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Effects of changing forest land definitions on forest inventory on the West Coast, USA

David L. Azuma · Andrew Gray

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Abstract A key function of forest inventory is to detect changes in the area of forest land over time, yet different definitions of forest land are used in different regions of the world. Changes in the definition of forest intended to improve international consistency can affect the ability to quantify true changes over time. The objective of this study was to evaluate the effects of a definitional change from relative stocking to canopy cover on the area classified as forest land and its relationship to species and forest density in California, Oregon, and Washington. Both western Juniper and ponderosa pine will yield higher estimates of forest land area using a canopy cover definition in comparison to a stocking-based definition, with the difference being most pronounced where land is marginally forested. The change in definition may result in an additional 146,000 ha of forest land identified on the West Coast. Measuring marginal forest lands with both metrics for the first cycle after implementation should make it possible to distinguish real change from definitional change.

D. L. Azuma (✉)
USDA Forest Service, Pacific Northwest Station,
Forest Inventory and Analysis Program,
Portland Forestry Sciences Lab, 620 SW Main St,
Suite 400, Portland, OR 97205, USA
e-mail: dazuma@fs.fed.us

A. Gray
USDA Forest Service, Pacific Northwest Research Station,
Forest Inventory and Analysis Program, Corvallis Forestry
Sciences Lab, 3200 SW Jefferson Way,
Corvallis, OR 97331, USA

A. Gray
e-mail: agray01@fs.fed.us

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Introduction

Forest land is declining globally, resulting in fluxes of CO_2 to the atmosphere and impacts on the services provided by forests, including hydrologic regulation, wildlife habitat, forest products, and reservoirs of biodiversity (Rudel et al. 2005; Defries and Eshleman 2004; Theobald et al. 1997). Quantifying the area of forested land is critical to our understanding on how forests are changing, but internationally inconsistent definitions of "forest" affect our ability to determine the amounts, causes, and consequences of impacts to forest land area. In general, most forest definitions establish a minimum area within which there is a minimum amount of tree vegetation as measured by stocking or canopy cover, or where that minimum amount is temporarily lost (through logging or disturbance) but likely to return through either active management or natural regeneration. The type of vegetation that qualifies as forest also varies by country; for example, in many countries bamboo is considered a grass, but in Vietnam, areas that are dominated by bamboo but were originally defined by the presence of trees are considered forest (UNFAO 2010). The European Commission has defined forest land as having at least 20 % tree canopy closure, 10 % in Mediterranean forest types, and a minimum area of 0.5 ha. The Food and Agriculture Organization of the United Nations uses the same 0.5 ha, with trees at least 5 m tall and a canopy cover of more than 10 % or stocking of more than 10 %, or trees able to reach those thresholds in situ (UNFAO 2008). Forest assessments in the USA are conducted by the US Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis program (FIA), which previously used minimum criteria of 10 % relative stocking of tree species (based on a national tree list), 0.4 ha (1 acre) in size, a minimum width of 36.6 m (120 ft), and no land use practices that prevent normal tree regeneration (e.g., regular mowing or intensive grazing) (Bechtold and Patterson 2004). In the latest version of the national field manual and database (version 6.0, implemented in 2013 in the Pacific coast region), FIA defines forest land as having at least 10 % canopy cover of the same species list and with the same size and land use restrictions.

The different approaches to defining forest land have little effect on assessments of areas with intact, productive forest land. These forests readily meet the minimum area requirements, and the land area is dominated by tall trees that commonly exceed even a 50 % occupancy threshold by either measure. The type of approach becomes important in areas of marginal forests with relatively sparse tree abundance, for example, in dry forests, alpine areas, areas that are transitioning from forest to non-forest, or fragmented forests mixed with a variety of land uses, like agriculture or urbanization. Although we suspect that majority of the effect of varying forest definitions will occur in marginally forested lands, the magnitude of the effect or the species that might contribute to it are unknown. Consistency in these areas is particularly important since these are likely to be the areas where most of the change occurs, either from changes in land use, disturbance regime, or climate. On the West Coast of the USA, 10 % relative stocking has been used to define productive forest ("timberland") in forest inventories since the 1930s (Andrews 1932; Andrews and Cowlin 1940). For many years, unproductive forest lands (e.g., western juniper in eastern Oregon and oak woodlands in the interior valleys of California) were not measured on the ground and only assessed for area, usually using a minimum cover definition for delineation on imagery. Increased attention to national and international consistency (e.g., Gillespie 1999) made using different metrics of tree density in different areas is an undesirable situation.

