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Differences Between Standing and Downed Dead Tree Wood Density Reduction Factors: A Comparison Across Decay Classes and Tree Species

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Abstract

Woody detritus or dead wood is an important part of forest ecosystems and has now become a routine facet of forest monitoring and inventory. Biomass and carbon estimates of dead wood depend on knowledge of species- and decay class- specific density or density reduction factors. While some progress has been made in determining these parameters for dead and downed trees (DD), there are very few estimates of these key parameters for standing dead trees (SD). In this study we evaluated indicators of decay to relate subjective SD and DD decay classifications then compared SD and DD density and density reduction factors by decay class for a total of 19 tree species at nine sites in the United States and Russia. A set of preliminary decay reduction factors for SD trees by species and decay class was developed for tree species inventoried by the U.S. Department of Agriculture's Forest Inventory and Analysis (FIA) program. Results indicate that SD density declined with decay class for all examined species. For six of the examined species, SD tree density could be assumed equal to that of DD tree density. The most common situation (13 species) was for SD density to be higher than for DD density. The likely cause of these differences was the drier microenvironment of SD which slows decomposition relative to that of DD. By applying these results, a new set of SD density reduction factors was developed for 260 species inventoried by FIA in forests of the United States. Comparison of biomass estimates using this study's proposed SD density reduction factors with existing SD volume estimates based solely on undecayed wood density indicated a possible biomass overestimate of 16.5 percent for Minnesota. Given the size of the potential biases involved and the uncertainty associated with decay reduction factors developed in this study, additional work to develop a multispecies SD decay class system and further empirical sampling of SD tree density is recommended.

Cover Photo

Standing dead tree on the shores of Octopus Lake, Boundary Waters Canoe Area Wilderness, Superior National Forest, Minnesota, USA. Christopher W. Woodall, U.S. Forest Service.

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INTRODUCTION

Woody detritus or dead wood is an important part of forest ecosystems, providing habitats and food sources, a store of carbon, nutrients, and water, as well as influencing geomorphic processes (Franklin et al. 1987, Harmon et al. 1986, Triska and Cromack 1980). In particular, standing dead trees provide structural complexity and enhance biodiversity in many forest ecosystems (Jonsell et al. 1998, Kruys et al. 1999, Nilsson et al. 2001). Therefore, dead wood is increasingly being included in ecological studies and environmental assessments (Woodall et al. 2009), with the number of publications on this subject rapidly growing. Both downed (DD) and standing dead (SD) wood store carbon and are important components of forest carbon dynamics, but also release carbon via decomposition and combustion in fires. However, given the contrasting microenvironments that SD and DD trees inhabit, their decay dynamics and attributes may vary (Aakala et al. 2008, Aakala 2010, Lee 1998, Vanderwel et al. 2006). Accurate estimates of standing dead tree carbon stocks are important for monitoring carbon flux, for characterizing processes such as respiration and combustion losses, and for validating simulation models that are used to project how carbon dynamics will change in the future.

It is difficult to develop accurate estimates of dead wood biomass for several reasons. First, until recently there have been few systematic, regional-scale dead wood inventories, resulting in highly uncertain dead wood population estimates (Harmon et al. 2001). However, regional-scale inventories of dead wood are becoming more common (Woodall et al. 2009). For example, the Forest Inventory and Analysis (FIA) program of the U.S. Forest Service now conducts a national inventory of woody material including fine woody detritus (FWD) and DD (for more details see Woodall and Monleon 2008). Second, given the size and actively decomposing nature of dead trees, direct measurements of biomass during forest inventories are not possible. Instead, the volume of individual DD pieces is estimated from fixed-area plot or line-intersect transect estimators (Woodall and Monleon 2008). Biomass of DD is then often estimated by multiplying volume by an estimate of density specific to a dead wood piece's individual attributes (e.g., species and stage of decay). Density reduction factors may be defined as the ratio of the decayed density (current mass/volume) of a piece of dead wood compared to its undecayed density (initial live tree mass/volume; Miles and Smith 2009). The development of DD species- and decay class-specific density and decay reduction values for the FIA program has offered the promise of substantially reducing the uncertainty associated with DD mass/carbon population estimates resulting from large-scale inventories (Harmon et al. 2008). Unfortunately, there are very few decay class- or species-

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specific estimates of density or decay reduction factors for SD trees. The lack of these estimates is likely due to the danger in felling snags during sampling and the historical lack of emphasis on SD biomass/carbon estimates during traditional forest inventories focused on estimating live tree growing stock volume on timberlands.

Several assumptions regarding wood density influence biomass estimates of SD trees. In the case of the FIA program, it is currently assumed that the density of SD trees is the same as that of live trees. While this seems unlikely, in some situations (e.g., extremely slow decomposition in arid environments) this assumption may be accurate. Alternately, (e.g., Smithwick et al. 2002) the density of SD trees for a given decay class may be assumed to be similar to that of DD wood. While this would seem to be a more realistic assumption, it has yet to be tested across a wide range of tree species and environments. The uncertainty associated with SD tree density is likely to have major impacts on biomass, carbon, and fuel estimates, but without knowledge of how SD tree wood density changes through its decay process, the effect of this uncertainty cannot be quantified.

OBJECTIVES

Given that deadwood inventories are rapidly becoming a common component of forest resource inventories around the world, there is a need to refine the constants used in biomass estimation procedures for both SD and DD. Our objective was to determine SD species- and decay-class specific density and density reduction factors for forest tree species in the United States by linking empirical SD data from a subset of study species with that of DD of those same species to develop constants that can then be applied to other SD species. The broad concept was to use SD:DD density relationships to utilize currently available DD density information to provide an initial approximation of SD density attributes for forest tree species in the United States.

Harmon et al. (2008) developed a set of density reduction factors, including estimates of uncertainty, for DD and FWD based on a thorough literature review and unpublished data. Our approach for this study was to sample SD and DD for 19 tree species in temperate forests of the northern hemisphere. As the decay classification system for both SD and DD trees are qualitative (i.e., visual assessments of wood condition and structure) and separate, the two classification systems need to be linked in order to propose SD to DD wood density relationships by decay class. First, indicators of decay were evaluated for SD and DD decay classes to ensure decay classification system compatibility. Second, the density of SD and DD was compared for the same decay classes and species. These ratios were then used to estimate SD density and density reduction factors for species that have not been sampled across the United States. Finally, to initially assess the impact of wood density decay reduction factors on SD population estimates, a SD tree inventory in Minnesota was used to calculate state SD biomass using no decay reduction factor and using factors developed in previous objectives.

MATERIALS AND METHODS

Study Areas

To ensure our study acquired a robust estimate of SD to DD, we sampled five study sites in the United States and four in Russia representing a range of species and climates in North America and Russia (Table 1). Given the similarity between the temperate and boreal forests of North America and Russia, it was felt that the additional statistical rigor resulting from the combination of data outweighed the loss of some regional specificity. As study objectives focus on tree species in the United States along with greater diversity among the study sites (e.g., species composition), study site locations in the United States were kept separate and identified by unique abbreviations in subsequent tables, while Russian study sites were pooled with the abbreviation "RUS." Site descriptions for Russian locations are based on information from Yatskov (2000).

