Attributes of Standing Dead Trees in Forests of the United States

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Abstract.—Standing dead trees in forests of the United States serve as wildlife habitat, a fuel loading component, and carbon stocks. Although standing dead trees are a vital component of forest ecosystems, information regarding this resource across the Nation is lacking. The first annual inventory of standing dead trees across the United States was initiated in 1999, resulting in a comprehensive assessment of this resource. The goal of this study is to broadly summarize the attributes of standing dead trees across the United States using the first national inventory of standing dead trees. Study objectives were to examine volume and biomass estimates by geographic regions, diameter at breast height/decay class distributions, and species composition. Results indicate that a substantial number of standing dead trees exists in forests across the United States, exceeding 7 billion nationwide. Rocky Mountain and Pacific Northwest forests have some of the highest volume and biomass of standing dead trees, while southeastern forests have the least. The species composition of standing dead trees is quite diverse, with 26 species groups having more than a billion trees nationwide. Overall, standing dead trees are a prevalent component of forests across the United States.

Why Are Standing Dead Trees Important?

Standing dead trees, sometimes referred to as snags, are remnants of once living trees that are still self-supported and leaning less than 45 degrees from vertical (as defined by the Forest Service, U.S. Department of Agriculture's Forest Inventory and Analysis (FIA) program [USDA Forest Service 2006]). Standing dead trees are a substantial component of fuel loadings. The total biomass of standing dead trees in some forests may exceed that of downed and dead woody debris (Kirby *et al.* 1998); in such cases, standing dead fuels constitute a substantial fire hazard. In addition, standing dead trees fuels serve as a fuel ladder to upper crown fuels (Stephens 1998), and may be an important predictor of down woody debris through fuel succession (Schimmel and Granstrom 1997). On the other hand, standing dead trees are a component of healthy forest ecosystems, serving as wildlife habitat and increasing stand structural diversity. Standing dead trees serve as critical habitat for numerous wildlife species including a variety of avian species (Raphael and White 1984). In addition, the decaying substrate of standing dead trees provides critical habitat to forest invertebrate species (Harmon *et al.* 1986). Finally, dead wood is often a reporting component for forest carbon pools in national assessments. The Intergovernmental Panel on Climate Change of the United Nations calls for yearly reporting of dead wood carbon stocks, of which standing dead trees are a considerable component (e.g., see EPA 2004). Overall, standing dead trees are an integral component of forest ecosystems.

A National Inventory of Standing Dead Trees

Very little analysis regarding standing dead wood resources across the United States exists. In the past, most standing dead tree analyses were at local or regional scales (e.g., see Goodburn and Lorimer 1998, Cline *et al.* 1980, Healy *et al.* 1989) while national-scale forest resource analyses omitted dead tree attributes entirely (e.g., see Smith *et al.* 2004). The lack of national standing dead tree estimates was due to the lack of a nationally consistent standing dead tree inventory. Standing

dead trees have been infrequently inventoried during periodic inventories across the United States or have been inventoried only within specific FIA regions since the early 20th century. Since many of these inventories were only for determination of growing stock mortality, older dead trees were possibly omitted during the inventory. With the inception of a national annual forest inventory across the United States in 1999 (Gillespie 1999), uniform standing dead tree inventory protocols have been adopted allowing the first ever national assessment of standing dead trees.

Due to the availability of a national inventory of standing dead trees, an analysis and interpretation of inventory estimates is highly warranted. Therefore, the specific objectives of this study were to (1) determine the average biomass of standing trees by geographic region across the United States, (2) determine the diameter at breast height (d.b.h.) (1.4 m) and decay class distribution of standing dead trees nationally, (3) determine the species composition distribution of standing dead trees, and (4) suggest opportunities for development of a forest health indicator using standing dead tree information.