Stocking in this study is a quantitative measure of tree density with respect to management objectives. Absolute stocking can be expressed in terms of basal area per acre, volume per acre, or trees per acre. Relative stocking is a measure of density in comparison to some standard such as the "normal" number of trees in a fully occupied stand at a certain stage of development, usually expressed as a percent of normal (e.g., McArdle et al. 1961). Normal density is controlled by the amount of resources, light, water, and nutrients, available for tree growth. FIA uses species-specific stocking functions that relate the area occupied by a single tree to the area of a tree of the same size growing in a fully stocked stand of similar trees using normal stocking guides as the standard (Arner et al. 2001). An individual tree's contribution to normal stocking is calculated as the power function of diameter at breast height (DBH), $\mathrm{PN}=b_0\mathrm{DBH}^{b1}$, where PN is the percent of normal stocking and b_0 and b_1 are species-specific coefficients (Arner et al. 2001). The coefficient for diameter is roughly a 3/2 power as described by Reineke (1933) and Curtis (1971).

Tree cover is a measure of the area of ground covered by the vertical projection of canopies of trees. A variety of methods exist to measure tree cover, most of which assume different definitions of "cover" (Bunnell and Vales 1990; Fiala et al. 2006). For inventory purposes, the cover of an individual tree is usually defined as the area within the outer edge of its crown, regardless of the density or gappiness of foliage within it. This type of cover can be estimated from aerial photography, line-intercept or point sampling, or measurement of individual crown dimensions (O'Brien 1989; Bechtold 2004; Korhonen et al. 2006). The latter measurements have been used to develop equations relating individual tree cover to DBH, which are important components of forest simulation models (e.g., Crookston and Stage 1999).

Previous definitions from the USDA Forest Service's Forest Health Monitoring program (FHM) divided forest land into various categories, one which was called woodland which had less than 10 % stocking in timberland species but had at least 10 % crown cover in timberland and woodland species, implying that in marginal forest land 10 % cover was a proxy for 10 % stocking (USDA 1996). Timberland species generally have a stocking equation assigned to them, and many of the woodland species which diameter may be measured at the root collar may not have a reasonable assignment. While stocking values are generally fixed for a given species and diameter, it is possible that the crown area of same-sized trees differs between dense, closed stands and open, marginal stands. In areas where the forest land is marginal at best, there may be some differences between relative stocking and canopy cover which may make a one-to-one relationship improbable.

The objective of this study was to evaluate the relationships between relative stocking and cover as they relate to the classification of a plot, and quantify the effect on estimates of forest land. In addition to these objectives, we also wanted to compare the relationship on more productive forested plots.

Methods

The data used in this study includes all the FIA plots measured in Oregon, California, and Washington from 2009 through 2011 where the field crews had to determine whether or not the plot was forested. FIA plots are a spatially consistent sample of field plots distributed across the entire landscape at roughly one plot per 2,400 ha; 10 % of the plots in the western USA are sampled each year. Plots are examined on aerial imagery in the office to determine if there is a chance that they are forested; those that are forested or have a chance to be forested are sent to the field for measurement. Plots that were obviously more than 10 % stocked, such as having eight or more trees per subplot, were not checked for stocking; others that were close to 10 % stocked were checked for stocking and cover. A total of 135 plots were sampled in marginally forested lands. In these situations, the crew measured tree crowns and diameters in a 0.4-ha (1 acre) area. Crown measurements consisted of the maximum width of the crown and the width at the widest point perpendicular to the longest axis. The crown measurements were taken to both the full length and the length where there was no overlap with taller crowns of adjacent trees. Diameter was measured at breast height (1.37 m above ground), with the exception of Utah juniper and single leaf pinion (*Juniperus osteosprema* (Torr.) Little, *Pinus monophylla* Torr. & Frem.), where diameter was collected at ground level.