Cascade Head Experimental Forest (CHE), Oregon

Cascade Head is located on the north-central coast of Oregon, 8 km north of Lincoln City. It lies entirely within the Hebo Ranger District of the Siuslaw National Forest. The site is in the Oregon Coast Range ecoregion and the forests are representative of the sitka spruce-western hemlock (*Picea sitchensis* (Bong.) Carrière -*Tsuga heterophylla* (Raf.) Sarg.) and Douglas-fir (*Pseudotsuga*

Table 1.—Site name, location, and climate description for areas sampled

Site Name	Climate	Temperature
Cascade Head EF, Oregon (CHE)	Very wet	Moderate
Fraser EF, Colorado (FEF)	Dry	Cool
Chapel Hill, North Carolina (NCB)	Moderate	Moderate
Marcell EF, Minnesota (MEF)	Moderate	Cold
Kenai Peninsula, Alaska (AK)	Dry	Cold
St. Petersburg, Russia (RUS)	Moderate	Cool
Krasnoyarsk, Russia (RUS)	Dry	Cold
Irkutsk, Russia (RUS)	Dry	Cold
Khabarovsk, Russia (RUS)	Moderate	Cold

menziesii (Mirb.) Franco) zones of the region. Soils, derived primarily from tuffaceous siltstones, are fine textured, moderately well drained, and deep (up to 100+ cm). Because of the Pacific Ocean influence, CHE has a moderate and very wet climate. Mean annual temperature is 10 °C with minimal seasonal variation. Average yearly rainfall is 2489 mm, although fog drip through the forest canopy can add 500 mm or more precipitation a year (Greene and Acker 1999).

Fraser Experimental Forest (FEF), Colorado

Fraser Experimental Forest is located in the heart of the central Rocky Mountains, about 80 km from Denver. FEF includes subalpine forests typical of the area, with Engelmann spruce (*Picea engelmannii* Parry x Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) predominating at higher elevations, and lodgepole pine (*Pinus contorta* var. *latifolia* (Douglas ex Louden var. latifolia Engelm. ex S. Watson)) predominating at lower elevations and on drier upper slopes. Soils are generally derived from gneiss and schist and typically contain angular gravel and stone with very little silt or clay. These soils are very permeable and can store considerable water during snowmelt. Climate varies strongly with elevation. Overall, the climate is cool and dry with long, cold winters and short, cool summers. Mean annual temperature at the Fraser Forest headquarters is 0.5 °C and mean annual precipitation over the entire FEF is 737 mm. (Adams et al. 2004).

Chapel Hill (NCB), North Carolina

The study was conducted at the North Carolina Botanical Garden, a 242-ha tract of oak-hickory-pine forest in Chapel Hill, North Carolina. The area sampled in this project was dominated by mixed hardwoods including *Liriodendron tulipifera* L. on the moist lower slopes and mixed hardwoods with pine (*Pinus taeda* L. and *Pinus echinata* Mill.) on the dryer mid and upper slopes. It is an area defined by undulating topography, soils of poor to good quality, and a temperate climate. Soils of the study area include Wedowee sandy loam and Goldston slaty silt loam (Dunn 1977). The average annual temperature is 14.6 °C and the average annual precipitation is 1220 mm. Precipitation is uniformly distributed throughout the year. The elevation ranges from 103 to 150 m (Fasth et al., in press).

Marcell Experimental Forest (MEF), Minnesota

The Marcell Experimental Forest is an 890-ha tract of land in the Chippewa National Forest, located 40 km north of Grand Rapids, Minnesota. Vegetation in the upland topography includes jack pine (*Pinus banksiana* Lamb.) and trembling aspen (*Populus tremuloides* Michx.) among other species. Mineral soils of the area are derived from glacial processes that occurred during and after the Wisconsinan glaciation. Soils are mainly loamy sands covered with fine sandy loam derived from eolean loess after glacial melt. The climate is subhumid continental, with wide and rapid diurnal and seasonal temperature fluctuations. The average annual temperature is 3 °C and the average annual precipitation is 785 mm with 75 percent occurring in the snow-free period (mid-April to early November) (Adams et al. 2004).

Kenai Peninsula (AK), Alaska

The study was conducted on the Kenai Peninsula of Alaska on Federal lands including the Chugach National Forest as well as on State owned lands. The maritime climate of this study site supports temperate, coniferous rainforest. The drier and colder climate inland from the coastal mountains supports forests dominated by white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Miller) Britt), and paper birch (*Betula papyrifera* Marsh). A fertile hybrid between white spruce and Sitka spruce (Lutz spruce, *Picea x lutzii* Little) is a common tree in maritime and mountainous areas of the Kenai Peninsula. The topography of the study area varies from lowlands to foothills. The lowlands of the Kenai Peninsula are a glaciated surface with gentle relief and a mean elevation of approximately 300 m. Throughout most of this lowland glacial till of Wisconsin age is overlain by deep glacial lake and fluvial sediments and is mantled with loess. The Alaska Climate Research Center (ACRC) climatic summaries indicate the study area has a mean annual temperature of approximately 1.1 °C and annual precipitation of 630 mm (Harmon et al. 2005).

St. Petersburg, Russia (RUS)

The region of northwestern Russia has a cool maritime climate with cool wet summers and long cold winters. Major forest tree species include silver birch (*Betula pendula* Roth.), Norway spruce (*Picea abies* (L.) Karst.), and Eurasian aspen (*Populus tremula* L.). The mean annual temperature of July is 16.5 °C, while the mean temperature of January is 8.5 °C with an annual mean of 3.4 °C. The mean annual precipitation is 708 mm.

Krasnoyarsk, Russia (RUS)

This region of central Siberia has a moderately cold and continental climate. It belongs to the Angara province of the southern taiga and is dominated by Russian larch-Scots pine (*Larix siberica* Ledeb. and *Pinus sylvestris* L.) forests. The vegetation period lasts 126 days with a frost-free period of 110 days. The mean temperature of July is 16 °C, while the mean temperature of January is -25 °C, and the overall mean annual temperature is -3.2 °C. The mean annual precipitation is 361 mm.

Irkutsk, Russia (RUS)

This region of Eastern Siberia has sites located in the area of strictly continental climate with permafrost. Forests were primarily comprised of Scots pine (*Pinus sylvestris*). In mountainous areas Siberian larch (*Larix siberica*), Siberian white pine (*Pinus siberica* Ledeb.), and Siberian spruce (*Picea obovata* Ledeb.) were common, and were associated with small amounts of Siberian fir (*Abies siberica* Ledeb.). The mean temperature of July is 17 °C and mean temperature of January is -20 °C with an overall mean annual temperature of -0.6 °C and a mean annual precipitation of 216 mm.

Khabarovsk, Russia (RUS)

This region is part of the Far East and has a continental climate that promotes the growth of a wide range of plant species, including Korean white pine (*Pinus koraiensis* Sieb. et Zucc.), Dahurian larch (*Larix dahurica* Turcz.) spruce (*Picea obovata* and *Picea ajanensis* Fisch.), true fir (*Abies siberica*), and yellow birch (*Betula costata* Trautv.). The vegetation period lasts 174 days in lowlands and 158 days in mountainous areas. The mean temperature of July is 17 °C, while mean temperature of January is -24 °C, with an overall annual mean of -1.9 °C. The mean annual precipitation is 909 mm.

