	1	1	100.0	—	0.0	—	0.0	—
Incense-cedar	17	38	73.7	9.4	21.1	7.1	5.3	3.6
Lodgepole pine	22	105	69.5	5.8	26.7	4.7	3.8	2.2
Western redcedar	15	39	43.6	15.5	38.5	13.3	17.9	14.3
Western woodland softwoods	1	1	100.0	—	0.0	—	0.0	—
Other western softwoods	29	68	70.6	9.9	27.9	9.3	1.5	1.4
All softwoods	253	1,125	58.1	5.1	37.3	5.2	4.5	1.0
Hardwoods								
Cottonwood and aspen	2	8	62.5	—	37.5	—	0.0	—
Red alder	16	55	52.7	10.8	38.2	8.1	9.1	4.3
Oak	54	214	67.3	5.1	28.5	4.6	4.2	1.8
Other western hardwoods	53	246	63.0	6.3	32.1	5.7	4.9	2.1
Western woodland hardwoods	4	5	60.0	—	40.0	—	0.0	—
All hardwoods	114	528	63.6	3.9	31.4	3.4	4.9	1.3
All trees	315	1,653	59.9	3.8	35.5	3.8	4.7	0.8

FIA = Forest Inventory and Analysis; SE = standard error (Standard error calculations consider the clustering of saplings on plots.); — = no 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.

Table 8—Distribution of sapling crown vigor class for all live saplings 1.0 to < 5.0 inches diameter by FIA species group and subregion, Washington and Oregon, 1996–99, area west of the Cascade Mountain Range vs. area east of the Cascade Mountain Range

Species group[a] and subregion	Plots[b]	Saplings	Crown vigor rating: Good Percent	Good SE	Fair Percent	Fair SE	Poor Percent	Poor SE
	- - - - number - - - -			*percent*		*percent*		*percent*
All species[c]								
East	91	465	56.6	4.3	36.5	3.6	6.9	1.9
West	102	506	48.4	8.9	48.0	9.1	3.6	1.3
Douglas-fir								
East	28	61	44.3	7.8	47.5	7.9	8.2	3.5
West	46	163	63.2	6.4	34.3	6.3	2.5	1.3
True fir[d]								
East	33	103	44.7	7.9	48.5	7.6	6.8	2.8
West	25	46	63.0	10.4	32.6	10.4	4.3	3.2

FIA = Forest Inventory and Analysis; SE = standard error. (Standard error calculations consider the clustering of saplings on plots.)

[a] See appendix table A.4.

[b] Total number of forested plots on which saplings were measured.

[c] Includes 22 species common to both sides of the Cascade Mountain Range.

[d] Includes five *Abies* species common to both sides of the Cascade Mountain Range: *A. amabilis, A. concolor, A. grandis, A. lasiocarpa, A. procera.*

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 32.4 and 57.9 percent. On average, the species with the highest crown densities and lowest foliage transparencies were in the fir, juniper (*Juniperus* spp.), and spruce (*Picea* spp.) genera 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 and certain pines (*Pinus* spp.) whose crowns tend to be more broad-spreading or open, e.g. gray pine (*P. sabiniana*). Such great variability inhibits direct comparisons of species because some species clearly tend to have denser crowns than others. For example, a noble fir tree with a crown density of 40 percent may indicate that the tree is under stress; however, a lodgepole pine (*P. contorta*) 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. For example, due to physiographic variations, species growing on the east side of the Cascade Mountain Range in Oregon and Washington were expected to have different average crown conditions than those growing on the west side of the range. In these States, forests west of the Cascades are highly influenced by the close proximity of the Pacific Ocean which moderates temperatures and provides abundant moisture. The ocean's influence declines with distance inland and due to the physical barrier formed by the Cascade Mountains. As a result, trees growing west of the Cascades primarily are limited by physical growing space and the competition for sunlight, whereas forests east of the Cascades are influenced by a lack of available moisture and temperature extremes throughout the year. These stark differences in growing conditions likely impact crown development as trees respond to local growing conditions. Due to limited sample sizes, only two species groups were compared, but both showed "better" tree and sapling crown conditions on the west side of the Cascades than on the east side.