The field data collection computer calculated both stocking and crown area. The crown area for individual trees was computed by taking the average area of two circles whose diameters were the long and short non-overtopped crown width measures. The non-overtopped measures are used in an effort to keep crown cover from being inflated due to the crown overlap being counted in more than one crown. Plot-level crown area was calculated by accumulating individual tree crown area. The relative stocking is computed using the stocking guide included in the field manual (USDA 2010), where tree species are assigned to one of 36 different stocking equations (Arner et al. 2001). Crews measured trees on the plot to determine if it was truly forested until both accumulated stocking and cover had reached 25 % or until they had measured all trees in the entire 0.4-ha area. It was assumed that once stocking or cover had reached the 25 % threshold, the other metric would be at least 10 % and the plot would be forested by either definition.

A second dataset consisting of FHM plots measured in Oregon and California between 1997 and 1999 were used as a comparison because crown diameters were collected from trees greater than 12.7 cm (5 in.) at DBH in a similar fashion. This FHM dataset is used for comparing individual trees because it came from a sample of all forested lands, while the first FIA dataset came from a sample of sparsely treed areas. The FHM dataset was also spatially consistent across all lands in California and Oregon at roughly one plot per 38,000 ha. Western juniper (*Juniperus occidentalis* Hook.) could not be compared between datasets because tree diameters were collected at the root collar in the FHM data, so comparing stocking would be problematic.

Comparisons were made between accumulated plot-level and individual tree-level stocking and cover. Plot-level averages were compared between states to help isolate particular areas that might be problematic. Statistically significant differences were based upon the mean difference and its 95 % confidence interval not containing zero, (calculated with the Z-statistic). Only ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.) had a sufficient sample size of trees over 12.7 cm DBH to run a linear model to examine the variability in the difference between cover and stocking as a function of diameter and type of plot (FIA or FHM).

Results

Accumulating both stocking and crown cover at the plot level resulted in 44 % of plots identified as non-forest by both metrics (less than 10 %, stocking or cover), and 29 % were called forest by both. Of the 67 plots that were called forest using a cover definition, 42 % were called non-forest by stocking (Table 1). The difference of percent cover minus percent stocking over all plots yielded a mean and 95 % confidence

Table 1 Classification of plots with low tree abundance as forest land using the stocking and cover definitions

	Cover definition		Total
	Forested	Not forested	
Stocking definition			
Forested	39	9	48
Not forested	28	59	87
Total	67	68	135

interval of 1.85±0.85 percentage points. When dividing the plots by state, only Oregon had a significant difference with an average and 95 % confidence interval of 3.50±1.5. There were many cases where the relationship between accumulated plot values for percent of normal stocking and percent of canopy cover is not one to one (Fig. 1).

The mean difference between cover and stocking for the annual FIA data on an individual tree basis was statistically different for all but one species, the Oregon white oak (*Quercus garryana* Dougl. Ex Hook.). The greatest positive average difference (cover minus stocking) was for gray pine (*Pinus sabiniana* Dougl.) with .09 percentage points, and the greatest negative average difference was −.18 percentage points for Utah juniper (Table 2). For western juniper, the most abundant species in marginal forested land, the distribution of individual tree differences was skewed to the positive with a mean of .06 percentage points (Fig. 2).

The relationship between stocking and canopy cover differed for trees sampled across all forest land and (FHM data) those on marginal forest land (FIA data), as seen with the mean difference between stocking and cover. Both Oregon white oak and Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) differed in their distributions between the annual data and the FHM data (Table 2). For ponderosa pine, the FHM data had a negative mean difference in comparison to the FIA plots that had a positive difference (Table 2). The results of the linear model indicate that regardless of diameter distribution differences, the type of sample is still significant in explaining the difference between stocking and cover. For example, for a given diameter of ponderosa pine, crown cover would be greater on average on marginally forested land in comparison to all forest land.