Linking SD and DD Decay Classifications through Indicators of Decay

To accurately estimate DD and SD population attributes such as biomass or carbon, the FIA program assigns each sampled DD and SD individual to a decay class. To facilitate linkage of DD and SD decay classes, indicators of decay were developed in this study that were assessed for each study dead wood piece. For both DD and SD, there were five decay classes that span a spectrum of decay from fresh mortality to nearly complete decay. Decay classes are largely qualitative based on the physical appearance and structural integrity of individual dead wood pieces (USDA 2007, Woundenberg et al. 2010). For SD trees the five decay classes were defined as:

Class 1: All limbs and branches are present; the top of the crown is still present; all bark remains; sapwood is intact, with minimal decay; heartwood is sound and hard.

Class 2: There are few limbs and no fine branches; the top may be broken; a variable amount of bark remains; sapwood is sloughing with advanced decay; heartwood is sound at base but beginning to decay in the outer part of the upper bole.

Class 3: Only limb stubs exist; the top is broken; a variable amount of bark remains; sapwood is sloughing; heartwood has advanced decay in upper bole and is beginning at the base.

Class 4: Few or no limb stubs remain; the top is broken; a variable amount of bark remains; sapwood is sloughing; heartwood has advanced decay at the base and is sloughing in the upper bole.

Class 5: No evidence of branches remains; the top is broken; <20 percent of the bark remains; sapwood is gone; heartwood is sloughing throughout.

For DD trees the five decay classes were defined as:

Class 1: Sound, freshly fallen, intact logs with no rot, no conks present indicating a lack of decay, original color of wood, no invading roots, fine twigs attached with tight bark.

Class 2: Sound log sapwood partly soft but can't be pulled apart by hand, original color of wood, no invading roots, many fine twigs are gone and remaining fine twigs have peeling bark.

Class 3: Heartwood is still sound with piece supporting its own weight, sapwood can be pulled apart by hand or is missing, wood color is reddish-brown or original color, roots may be invading sapwood, only branch stubs are remaining which cannot be pulled out of log.

Class 4: Heartwood is rotten with piece unable to support own weight, rotten portions of piece are soft and/or blocky in appearance, a metal pin can be pushed into heartwood, wood color is reddish or light brown, invading roots may be found throughout the log, branch stubs can be pulled out.

Class 5: There is no remaining structural integrity to the piece with a lack of circular shape as rot spreads out across ground, rotten texture is soft and can become powder when dry, wood color is red-brown to dark brown, invading roots are present throughout, branch stubs and pitch pockets have usually rotten down.

Based on decades of research into the ecological role of detritus in forest ecosystems, we hypothesized that the differences between SD and DD would be greatest for intermediate decay classes (i.e., 2 and 3). Given the lack of time in decay class 1, decay reductions are likely minimal for both SD and DD. For decay classes 4 and 5, which are based on structural strength, it is likely that SD and DD are similar given that structural strength of wood is highly dependent on density. We also hypothesized that the wood density of SD and DD would diverge more in dry climates than in humid ones due to moisture limitations in dry climates that inhibit SD decomposition. Since SD falls and becomes DD, the input of decayed SD-related wood might influence the overall density of DD. Since decay classes are largely based on exterior appearances, it is likely that SD in dry climates will be denser than DD for a given decay class because the exterior of SD will continue to degrade (e.g., bark loss, fragmentation of twigs, etc) whereas the interior will remain relatively sound. Conversely, in very wet environments, fragmentation of bark and cover of mosses and other bryophytes are likely to make the exterior of DD look decayed despite the slow rate of decomposition of DD in very wet environments. Based on these hypotheses, a variety of indicators of decay were visually assessed for both SD and DD in this study (Table 2). Similarities in indicators of decay among SD and DD pieces sampled in this study will suggest appropriate linkage between the SD and DD decay classification systems and subsequent development of SD decay reduction factors based on extensive DD woody decay information.

FIELD AND LABORATORY

Decay Classes and Indicators of Decay

At each study site we sampled SD and DD covering the full range of decomposition stages, which necessitated the felling of SD trees. To sample indicators of decay, selected SD or DD pieces were categorized into one of five decay classes based on visual characteristics linked to the degree of decomposition that was noted in the previous section: the presence of leaves, twigs, branches, percent bark cover on branches and bole, sloughing of wood, collapsing and spreading of DD or SD (indicating the transition from intact elliptical forms to degraded

Table 2.—Decay indicators used to determine decay classes for standing and downed dead trees

Code	Indicator question
Foliage	Is foliage present?
Twigs	Are twigs present?
Branches	Are branches present?
Bark_br	Is there bark present on the branches?
Bark_bole	Is there bark present on the bole?
Moss	Is there moss present?
Lichens	Are there lichens present?
Beetles	Is there evidence of beetle presence?
Woodborer	Is there evidence of woodborer presence?
Conks	Are there conks present?
Whiterot	Is there white rot present?
Brownrot	Is there brown rot present?
Casehard	Does the bole exhibit case hardening?
SW_friable	Is the sapwood crushable by hand?
HW_friable	Is the heartwood crushable by hand?
Ants	Is there evidence of ants present?
SW slough	Is the sapwood sloughing?
Collapse	Has the bole shape collapsed?
Scatter	Is the bole scattered in the ground?
Stub_move	Do the branch stubs move in the bole?

shapes), friability or crushability of wood, color of wood, and mobility of branch stubs (Triska and Cromack 1980, Graham and Cromack 1982, Sollins 1982, Harmon and Sexton 1996). In addition to visual and structural indicators of decay used by the FIA program, biological indicators (Table 2) of decomposition, such as moss cover, presence of fungal fruiting bodies, and the presence of insect galleries, were also noted. In addition, at most sites we sampled live trees to determine densities of undecayed wood and bark. Dimensions recorded for each tree sampled included length, base and top diameters, and current d.b.h. The decay classes of both SD and DD used in this study align with the same decay classes used by the FIA program. Please refer to USDA (2010), Woodall et al. (2010), and Woudenberg et al. (2010) for details regarding the SD and DD decay classification systems used by FIA.

Wood Density and Density Reduction Factors

To measure wood density of SD and DD, samples were divided into four sections of similar length. Short pieces (e.g., in more advanced decay classes) were divided into two or three sections. For each section, end diameters and length were recorded. From the end of each section, a disk (a cross section 5 to 10 cm thick) was cut with a chainsaw to determine wood and bark density. To determine disk volume, for each cross-section disk we recorded the outermost diameter, outer wood diameter, mean longitudinal thickness, circumference covered by bark, radial thickness of bark, and mean radial depth of decay. Bark was separated from wood and the total wet weight of each tissue was determined. Lengths of bark and wedge-shaped wood subsamples of ~100 g taken from each disk using a hammer and chisel were weighed. Dry weights were recorded after oven drying at 55 °C to a constant weight (within 0.01 g). For disks that had not been dried and weighed, dry weights of wood and bark were calculated from total wet weights of these tissues and the ratio of dry-to-wet weight determined from subsamples. The density of the bark and wood for each disk was calculated as the ratio of its dry weight to undecayed volume (g/cm^3). Mean bark density and mean wood density for each tree were calculated by averaging the density of all the cross-section values of each tissue for each tree. Recorded values of percent bark cover for the whole tree and bark circumferential length for each disk were used to determine the proportion of total tree volume that was bark. Total density per tree was calculated as the summation of each tissue density multiplied by the proportion of total tree volume applicable to that tissue. An average density for each tree species, decay class, and position (i.e., SD or DD) was calculated using total tree density. Trees were also categorized as either hardwood (i.e., angiosperm) or softwood (i.e., gymnosperm) and total density per tree was averaged across each category for each decay class and position. Finally, an average of total density was calculated for all trees by decay class and position.