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 ecoregion, 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. Fire, drought, and other events such as wind, frost, and ice can damage tree crowns, as may grazing livestock, particularly on sapling-sized trees. In addition to these factors, there are numerous insects and diseases that damage trees in the forests of California, Oregon, and Washington. Some directly impact the crown by actively feeding on foliage, whereas for others, foliage discoloration, crown thinning, and defoliation are secondary signs of their presence. Among the insects that directly defoliate the crown, those that were active when these data were collected include, but are not limited to, the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) and western spruce budworm (*Choristoneura occidentalis* Freeman) in Oregon and Washington (Campbell and others 2001a, 2001b), and the Douglas-fir tussock moth, California and Modoc budworms (*C. carnana californica* and *C. retiniana* Walsingham), fruittree leaf roller (*Archips argyrospilus*), and lodgepole pine needleminer (*Coleotechnites milleri* Busck) in California (California Forest Pest Council 1996; U.S. Department of Agriculture Forest Service, Forest Pest Management 1997; U.S. Department of Agriculture Forest Service, Pacific Southwest Region, State and Private Forestry 1998, 1999).

Damage to crowns also occurs from a variety of other nondefoliating insects and diseases including the sapsucking spruce aphid (*Elatobium abietinum* Walker), Swiss needle cast (*Phaeocryptopus gaeumannii*), diplodia blight (*Sphaeropsis sapinea (Diplodia pinea)*), and a variety of dwarf mistletoes (*Arceuthobium* spp.). Of these, dwarf mistletoe is perhaps the most damaging overall. In Oregon, nine percent of all conifers tallied on FIA inventory plots in the 1990s were infected with dwarf mistletoe (Dunham 2008). The distribution of dwarf mistletoe has been relatively stable for the last several decades, affecting about 13.5 million acres of forest land in California, Oregon, and Washington (U.S. Department of Agriculture Forest Service, Forest Health Protection 2000). Dwarf mistletoe infections impact crown condition by diminishing overall tree vigor and causing witches' brooms, branch breakage, and branch dieback at infection sites. In this region, dwarf mistletoe primarily affects ponderosa pine (*Pinus ponderosa*), lodgepole pine, Douglas-fir, true firs, western hemlock, and western larch (*Larix occidentalis*).

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). California, Oregon, and Washington each have enough forested area to supply the minimum sample size individually. When combined with Alaska and Hawaii, <3 percent of the total combined forested area in these five States would need to be impacted in order to detect a significant change in crown condition (Bechtold and others 2009).

In addition to having an adequate sample size, any data used in hypothesis testing must meet the underlying assumptions of the tests being used. 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 California, Oregon, and Washington were similar to those in the South. The distribution of foliage transparency was more skewed in this three-State region than in the South.

Conclusion

With increasing introductions (and subsequent establishment and spread) of damaging exotic pests, continued impacts from air pollution and native insects and diseases, and the effects of climate change (such as drought), FHM in California, Oregon, and Washington 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, calculation of changes in the crown measurements will indicate whether crown condition—and by extension, forest health—is stable, improving, or declining.

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Appendix

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

Species group[c]	Plots[d]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	90th percentile	Maximum
	- - - number - - -		*- - - percent - - -*						
Softwoods									
Douglas-fir	228	2,706	1.2	0.2	0.9	1.6	0	5.0	99
Ponderosa and Jeffrey pines	141	1,108	0.9	0.2	0.6	1.2	0	5.0	90
True fir	157	1,495	1.8	0.3	1.1	2.5	0	5.0	95
Western hemlock	77	918	1.3	0.3	0.7	1.8	0	5.0	35
Sugar pine	29	106	0.9	0.4	0.1	1.7	0	5.0	25
Western white pine	22	69	3.5	1.0	1.6	5.4	0	5.0	60
Redwood	6	54	1.7	0.4	0.9	2.4	0	5.0	15
Sitka spruce	9	45	0.9	0.2	0.6	1.2	0	5.0	10
Engelmann and other spruces	17	103	1.5	0.9	-0.2	3.2	0	5.0	70
Western larch	23	100	2.5	0.7	1.2	3.7	0	7.5	40
Incense-cedar	44	212	0.8	0.2	0.3	1.2	0	5.0	25
Lodgepole pine	61	738	2.2	0.3	1.5	2.8	0	5.0	99
Western redcedar	35	199	0.6	0.2	0.2	1.0	0	0.0	20
Western woodland softwoods	13	78	2.4	1.1	0.2	4.6	0	10.0	30
Other western softwoods	107	700	2.7	0.4	2.0	3.4	0	5.0	99
Hardwoods									
Cottonwood and aspen	7	50	6.3	1.6	3.2	9.4	0	12.5	60
Red alder	44	404	3.1	1.3	0.4	5.7	0	5.0	99
Oak	108	1,090	4.8	0.6	3.7	5.9	0	10.0	99
Other western hardwoods	93	892	3.4	0.7	2.0	4.9	0	5.0	99
Western woodland hardwoods	9	68	5.7	0.5	4.7	6.8	0	10.0	25

FIA = Forest Inventory and Analysis; 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 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.