Data and Analysis

The FIA program conducts a 3-phase inventory of forest attributes of the United States (Bechtold and Patterson 2005). The FIA sampling design is based on a tessellation of the United States into hexagons, approximately 2,420 ha in size with at least one permanent plot established in each hexagon. In phase 1, the population of interest is stratified and plots are assigned to strata, such as forest, nonforest, and edge, to increase the precision of estimates. In phase 2, tree and site attributes are measured in forested conditions for plots established in the 2,428-ha hexagons. Phase 2 plots consist of four 7.32-m fixed-radius subplots on which standing dead trees are inventoried

with measurement of numerous individual tree variables such as species, diameter, and total height (for more information, see USDA Forest Service 2006, Bechtold and Patterson 2005).

All standing dead data were from the most current, publicly available inventory for each State in the coterminous United States. All inventory data were from annual inventories conducted since 1999 except for the following states where periodic inventories were used in the study analyses: Mississippi (1994), New Mexico (1999), North Carolina (2002), Oklahoma (1993), and Wyoming (2000). The number of FIA plots used in this study totaled 87,401.

Mean volume (m^3/ha) and dry biomass (tonnes/ha) of standing dead trees on forestland in the United States were determined by geographic region. The total number of standing dead trees was determined for 10 cm d.b.h. classes and decay class (five classes; USDA Forest Service 2006). Decay class is a subjective determination of the stage of decay of a standing dead tree (USDA Forest Service 2006). A decay class one tree still has an upper crown with sapwood intact and minimal decay; whereas a decay class five trees has no branches remaining, absent sapwood, and often a broken top. The total volume (gross cubic volume, m^3) of standing dead trees was determined by selected species group for the entire United States. Finally, the ratio of the number of standing live trees to standing dead trees was determined by State across the United States. Population estimation procedures are detailed by Bechtold and Patterson (2005).

Biomass by Region

The western regions of the United States (Pacific Coast and Rocky Mountains) had the largest estimates of mean standing dead tree biomass per hectare (table 1). The States of California, Washington, and Oregon in the Pacific Coast region had

Table 1.—*Mean dry biomass (tonnes/ha) of standing dead trees on forestland in the United States by geographic region.*

| Geographic region	Constituent states	Biomass (tonnes/ha)
Northern	CT, DE, IL, IN, IA, KS, ME, MA, MS, MI, MN, MO, NE, NH, NJ, NY, ND, OH, PA, RI, SD, VT, WV, WI	8.62
Pacific Coast	CA, OR, WA	12.50
Rocky Mountain	AZ, CO, ID, MT, NV, NM, UT, WY	11.08
Southeastern	AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA	0.98

mean biomass/hectare estimates of 12.5 tonnes/ha compared to mean estimates of southeastern States that were less than 1 tonne/ha. These results indicate that standing dead trees are a prevalent component of forests across of the United States. The disparity in standing dead resources between eastern and western forests may be due to numerous speculative factors. First, the majority of eastern forests are privately owned where they may be more actively managed to reduce mortality and increase timber production. Western forests have a greater proportion of land area managed by Federal land agencies where timber production objectives may not take priority over other management objectives such as wildlife habitat maintenance (i.e., snag creation). Second, numerous areas of the western United States have endured prolonged drought (Cook *et al.* 2004) or experienced recent wildfires that may have increased mortality. Third, areas of the Pacific Northwest are some of the most productive forestland in the United States (Smith *et. al.* 2004); not only do these areas have high volumes of standing live trees but also standing dead trees. Ultimately, these disparities in standing dead tree biomass estimates are most likely due to a mix of biotic factors (e.g., insects/diseases), abiotic factors (e.g., droughts), and cultural and management practices (e.g., timber production versus wildlife habitat maintenance) that differ across the Nation.