The density reduction factor was calculated as the ratio of the average current density to average undecayed density for each species, category, or combination and by each decay class and position (i.e., SD versus DD) to indicate the relative rate that tree density declined for each scenario.

Statistical Analysis

We used analysis of variance (ANOVA) to test how the dependent variable density reduction factor varied by the independent variables taxa (i.e., species or hardwood/softwood), decay class, and position. The following model was fit:

$$Y_{khij} = m + \alpha_k + \beta_h + d_i + a_j + da_{ij} + \varepsilon_{khij}$$

where:

m is the overall mean value of Y_{khij}, the average density reduction factor of the j^{th} decay class in the i^{th} position in region *k* and stand *h*

α_k is the random effect of the region k that was sampled, that adds variability to the value of Y, k=region name, $\alpha_{k\,h} \sim N(0, \sigma^2_b)$, α_k and $\alpha_{k'}$ are independent

β_h is the random effect of stand h that was sampled, that adds variability to the value of Y, h=stand name, $\beta_h \sim N(0, \sigma^2_b)$, β_h and $\beta_{h'}$ are independent

d_i is the effect of the i^{th} level of the independent variable position, i=SD or DD

a_j is the effect of the j^{th} level of the independent variable decay, j= 1, 2, 3, 4

da_{ij} is the interaction of position and decay

ε_{khij} is the random error term that adds variability to the value of Y, $\varepsilon_{khij} \sim N(0, \sigma^2)$ and ε_{khij} and $\varepsilon_{khi'j'}$ are independent.

When comparing softwoods and hardwoods, species was added as an additional random variable in the model. In the case of all species combined, the variables species and type (softwood or hardwood) were added as additional random variables. Residuals from the models were fairly symmetric and there was no indication of increasing variance with decreasing mean. Therefore, assumptions of normality and constant variance of residuals appeared to be adequately met. Through ANOVA testing, three results were postulated: 1) No significant difference between DD and SD density reduction factors by decay classes. This would indicate that decay occurred with similar patterns for dead wood in standing or lying positions; 2) The main effects of position and decay class would both be significant when the density reduction diverged early in the decomposition process (i.e., between class 0 and 1). This might suggest that one position started with a lower density than the other; 3) A significant interaction of position and decay class. This would indicate that one position was decaying to a lesser extent than the other and that density reduction factors were diverging. We tested these hypotheses at three separate levels: individual species, softwoods versus hardwoods, and for all species combined.

To examine why DD and SD might have different densities and density reduction factors, we compared indicators of decay (Table 2) between the two positions. We computed the relative frequency that indicators were present for two positions and the three taxonomic levels described above to examine which characteristics might be associated with differences in dependent variables.

All statistical tests based on the model outlined above were performed by the MIXED procedure of SAS (SAS Institute Inc.) using the LSMEANS statement which computes least squares means of fixed effects and corresponding *t* and *F* tests. Statistical tests were significant if $0.05 > P > 0.01$ and highly significant if P < or = 0.01. We emphasize that a minimal amount of replication was conducted within species, study sites, and decay classes. Replication was limited by the difficulty in finding study sites with a full representation of DD and SD decay classes. Furthermore, the felling of SD trees is extremely hazardous to the sawyer. We have expressed the high levels of uncertainty in Appendix C. The results presented in this study should be considered preliminary to guide future research and promote refined SD population estimation (i.e., use of decay reduction factors in biomass/carbon estimates).

Development of Standing Dead (SD) Databases

We used the findings of the current study to estimate decayed density and the density reduction factors of SD for tree species inventoried by the FIA program. For the species that we sampled, we used the observed densities and density reduction factors. For the species that we did not sample, we calculated decayed density and density reduction factors using ratios of the species we sampled and the estimated values for DD from Harmon et al. (2008). Specifically, for decay classes 1 to 3 we multiplied the SD to DD ratio for either hardwoods or softwoods (depending on the species) by the DD density or density reduction factor. For decay class 4, there were few species sampled. We therefore used the average SD to DD ratio of all species sampled. For decay class 5, as no species were sampled given the scarcity of these trees, this study suggests future research or assuming decay class 4 wood density results can be extrapolated to decay class 5.

To provide an estimate of uncertainty, we used one of the following methods:

A. Species that had been sampled for SD density. We used standard error of the observed values of decayed density or the density reduction factor.

B. Species lacking sampling to determine decayed SD density. The uncertainty (U) in the decayed SD density for this set of species was estimated by:

$$U_{\text{Decayed SD}} = \sqrt{(\text{Den}_{\text{DD}}^2)(U_{\text{DD}}^2) + (R^2)(U_R^2)}$$

where U_{DD} is the uncertainty in DD (Harmon et al. 2008), Den_{DD} is the mean DD density, and U_R is the uncertainty in R, the mean SD to DD density ratio. This formula accounts for the fact that uncertainty for decayed SD density is a function of two uncertainties. Our formula assumed no correlation between the uncertainties. Uncertainty was estimated for each decay class of SD. For decay classes 1 to 3 we used R values associated with either hardwoods or softwoods and applied them to appropriate taxa. For decay class 4 there were few observations, so we used values for all the taxa sampled.

A similar uncertainty estimate was made for density reduction factors using the average density reduction factor and associated uncertainty for DD.

RESULTS

Decay Indicators

All Species

The relative frequency of decay indicators (Table 2) as DD and SD decomposed was surprisingly similar (Figure 1). In terms of physical indicators (presence of parts, shape, friability) prior to reaching decay class 4, DD and SD were quite comparable and go through a similar progression from one decay class to the next. Decay class 4 DD and SD differed in terms of structural integrity indicators. This is a logical result as SD that lacks physical integrity tends to fall and form DD. The nearly entire lack of bark in decay class 4 SD, as compared to DD, is related to vertical orientation, as even loose bark can remain on the surface of DD. Across all species and study sites, the means of SD bark cover (percent of piece covered by bark) were 91.62, 65.55, 38.91, and 21.11 for decay classes 1 through 4, respectively.

In terms of biological indicators (presence of moss, lichens, insects, and fungi), the major difference between SD and DD appeared to be the abundance of moss. DD tended to have higher presence of moss than SD, which would be consistent with the wetter microclimate associated with DD versus SD. Conversely, lichens were slightly more abundant on SD than DD, which is consistent with a drier microclimate associated more with SD than DD. DD also had a greater tendency to support fungal fruiting bodies, whereas SD had a greater tendency to support wood borers. The former may indicate a more favorable decomposition environment; the latter may be an artifact related to greater moss cover and decay state in DD hiding evidence of wood borers. For further evaluation of these moss/lichen results we suggest consulting the abundance of literature regarding lichen substrate preferences.