Discussion

This study found significant differences in the number and type of plots classified as forest land between occupancy using 10 % cover or 10 % stocking thresholds. The relationship between cover and stocking differed by plot sample type. The nature of the plots where stocking was checked may explain the differences in comparison to the general population of forested plots. Along a gradient from forest to non-forest, there is usually a transitional zone where trees are sparse. In many cases, the transition may be due to elevation effects on precipitation. If trees are more dependent on moisture than

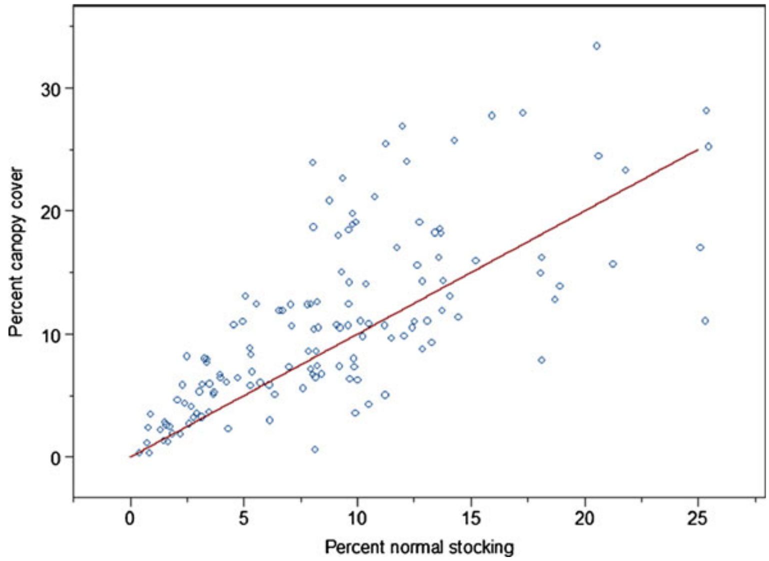

Fig. 1 Accumulated plot-level percent of stocking and canopy cover with one-to-one line for marginally forested annual plots, 2009–2011

Table 2 Average and 95 % confidence intervals for the difference between percent canopy cover and percent relative stocking by species for individual trees

Species	Count	Mean	SE	95 % CI
Annual 2009–2011				
Abies concolor	303	−0.02[a]	0.004	(−0.026, −0.009)
J. occidentalis	3,598	0.06[a]	0.003	(0.056, 0.070)
J. osteosperma	193	−0.18[a]	0.026	(−0.230, −0.124)
P. jeffreyi	147	−0.04[a]	0.016	(−0.078, −0.012)
P. monophylla	283	0.02[a]	0.007	(0.007, 0.036)
P. ponderosa	450	0.04[a]	0.011	(0.014, 0.060)
P. sabiniana	161	0.09[a]	0.025	(0.043, 0.143)
Prunus virginiana	215	−0.02[a]	0.001	(−0.022, −0.018)
Pseudosuga menziesii	174	0.07[a]	0.019	(0.030, 0.104)
Q. garryana	129	0.02	0.017	(−0.014, 0.054)
FHM data 1997–1999				
A. concolor	566	−0.03[a]	0.011	(−0.052, −0.008)
P. jeffreyi	87	0.03	0.021	(−0.011, 0.075)
P. monophylla	58	0.04	0.022	(−0.004, 0.084)
P. ponderosa	1,004	−0.03[a]	0.005	(−0.042, −0.019)
P. sabiniana	25	0.48[a]	0.128	(0.214, 0.744)
P. menziesii	1,708	0.16[a]	0.010	(0.139, 0.179)
Q. garryana	116	0.10[a]	0.021	(0.059, 0.143)

[a]Mean difference is statistically different than zero

light, they may tend to be more open grown and this results in cover being greater than stocking. Since the stocking guides are based on normally stocked stands, one would expect there to be a different relationship (Maclean and Bolsinger 1973) in transitional stands, where the number of trees that would fully occupy the stand may be much less than a normally stocked stand. On the West Coast, ponderosa pine is one of the most prevalent species in marginal forests. There is strong evidence from the comparison of the general population of ponderosa pine trees (FHM plots) to the trees on marginally forested plots that stocking and canopy cover