Table A.2—Mean foliage transparency and other statistics[a] for all live trees ≥ 5.0 inches diameter[b] by FIA species group for California, Oregon, and Washington, 1996–99

					95% confidence				
Species group[c]	Plots[d]	Trees	Mean	SE	Lower	Upper	Minimum	Median	Maximum
	number		*percent*						
Softwoods									
Douglas-fir	228	2,706	15.2	0.3	14.7	15.7	5	15.0	99
Ponderosa and Jeffrey pines	141	1,108	18.3	0.6	17.2	19.4	5	20.0	60
True fir	157	1,495	14.7	0.4	13.9	15.6	0	15.0	95
Western hemlock	77	918	13.7	0.5	12.7	14.7	5	15.0	30
Sugar pine	29	106	20.1	1.6	16.9	23.4	5	20.0	35
Western white pine	22	69	17.7	1.0	15.7	19.7	5	20.0	35
Redwood	6	54	18.7	1.3	16.1	21.3	10	17.5	50
Sitka spruce	9	45	14.3	0.7	13.0	15.7	10	15.0	30
Engelmann and other spruces	17	103	14.4	1.2	12.0	16.7	5	15.0	40
Western larch	23	100	22.5	1.1	20.4	24.6	10	20.0	40
Incense-cedar	44	212	17.4	1.0	15.4	19.3	5	17.5	35
Lodgepole pine	61	738	18.3	0.8	16.7	19.9	5	15.0	99
Western redcedar	35	199	17.3	1.4	14.6	20.0	5	15.0	35
Western woodland softwoods	13	78	16.8	1.5	13.9	19.7	5	15.0	30
Other western softwoods	107	700	15.0	0.5	13.9	16.1	5	15.0	99
Hardwoods									
Cottonwood and aspen	7	50	25.4	4.6	16.3	34.5	10	22.5	75
Red alder	44	404	21.8	1.7	18.4	25.2	5	20.0	99
Oak	108	1,090	18.6	0.9	16.9	20.2	0	15.0	99
Other western hardwoods	93	892	18.0	1.2	15.5	20.4	0	15.0	99
Western woodland hardwoods	9	68	17.9	1.1	15.8	19.9	10	15.0	35

FIA = Forest Inventory and Analysis; 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 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.

Table A.3—Mean crown density and other statistics[a] for all live trees ≥ 5.0 inches diameter[b] by FIA species group for California, Oregon, and Washington, 1996–99

Species group[c]	Plots[d]	Trees	Mean	SE	95% confidence Lower	95% confidence Upper	Minimum	Median	Maximum
	- - - *number* - - -		- - - *percent* - - -						
Softwoods									
Douglas-fir	228	2,706	49.5	1.0	47.7	51.4	0	50	95
Ponderosa and Jeffrey pines	141	1,108	47.2	1.4	44.5	49.9	5	45	95
True fir	157	1,495	49.4	1.0	47.3	51.4	5	50	95
Western hemlock	77	918	49.6	2.8	44.1	55.1	10	50	90
Sugar pine	29	106	46.3	1.7	43.0	49.6	5	45	75
Western white pine	22	69	47.5	2.8	42.1	52.9	20	45	85
Redwood	6	54	34.8	3.2	28.5	41.1	10	35	80
Sitka spruce	9	45	48.4	2.2	44.1	52.8	20	50	70
Engelmann and other spruces	17	103	51.6	1.4	48.9	54.2	15	50	85
Western larch	23	100	47.6	1.6	44.5	50.6	15	50	80
Incense-cedar	44	212	46.7	2.2	42.5	51.0	15	45	95
Lodgepole pine	61	738	43.3	1.4	40.5	46.2	0	45	85
Western redcedar	35	199	45.0	1.4	42.3	47.7	15	45	80
Western woodland softwoods	13	78	48.7	2.9	43.1	54.4	5	45	90
Other western softwoods	107	700	50.3	1.6	47.2	53.4	0	50	95
Hardwoods									
Cottonwood and aspen	7	50	36.4	1.0	34.5	38.3	5	35	65
Red alder	44	404	48.1	1.7	44.8	51.4	0	50	90
Oak	108	1,090	36.3	0.7	34.9	37.6	0	35	99
Other western hardwoods	93	892	40.5	1.1	38.4	42.6	0	40	80
Western woodland hardwoods	9	68	34.3	1.2	32.0	36.6	15	35	60

FIA = Forest Inventory and Analysis; 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 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.