We observed little bark cover in both class 2 and 3 SD for some species, making the characteristic less useful as an indicator than for DD. Two characteristics proved

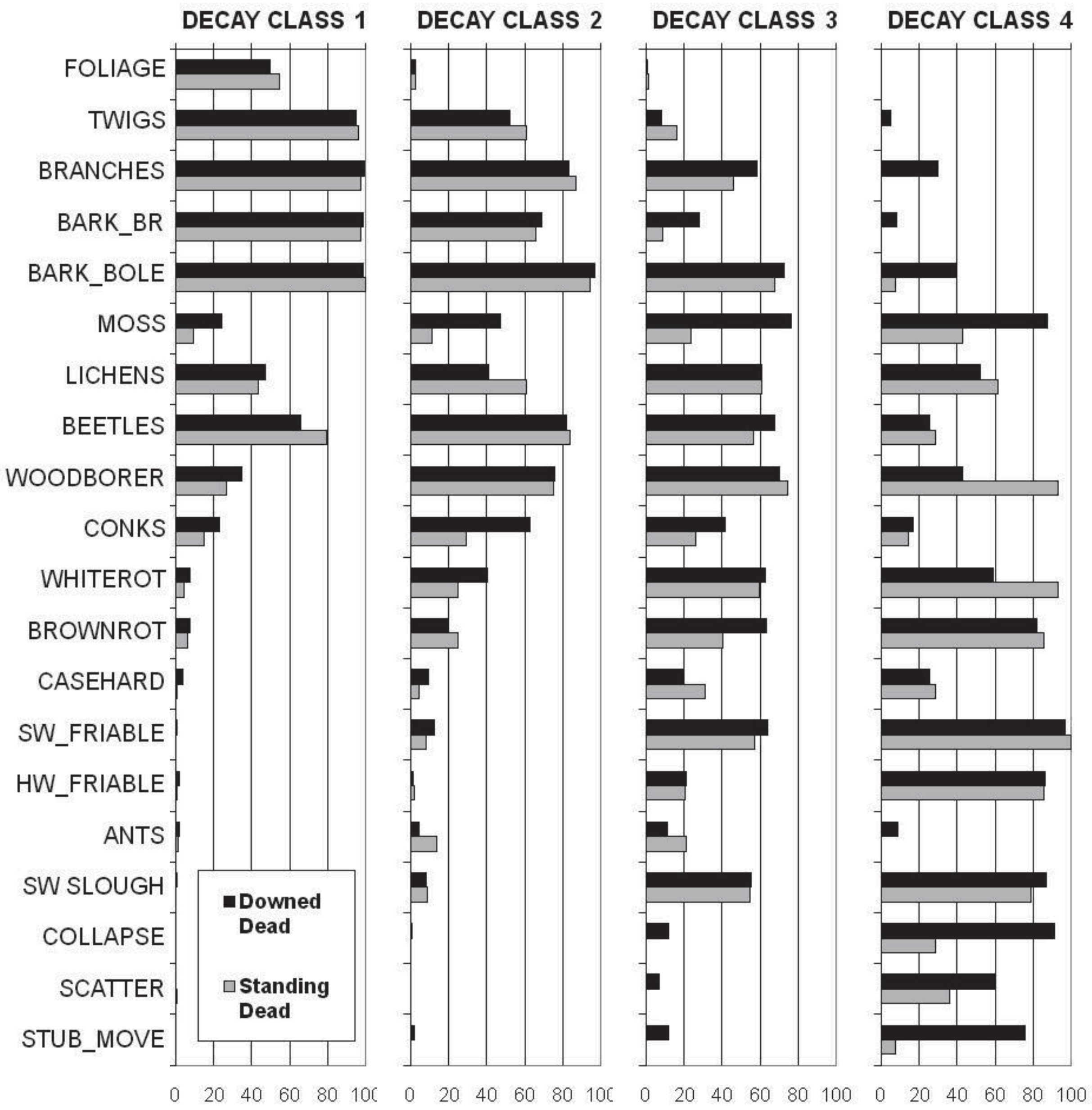

Figure 1.—Percent frequency of abundance for physical indicators of decay class for standing dead and downed dead trees

useful in distinguishing these two decay classes when SD had little bark cover. First, decay class 3 SD tended to have more lichens than decay class 2 SD. This is likely related to the older surface having more time to accumulate lichens. Second, the wood of decay class 3 SD tended to take on what might be described as a "ropey" texture. This is caused by a weakening of the outer wood layers causing cracks that look similar to the strands in a rope often associated with white-rot fungus. Findings by Aakala et al. (2008) indicate that the surface appearance of standing dead trees can remain static for long periods of time, thus the presence/absence of surface biological indicators may not fully indicate internal decay dynamics. Barring destructive sampling, standard forest inventory field crew must continue to rely on qualitative SD appearance to determine decay classification.

Hardwoods versus Softwoods

While the overall relationship between external characteristics and decay classes were similar for hardwoods and softwoods, there were some notable differences (Figure 2). In terms of physical indicators,