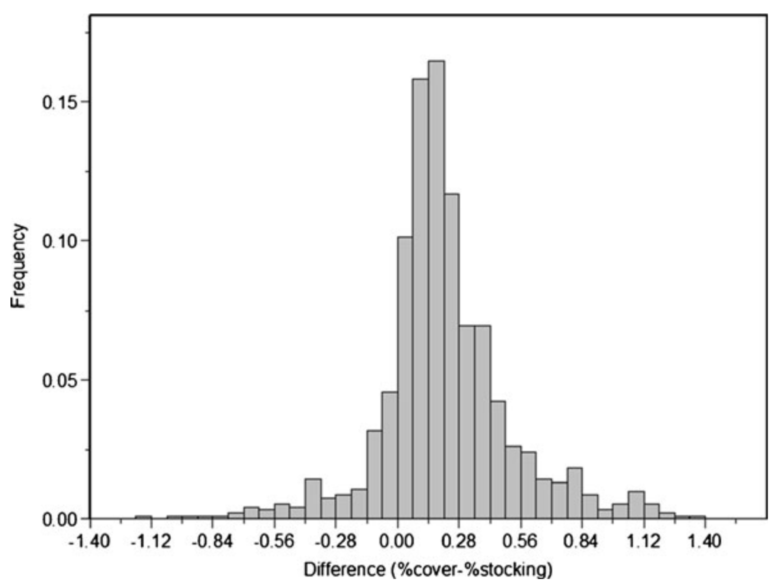

Fig. 2 Distribution of differences for cover minus stocking for individual juniper trees from marginally forested annual plots

are not equivalent measures of forest land. The results suggest that in marginally forested land, or where trees are on the edge of their range, cover will be greater than stocking, leading to a positive bias to calling a piece of land forested in comparison to all lands in general. In areas where western juniper is a large component of the forest, one would expect to find more forest land using a cover in comparison to a stocking definition.

There are some advantages and disadvantages to both types of definitions. It is much easier to estimate stocking of a prior stand from stumps and snags than to estimate the missing cover. The stocking contribution to a future stand can also be measured from seedlings that may have little or no cover. Stocking can also be repeatedly calculated using species and DBH, while canopy cover can be difficult to measure accurately. On the other hand, canopy cover is more intuitive than relative stocking, and it is much easier to visually estimate canopy cover than stocking by looking at a piece of ground. Using canopy cover to define forest land in the field is more compatible with the pre-field procedure that uses canopy cover estimated from remote imagery to select the plots that are to be field sampled.

A primary function of forest inventory is to track changes in the forest resource over time, and it is necessary to be able to detect actual change from definitional change. In cases where the land is obviously stocked with an adequate number of trees, there will be no differences in a forest land definition using either relative stocking or canopy cover. In areas where recent disturbances such as fire or harvesting has removed the trees, both missing cover and stocking can usually be estimated by remaining stumps or downed logs. In areas that have been disturbed and planted, cover may be close to zero but the number of seedlings can be used to define forest land. In areas that are marginal and there has been no actual change, there will be some fluctuation in plots between the two definitions. Our study uses only 30 % of the data that will eventually be collected over the 10-year inventory cycle; if the same rates hold true, we estimate that the projected inventory of Oregon, Washington, and California would see an increase of 146,000 ha of forest land as defined by cover. Although this number is only 0.4 % of the total forest land in the three states, it is roughly double the land use change from forest to non-forest in Oregon between the 1970s and 2000s (Lettman et al. 2009). When comparing the increase to the area of the typical transitional forest type (juniper) in Oregon and California, it would represent a 6 % increase.

It will be important for the Pacific Northwest FIA to identify plots that were assessed using stocking in the first inventory and have changed status due to using a definition of cover. Using both field-collected measures will enable the detection of change due to definition on remeasured plots. It will also be necessary to reevaluate plots that were classified as non-forest based on stocking in the first inventory cycle. For plots that have changed classification due to definition, it will be necessary to use a combination of imagery and disturbance history to evaluate if there was enough cover in the first cycle to have classified the plot as forested. In the absence of both field-collected measures, the estimation of change will become problematic in the marginally forested areas.

References

Andrews, H. J. (1932). Forest survey in the Douglas-fir region. *Journal of Forestry, 30*, 264–275.

Andrews, H. J., & Cowlin, R. W. (1940). *Forest resources of the Douglas-fir region. Misc. Pub. 389*. Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 169 p.