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

Species group and common name	Scientific name[b]	Species group and common name	Scientific name[b]
Douglas-fir	*Pseudotsuga menziesii*	Cottonwood and aspen	
Ponderosa and Jeffrey pines		Cottonwood and poplar spp.[c]	*Populus* spp.
Jeffrey pine	*Pinus jeffreyi*	Quaking aspen	*P. tremuloides*
Ponderosa pine	*P. ponderosa*	Black cottonwood[c]	*P. balsamifera*
True fir		Red alder	*Alnus rubra*
Pacific silver fir	*Abies amabilis*	Oak	
White fir	*A. concolor*	Coast live oak, California live oak	*Quercus agrifolia*
Grand fir	*A. grandis*	Canyon live oak	*Q. chrysolepis*
Subalpine fir, corkbark fir	*A. lasiocarpa*	Blue oak	*Q. douglasii*
California red fir	*A. magnifica*	Oregon white oak	*Q. garryana*
Noble fir	*A. procera*	California black oak	*Q. kelloggii*
Shasta red fir	*A. shastensis*	Valley oak, California white oak[c]	*Q. lobata*
Western hemlock	*Tsuga heterophylla*	Interior live oak	*Q. wislizeni*
Sugar pine	*Pinus lambertiana*	Other western hardwoods	
Western white pine	*P. monticola*	Bigleaf maple	*Acer macrophyllum*
Redwood[c]	*Sequoia sempervirens*	California buckeye	*Aesculus californica*
Sitka spruce	*Picea sitchensis*	White alder	*Alnus rhombifolia*
Engelmann and other spruces		Pacific madrone	*Arbutus menziesii*
Engelmann spruce	*Picea engelmannii*	Paper birch[c]	*Betula papyrifera*
Western larch	*Larix occidentalis*	Western paper birch[d]	*B. papyrifera* var. *commutata*
Incense-cedar	*Calocedrus decurrens*		
Lodgepole pine	*Pinus contorta*	Golden chinkapin	*Chrysolepis chrysophylla*
Western redcedar	*Thuja plicata*		
Western woodland softwoods		Pacific dogwood	*Cornus nuttallii*
California juniper	*Juniperus californica*	Hawthorn spp.[d]	*Crataegus* spp.
Utah juniper[c]	*J. osteosperma*	Oregon ash[c]	*Fraxinus latifolia*
Common pinyon[c]	*Pinus edulis*	Tanoak	*Lithocarpus densifloru*
Singleleaf pinyon[c]	*P. monophylla*		
Other western softwoods		Apple spp.	*Malus* spp.
Port-Orford-cedar	*Chamaecyparis lawsoniana*	Bitter cherry	*Prunus emarginata*
Alaska yellow-cedar	*C. nootkatensis*	Willow spp.	*Salix* spp.
Monterey cypress[c]	*Cupressus macrocarpa*	Bonpland willow[c]	*S. bonplandiana*
Western juniper	*Juniperus occidentalis*	Scouler willow[d]	*S. scouleriana*
Subalpine larch[c]	*Larix lyallii*	California-laurel	*Umbellularia californica*
Whitebark pine	*Pinus albicaulis*		
Knobcone pine[c]	*P. attenuata*	Western woodland hardwoods	
Coulter pine[c]	*P. coulteri*	Rocky Mountain maple[d]	*Acer glabrum*
Gray pine, California foothill pine	*P. sabiniana*	Hairy mountain-mahogany[d]	*Cercocarpus breviflorus*
Pacific yew	*Taxus brevifolia*		
California torreya	*Torreya californica*	Curlleaf mountain-mahogany	*C. ledifolius*
Mountain hemlock	*Tsuga mertensiana*	Alderleaf mountain-mahogany[d]	*C. montanus*

FHM = Forest Health Monitoring.

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

[b] Little (1979).

[c] Tree only.

[d] Sapling only.

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

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