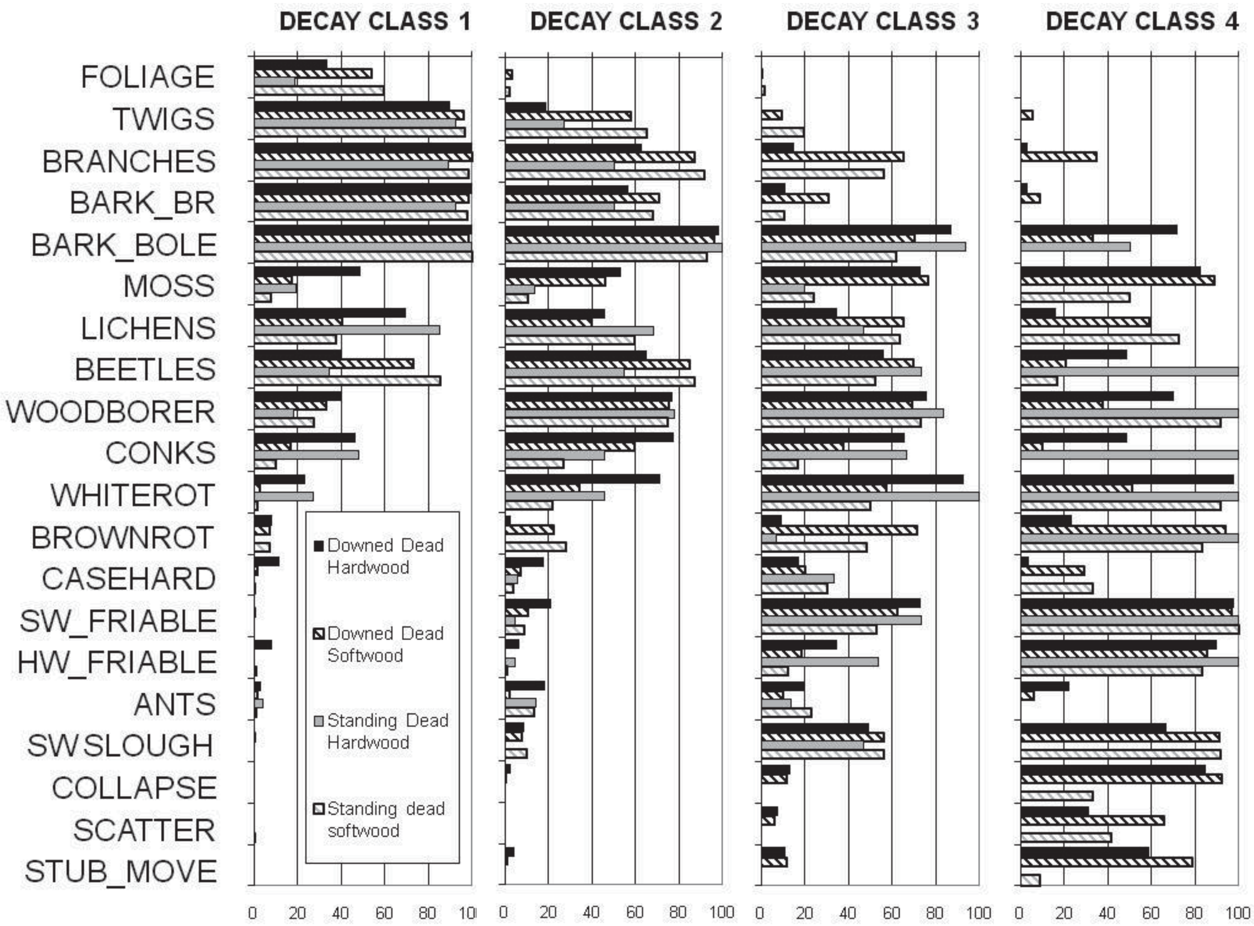

Figure 2.—Percent frequency of abundance for physical indicators of decay class for hardwood and softwood standing and downed dead trees

hardwoods appeared to lose twigs and branches to a higher degree than softwoods as decay class increased. Conversely, softwoods lost bark on the bole to a higher degree than hardwoods, although this was likely related to the presence of birch (*Betula* sp.), a genus well known for bark retention. For the biological indicators, hardwoods were more likely to have white-rot fungus, whereas softwoods were more likely to have brown-rot fungus, at least in decay classes 2 and 3. In decay class 1, hardwood SD were more likely to have lichens and mosses present than softwoods, but this likely stems from the difference of these tree taxa to support epiphytes in general.

Overall, indicators of decay were not evaluated in this study as an in-depth discourse on SD and DD decay dynamics and ecology, rather as a qualitative means to assure differentiation between decay classes and alignment with FIA sampling protocols. Results indicated adequate decay class differentiation, linkage between SD and DD decay classification systems, and FIA sampling protocol alignment allowing subsequent development of wood density estimates for SD tree species in U.S. forests based on relatively extensive DD wood density information.

Wood Density

As expected, SD wood density declined with decay class (Appendix A). The initial, undecayed tree densities for the 19 species studied ranged from 0.31 to 0.54 g/cm^3 (Table 3). The overall mean initial density was 0.39 g/cm^3. Decay class 3, the most advanced decay class common to SD and DD, had densities that ranged from 0.16 to 0.34 g/cm^3 for DD and 0.21 to 0.46 g/cm^3 for SD. Decay class 3 density for all species of DD averaged 0.26 g/cm^3 and averaged 0.35 g/cm^3 for SD indicating that SD contain less decay than logs (Table 4). This is

Table 3.—Undecayed wood density by tree species code, scientific name, and location of sample collection (U.S. study site or general Russian location)

Code	Scientific name	Location	Undecayed Density (g/cm^3)
PILU	*Picea x lutzii*	AK	0.36
PICO	*Pinus contorta*	FEF	0.40
PIBA2	*Pinus banksiana*	MEF	0.42
POTR	*Populus tremuloides*	MEF	0.39
LITU	*Liriodendron tulipifera*	NCB	0.41
PINE	*Pinus species*	NCB	0.49
TSHE	*Tsuga heterophylla*	CHE	0.44
ABSI	*Abies siberica*	RUS	0.31
BECO	*Betula costata*	RUS	0.54
BEPE	*Betula pendula*	RUS	0.48
LADA	*Larix daurica*	RUS	0.46
LASI	*Larix sibirica*	RUS	0.49
PIAB	*Picea abies*	RUS	0.37
PIAJ	*Picea ajanensis*	RUS	0.36
PIOB	*Picea obovata*	RUS	0.38
PIKO	*Pinus koraiensis*	RUS	0.35
PISI2	*Pinus sibirica*	RUS	0.34
PISY	*Pinus sylvestris*	RUS	0.38
POTR2	*Populus tremula*	RUS	0.35

Table 4.—Average density (g/cm^3) for standing dead (SD) to downed dead (DD) trees and associated ratio (SD/DD average density) for all species and sites combined by decay class

Decay class	SD (g/cm^3)	n	DD (g/cm^3)	n	SD/DD Ratio
1	0.40 (0.00)	175	0.40 (0.00)	185	1.00
2	0.38 (0.00)	189	0.33 (0.00)	292	1.15
3	0.35 (0.01)	78	0.26 (0.00)	391	1.35
4	0.25 (0.03)	14	0.15 (0.00)	246	1.67
5			0.11 (0.00)	174	

Note: Values are means with standard errors in parentheses. “n” is the number of SD or DD.

consistent with the notion that SD must retain some sound wood to remain upright. Aakala’s (2010) study in *Picea abies* forests in northern Europe found a range of SD decayed density ranging from 0.14 to 0.47 g/cm^3.

Hardwoods tended to have slightly higher initial density than softwoods, but the opposite was true after extensive decay (Table 5). For example, the mean initial, undecayed density for hardwoods and softwoods was 0.40 and 0.38 g/cm^3, respectively. However, decay class 3 hardwood DD and SD had mean densities of 0.23 and 0.24 g/cm^3, whereas softwood DD and SD had mean densities of 0.27 and 0.38 g/cm^3, respectively.

Density Reduction Factors

Individual species

Density reduction factors for decay class 3 ranged from 0.34 to 0.80 and from 0.44 to 1.11 for DD and SD, respectively (Appendix B). Statistical analysis showed five species with highly significant interactions and two with significant interactions between position and decay class (*P*-values: *Larix sibirica* 0.00; *Pinus contorta* 0.00; *Picea lutzii* 0.00; *Pinus* species 0.01; *Pinus sibirica* 0.01; *Pinus banksiana* 0.05; *Pinus koraiensis* 0.05). Of these seven species, four were in the genus *Pinus*. This interaction indicated that SD for these species retained a higher density than DD and that these differences increased as decay proceeded. Aakala (2010) found similar results in *Picea abies* forests of northern Europe, with the wood density of SD significantly higher than DD. Furthermore, in our study three species (two hardwood and one softwood) had highly significant decay class and position main effects, but no significant interaction between the two factors. This result may indicate that early in the decay process, DD and SD diverge, with DD undergoing an initial rapid period of decomposition and SD subject to a lag. Four species (three hardwoods and one softwood) showed only decay class as a highly significant factor in density reduction (*P*-values: *Betula pendula* 0.00; *Tsuga heterophylla* 0.00; *Populus tremula* 0.00; *Populus tremuloides* 0.00). This would indicate that decay progresses similarly in SD and DD for these species. Two species showed only position as a highly significant factor in density reduction, but this was likely an artifact related to the few decay classes sampled for these species.