Arner, S.L., Woudenberg, S., Waters, S., Vissage, J., MacLean, C., Thompson, & M. Hansen, M. (2001).National algorithm for determining stocking class, stand size class, and forest type for forest inventory and analysis plots. USDA Forest Service Northeastern Research Station Internal Rep., Newtown Square, PA, 10 p. http://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/National%20algorithms.doc. Accessed 18 March 2013.

Bechtold, W. A. (2004). Largest crown-width prediction models for 53 species in the western United States. *Western Journal of Applied Forestry, 19*, 245–251.

Bechtold, W. A., & Patterson, P. L. (2004). *The enhanced Forest Inventory and Analysis Program–national sampling design and estimation procedures* (General Technical Report SRS-80). Asheville: USDA Forest Service, Southern Research Station.

Bunnell, F. L., & Vales, D. J. (1990). Comparison of methods for estimating forest overstory cover: differences among techniques. *Canadian Journal of Forest Research, 20*, 101–107.

Crookston, N. L., & Stage, A. R. (1999). *Percent canopy cover and stand structure statistics from the forest vegetation simulator. General Technichal Report RMRS-GTR-24* (p. 11). Ogden: USDA Forest Service, Rocky Mountain Research Station.

Curtis, R. O. (1971). A tree area power function and related stand density measures for Douglas-fir. *Forest Science, 7*, 35–42.

Defries, R., & Eshleman, K. N. (2004). Land-use change and hydrologic processes: a major focus for the future. *Hydrological Processes, 18*, 2183–2186.

Fiala, A., Garman, S., & Gray, A. (2006). Comparison of five canopy-cover estimation techniques in the western Oregon Cascades. *Forest Ecology Management, 232*, 188–197.

Gillespie, A. J. R. (1999). Rationale for a national annual forest inventory program. *Journal of Forestry, 97*, 16–20.

Korhonen, I., Korhonen, K. T., Rautiainen, M., & Stenberg, P. (2006). Estimation of forest canopy cover: a comparison of field measurement techniques. *Silva Fennica, 40*(4), 577–588.

Lettman, G. J., Azuma, D. L., Herstrom, A. A., McKay, N., & Robinson, T. J. (2009). *Forest, farms, and people: land use change on non-federal land in Oregon, 1974–2005*. Salem: Oregon Department of Forestry. 74 p.

MacLean, C.D., & Bolsinger, C.L. (1973). Estimating productivity on sites with a low stocking capacity. U.S. Dept, Agric, Forest Service, Res. Pap. PNW-152, Portland, Oregon.

McArdle, R. E., Meyer, W. H., & Bruce, D. (1961). *The yield of Douglas-fir in the Pacific Northwest. Technical Bulletin #201, revised*. Washington: US Department of Agriculture. 65 p.

O'Brien, R. A. (1989). *Comparison of overstory canopy cover estimates on forest survey plots. Research Paper INT-417*. Ogden: USDA Forest Service, Intermountain Research Station. 5 p.

Reineke, L. H. (1933). Perfecting a stand-density index for even-aged forests. *Journal of Agricultural Research, 46*, 627–638.

Rudel, T. K., Coomes, O. T., Moran, E., Achard, F., Angelsen, A., Xu, J., et al. (2005). Forest transitions: towards a global understanding of land use change. *Global Environmental Change, 15*(2005), 23–31.

Theobald, D. M., Miller, R. J., & Hobbs, N. T. (1997). Estimating the cumulative effects of development on wildlife habitat. *Landscape and Urban Planning, 39*(1997), 25–36.

United Nations Food and Agriculture Program (2008). Guidelines for country reporting to FRA 2010. Forest Resources Assessment Programme, Working Paper 143, 80 pp. http://www.fao.org/forestry/14097-0a8d9580c21c82a81175207120544e2b8.pdf. Accessed 18 March 2013.

United Nations Food and Agriculture Program (2010). Global forest resources assessment, FRA 2010. Country Report, Vietnam 54 pp. http://www.fao.org/docrep/013/al664E/al664e.pdf. Accessed 18 March 2013.

USDA Forest Service (1996). Forest health monitoring 1996 field methods guide. Internal Rep. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, National Forest Health Monitoring Program. 128 p.

USDA Forest Service. (2010). *Forest Inventory and Analysis Program: field instructions for the annual inventory of Washington, Oregon, and California*. Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.