Diameter and Decay Class Distribution

This study estimated more than 7 billion standing dead trees in forests of the United States. The d.b.h. distribution of this population is highly skewed towards smaller-sized trees (fig. 1). More than 4 billion standing dead trees have a d.b.h. between 15 and 25 cm in forests of the United States. In comparison, the total of standing dead trees with a d.b.h. of greater than 25 cm is less than 3 billion trees. Relative to the preponderance of the smaller-sized trees, the number of large-sized trees is considerably lower (d.b.h. greater than 55 cm). These trends are most likely indicative of suppression-related mortality and the natural "negative exponential" distribution of uneven-aged stands that can result in higher standing dead tree densities (Goodburn and Lorimer 1998). The observed trends are not indicative of any widespread forest health issues that may be detrimental to larger-sized trees (e.g., chestnut blight).

The distribution of standing dead trees by decay class is skewed toward less decayed trees (fig. 2). More than 1.5 billion standing dead trees in decay class two are spread across the Nation. Decay classes two and three are nearly equal, at nearly 1.4 billion trees nationwide. Comparatively, only 0.5 billion standing dead trees are in decay class five. These results are logical given the decay progression of deceased trees. A recently deceased tree will progress rather rapidly through decay class one, losing some bark and fine twigs. A standing dead tree may reside in decay classes two and three for some time depending on wind disturbances, microclimate, and abiotic factors (e.g., fungi and wildlife disturbance) (e.g., see Harmon 1982, Sun *et al.* 2004). Once a tree reaches the decay class of four and five, it is much more susceptible to windthrow with an inability to support its own weight. Overall, the current decay class distribution of standing dead trees across the United States appears to follow a natural progression of tree decay.

Figure 1.—*Distribution of standing dead trees by d.b.h. class (cm) across the United States.*
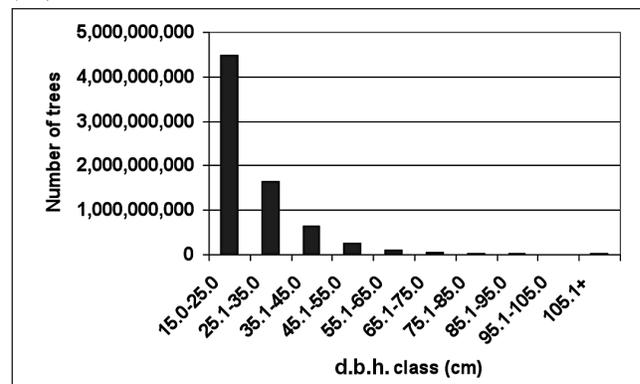
d.b.h. = diameter at breast height.

Figure 2.—*Distribution of standing dead trees by decay class across the United States.*
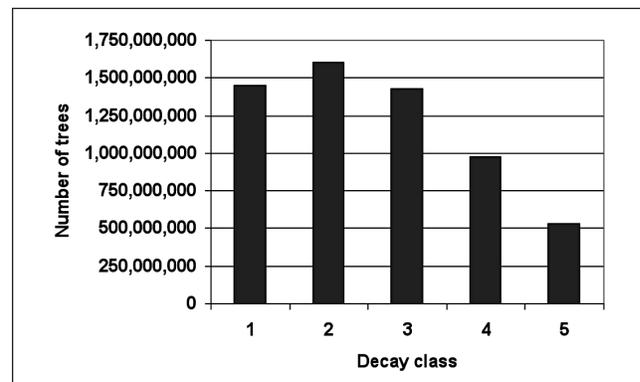
Species Composition

Given that western United States forest regions had relatively large amounts of standing dead tree biomass (table 1), western tree species groups dominate the species composition of standing dead trees nationally (table 2). With regard to total gross volume of standing dead trees across the United States, the top three species groups were true firs, Douglas-fir, and lodgepole pine, with more than 35 billion m³ combined. Prevalent eastern tree species groups were that of other eastern soft hardwoods, other red oaks, and soft maple. Nationally, the species composition of standing dead trees is very diverse, with 26 species groups having an estimate of total gross volume exceeding 1 billion m³. Whether mortality is the result of suppression mortality, drought, or insects/diseases, the question arises as to what amount of standing dead trees is a "healthy" amount? Standing dead trees are a valuable source of wildlife habitat and structural diversity, but, at the same time, they serve as an indicator of widespread tree mortality and fire hazard. If eastern tree species groups serve as an indicator, then amounts of standing dead trees may indicate regional forest health issues. The species group of other eastern soft hardwoods is the top eastern species group in terms of standing dead trees due

to Dutch Elm disease killing so many American Elms in this species group. In addition, the second most prevalent eastern tree species group is that of other red oak—a species group suffering from regional oak decline for years (Thomas and Boza 1984). Although standing dead trees are a valuable resource across the country, they may serve as an indicator of accumulated forest health issues since they represent cumulative tree mortality reduced by site specific decay processes.