Hardwoods versus softwoods

Compared to hardwoods, softwoods, on average, are more likely to have a greater divergence in SD and DD decay reduction factors as decay progresses (Table 6). For example, the mean density reduction factors for decay class 3 hardwood DD and SD were 0.51 and 0.54,

Table 5.—Average density (g/cm^3) for standing dead (SD) and downed dead (DD) trees and associated ratio (SD/DD average density) by hardwood/softwood and decay class

Type	Decay class	SD (g/cm^3)	n	DD (g/cm^3)	n	Ratio SD/ DD
Hardwood	1	0.46 (0.01)	37	0.43 (0.01)	51	1.07
	2	0.36 (0.01)	31	0.33 (0.01)	58	1.09
	3	0.24 (0.02)	14	0.23 (0.01)	60	1.04
	4	0.20 (0.03)	2	0.13 (0.01)	55	1.54
	5			0.11 (0.01)	31	
Softwood	1	0.38 (0.00)	138	0.38 (0.00)	134	1.00
	2	0.39 (0.00)	158	0.34 (0.00)	234	1.15
	3	0.38 (0.01)	64	0.27 (0.00)	331	1.41
	4	0.26 (0.03)	12	0.15 (0.00)	191	1.73
	5			0.11 (0.00)	143	

Note: Values are means with standard errors in parentheses. “n” is the number of SD or DD.

Table 6.—Average density reduction factor (decayed density/undecayed density) for standing dead (SD) and downed dead (DD) trees and associated ratio (SD/DD density reduction factor) by hardwood/softwood and decay class

Type	Decay class	SD	n	DD	n	Ratio SD/ DD
Hardwood	1	0.99 (0.01)	37	0.95 (0.01)	51	1.04
	2	0.80 (0.02)	31	0.74 (0.02)	58	1.08
	3	0.54 (0.04)	14	0.51 (0.03)	60	1.06
	4	0.43 (0.05)	2	0.29 (0.02)	55	1.48
	5			0.22 (0.02)	31	
Softwood	1	0.97 (0.01)	138	0.93 (0.01)	134	1.04
	2	1.00 (0.01)	158	0.87 (0.01)	234	1.15
	3	0.92 (0.03)	64	0.70 (0.01)	331	1.33
	4	0.55 (0.06)	12	0.40 (0.01)	191	1.38
	5			0.29 (0.01)	143	

Note: Values are means with standard errors in parentheses. “n” is the number of SD or DD.

respectively. In contrast, the mean density reduction factors for decay class 3 softwood DD and SD were 0.70 and 0.92, respectively. For softwood species collectively, there was a highly significant interaction between position and decay class effects. For hardwood species, decay class was a highly significant factor in density reduction. This indicates that DD density factors could be substituted for SD ones in hardwoods, but not for softwoods.

All species combined

The density reduction factors for all decay class 3 DD and SD was 0.67 and 0.86, respectively (Table 7). There was a highly significant interaction between position and decay class in the reduction factor, which may be due to softwood species being over represented in the data set.

Standing Dead Databases

Of 260 species considered by the FIA inventory, eight (3 percent) have had some SD decay classes sampled. For sampled species, the uncertainty of SD density was approximately 3 to 14 percent of the mean estimate. In contrast for species in which SD density had to be estimated from the DD database produced by Harmon et al. (2008), the uncertainty is approximately 20 to 100

Table 7.—Average density reduction factor for standing dead (SD) and downed dead (DD) trees and associated ratio (SD/DD density reduction factor) for all sites/species combined by decay class

Decay class	SD	n	DD	n	Ratio SD/DD
1	0.97 (0.01)	175	0.94 (0.01)	185	1.03
2	0.97 (0.01)	189	0.84 (0.01)	292	1.15
3	0.86 (0.03)	78	0.67 (0.01)	391	1.28
4	0.53 (0.06)	14	0.38 (0.01)	246	1.39
5			0.28 (0.01)	174	

Note: Values are means with standard errors in parentheses. "n" is the number of SD or DD.

percent of the mean estimate, the latter for decay class 4 SD. This indicates that actual sampling of SD density could reduce the uncertainties with this material at least an order of magnitude.

Implications of Density Reduction on Population Estimates

The implications of assumptions of SD density can be potentially profound in terms of biomass estimates. Using FIA's forest inventory of the state of Minnesota (2005-2009), we explored the impact of three plausible scenarios for estimating total SD biomass (i.e., SD wood density assumptions): 1) SD wood density equals live tree wood density; 2) SD and DD wood density are equal; and 3) SD wood density based on this study's newly created SD density reduction factors. To convert that volumetric estimate to one of biomass, the three SD wood density assumptions were evaluated. Assuming that SD wood density was equal to live trees gives a total SD biomass estimate of 32.98 million Mg. By assuming that SD and DD wood density are equal, the estimated biomass was 24.38 million Mg, or 26 percent less. Using the new estimates of SD wood density provided an estimated biomass of 27.52 million Mg or 16.5 percent less than the assumption of undecayed density.

DISCUSSION

SD inhabit a very different environment than DD, with the former usually being drier. Given that the response of decomposition to moisture shows an optimum range (i.e., woody tissues can be too dry or too wet to decompose readily), the position supporting the fastest decomposition can change with macroclimate (Harmon 2009). This might lead to consistent differences in the density of SD versus DD. In very humid environments, DD and SD both may retain moisture and hence the density of SD and DD might remain similar. This may explain our results from Cascade Head, the wettest site examined. In very dry environments SD decay may be limited relative to that of DD and that could lead to an increasing difference as decay class increases. Specific to sites in this study, but possibly not pertinent to all forest conditions across the United States, softwoods tended to grow in drier climates and microsites than hardwoods, which may explain why many softwoods exhibited an increasing difference in density as decay classes increased. In environments with intermediate moisture, SD may be slightly drier than DD. This could lead to a relatively short lag in decomposition that would result in a constant difference between decay classes in terms of density. While our observations are consistent with these hypotheses, other factors could be causing the patterns observed and more SD:DD comparisons in a wider range of environments would be helpful in determining the mechanisms explaining these phenomena. Differences in the density of SD versus DD may also be related to the physical limits of strength of woody tissues. That is, SD have to be fully self supporting, and once their strength decreases past a threshold they will collapse to form DD. In contrast, DD with minimal structural strength can collapse, but remain as DD. This may lead to an apparent abundance of higher wood density SD trees as less sound SD fall to become DD. However, SD do not necessarily have to decompose throughout to fall. For example, SD in dry environments fall after root systems decompose, adding relatively sound wood to the DD pool. When this occurs the density of DD might increase due to this input of relatively sound SD wood. Therefore, the difference in wood density between SD and DD are likely to be controlled by a number of interacting factors. Care should be taken not to infer rates of decay with assigned decay classes. Differences in wood density were quantitively determined between SD and DD qualitative decay classes in this study. Rates of decay are only inferred as initial hypotheses for future research.

There is an emerging abundance of research discussing the dynamics of SD and DD decay and subsequent effects on biomass/residence times (Aakala et al. 2008, Aakala 2010, Kruys et al. 2002, Vanderwel et al. 2006, Zielonka 2006,). Moving beyond initial characterizations of SD and DD decay dynamics on intensively monitored study sites towards estimates of SD wood density by decay class for all forest tree species in the United States is a tremendous change in study scope. However, the immediate need to develop and document SD decay reduction factors for most forest tree species in the United States to meet mandated carbon stock reports requires a timely assimilation of the best available science. Given the lack of information on SD decayed wood density for hundreds of tree species in the United States, several approaches were considered. First, SD tree density can be assumed to be similar to undecayed tree density. For some environments in which decomposition is very slow, this might be acceptable. However, in our analysis we did not find a single species in which density did not decline with decay class. Second, SD tree density could be assumed equal to that of DD tree density. This would be appropriate for 6 of the 19 species we examined. The most common situation in our study (13 of 19 species) was for either position or a position X decay class interaction to be significant.