Standing Dead Trees as an Indicator of Forest Health

When examining standing dead trees across the country, it is apparent that certain regions may have more productive forests that are constantly experiencing a "turnover" of trees into standing dead trees. Through combination of both standing live and dead tree resources into a ratio, one might better ascertain an assessment of standing dead tree resources. The ratio of the number of standing live to standing dead trees ranged from 4 to 34 for States across the United States. Idaho had the lowest ratio at 4.3. The median ratio was approximately 11. In other words, the median forest in the United States has 11 live trees for

Table 2.—*Total gross volume (billions of cubic meters) of standing dead trees by selected species groups across the United States (species groups with total volume below 1.29 billion m3 not included)*

Species group	Constituent species examples*	Total volume (billions, m3)
True firs	Abies amabilis, Abies concolor, Abies procera, Abies grandis	13.15
Douglas-fir	Pseudotsuga menziesii	12.29
Lodgepole pine	Pinus contorta	10.25
Engelmann/other spruces	Picea engelmannii, Pivea breweriana	5.28
Other eastern soft hardwoods	Acer negundo, Aesculus glabra, Celtis occidentalis, Ulmus americana	4.33
Ponderosa/Jeffrey pines	Pinus jeffreyi, Pinus ponderosa	3.76
Other western soft hardwoods	Cupressus lawsoniana, Cupressus macrocarpa, Larix lyalli	3.71
Western cottonwood/aspen	Populus deltoids, Populus tremuloides	2.93
Western woodland soft hardwoods	Juniperus occidentalis, Pinus edulis	2.51
Other red oaks	Quercus coccinea, Quercus laurifolia	2.50
Spruce/balsam fir	Abies balsamea, Picea rubens	2.41
Western red cedar	Thuja plicata	2.09
Eastern cottonwood/aspen	Populus deltoids, Populus tremuloides	1.82
Soft maple	Acre rubrum, Acer saccharinum	1.67
Western hemlock	Tsuga heterophylla	1.58
Eastern white/red pine	Pinus resinosa, Pinus strobes	1.43
Select white oaks	Quercus alba, Quercus macrocarpa	1.37
Loblolly/shortleaf pines	Pinus echinata, Pinus taeda	1.37
Beech	Fagus grandifolia	1.36
Select red oaks	Quercus rubra, Quercus shumardii	1.29

* See Miles et al. (2001) for details.

every standing dead tree. States with an extremely high ratio would indicate that constituent forests are heavily managed or are young with little potential for accumulation of wildlife habitat. States with extremely low ratios would indicate that constituent forests are dense or unmanaged (large wilderness areas) with the potential for catastrophic fires. Given the dual role that standing dead trees play in forest ecosystems (e.g., wildlife habitat versus fire hazard), the recent availability of national standing dead tree inventory data, and the confounding process of decay/turnover, continued exploration of standing dead tree data and subsequent development of forest health indicators is highly warranted.

Overall, standing dead trees are an abundant natural resource across the United States. This resource is not equally distributed, however, with western forests having more than five times as much standing dead tree biomass as the eastern forests. Amounts of standing dead trees are not necessarily indicative of unhealthy forests since they serve as critical wildlife habitat and increase forest structural diversity. Exploring the use of standing dead tree estimates in forest health indicators is strongly suggested for future research. A key research question to explore is, tree mortality is a natural process, but how much mortality is unnatural?

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