To create the needed SD decay reduction factors for all tree species in the United States, decay classes in this study were aligned with those used by FIA using this study's indicators of decay. FIA's SD decay classes 1 and 2 were quite similar to the classes 1 and 2 assessed in this study. Given the more highly decayed nature of SD decay classes 3 and 4, FIA's SD decay classes 3 and 4 seem to span the characteristics of decay class 3 SD trees with some overlap into decay class 4. The FIA SD decay class 5 would seem to be similar to this study's SD decay class 4. Based on this finding, it is suggested that the decay reductions for SD decay class 4 be used as an approximation for SD decay class 5 until such time that empirical information refines SD decay class 5 attributes or a model is suggested to extrapolate decay class 4 attributes to decay class 5 pieces. Furthermore, given the potential safety hazard of felling decay class 5 SD trees, this assumption may be the most practical. In general, these are gross approximations and, given the fact that the FIA system is based on Douglas-fir with unspecified modifications for other species, it would be logical to develop a SD decay class system based on a wider range of species better aligned with the DD system.

While it is important to eventually determine density and density reduction factors for SD and DD of the major species encountered in inventories, in the short-term one is forced to make assumptions when species or positions have not been sampled. Whether considering individual species, hardwoods and softwoods, or all samples combined, the ranges of density reduction factors for SD were consistently higher compared to DD. This indicates generally less reduction in density as decay progresses in SD than DD. Softwood species tended to exhibit this pattern more strongly than hardwood species, sometimes even increasing in density. There were exceptions to this pattern in the statistical analysis (insignificant effect of position), but inspection of the charted data indicated that these cases had samples for only decay classes 1 and 2, were hardwood species, or were located in a warm and wet climate. The assumption with the strongest support at this time is that softwoods tend to have a greater divergence in SD and DD density reduction factors than hardwoods. However, additional sampling of species, hardwoods in particular, is required to confirm if this is actually the case.

Irrespective of the findings of this study, SD wood density at some point in its decay process will become substantially less than that of living trees. The selection of density reduction factors can have a profound effect on resulting population estimates (e.g., SD carbon in a state). This study found substantial variation in SD biomass population estimates for Minnesota when using undecayed density versus reduced wood density values. The differences in estimates depend strongly on the dominance of hardwoods versus softwoods. When only softwood species were considered, the difference between the assumption of live tree wood density and the SD densities that we estimated was 2.5 percent. In contrast, when only hardwood species were considered the difference between these two methods was 22 percent. Therefore, the potential biases contained in current SD estimates are likely to vary substantially. This analysis is considered preliminary for illustrative purposes as structural reductions for decay were not incorporated into the estimation procedures.

CONCLUSIONS

To provide accurate, unbiased estimates of the biomass and carbon stocks of SD trees, it is necessary to have species- and decay class-specific estimates of either density or density reduction factors. Empirically sampling the wood density of SD by species and decay class across the forests of the United States is currently restricted by the inherent costs and felling hazards involved. As an approach to estimate preliminary SD wood density reduction factors, this study established relationships between SD and DD such that extensive DD woody density studies could be used to suggest SD wood density attributes. This study suggests a new set of SD decay specific density and density reduction factors for many tree species in the United States that may be used to refine FIA's SD population estimation procedures. Given the size of the uncertainty involved with the SD wood decay attributes proposed in this study, additional work to develop a multispecies SD decay class system and to better characterize differences between SD and DD trees is recommended.

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Appendix A

Average density (g/cm^3) for standing dead (SD) and downed dead (DD) trees and their associated ratio (SD/DD average density) for all study species

Species code	Decay class	SD (g/cm^3)	n	DD (g/cm^3)	n	Ratio SD/DD
ABSI	1	0.30 (0.02)	7			
ABSI	2	0.33 (0.02)	4	0.30 (0.02)	4	1.10
ABSI	3	0.32 ()	1	0.25 (0.03)	7	1.28
ABSI	4			0.20 (0.02)	10	
ABSI	5			0.17 (0.02)	7	
BECO	1	0.54 (0.01)	5	0.50 (0.01)	8	1.08
BECO	2			0.33 (0.04)	3	
BECO	3	0.24 (0.00)	2	0.18 (0.01)	8	1.33
BECO	4			0.12 (0.00)	2	
BECO	5			0.08 (0.00)	2	
BEPE	1	0.48 (0.01)	21	0.47 (0.01)	25	1.02
BEPE	2	0.39 (0.01)	19	0.37 (0.01)	28	1.05
BEPE	3	0.27 (0.03)	6	0.25 (0.02)	29	1.08
BEPE	4	0.20 (0.03)	2	0.15 (0.01)	41	1.33
BEPE	5			0.11 (0.01)	29	
LADA	1	0.44 (0.01)	2	0.46 (0.01)	13	0.96
LADA	2	0.46 (0.03)	8	0.39 (0.02)	13	1.18
LADA	3			0.33 (0.02)	14	
LADA	4			0.19 (0.01)	9	
LADA	5			0.11 (0.02)	4	
LASI	1	0.45 (0.01)	12	0.46 (0.01)	16	0.98
LASI	2	0.46 (0.02)	11	0.40 (0.01)	13	1.15
LASI	3	0.46 (0.01)	12	0.34 (0.02)	16	1.35
LASI	4			0.15 (0.01)	16	
LASI	5			0.11 (0.01)	16	
LITU	0			0.40 (0.00)	2	
LITU	1	0.37 (0.01)	6	0.31 (0.05)	3	1.19
LITU	2	0.35 (0.01)	5	0.28 (0.02)	9	1.25
LITU	3			0.20 (0.03)	5	
LITU	4			0.11 (0.02)	3	
PIAB	1	0.37 (0.03)	4	0.33 (0.01)	5	1.12
PIAB	2	0.37 (0.02)	5	0.27 (0.01)	6	1.37
PIAB	3			0.21 (0.02)	7	
PIAB	4			0.13 (0.05)	3	
PIAJ	1	0.38 (0.01)	8	0.34 (0.01)	11	1.12
PIAJ	2	0.39 (0.01)	3	0.32 (0.02)	11	1.22
PIAJ	3	0.36 ()	1	0.24 (0.02)	15	1.50
PIAJ	4			0.15 (0.02)	10	
PIAJ	5			0.12 (0.01)	6	
PIBA2	1	0.39 (0.02)	7	0.39 (0.01)	5	1.00
PIBA2	2	0.38 (0.01)	5	0.36 (0.01)	7	1.06
PIBA2	3	0.32 (0.04)	6	0.22 (0.02)	6	1.45
PIBA2	4			0.12 (0.01)	7	
PICO	1	0.39 (0.00)	27	0.37 (0.01)	18	1.05
PICO	2	0.41 (0.01)	8	0.36 (0.01)	15	1.14

continued

Appendix A.—continued

Species code	Decay class	SD (g/cm^3)	n	DD (g/cm^3)	n	Ratio SD/DD
PICO	3	0.40 (0.00)	7	0.32 (0.02)	15	1.25
PICO	4			0.17 (0.01)	7	
PICO	5			0.16 (0.01)	9	
PIKO	1	0.36 (0.00)	4	0.35 (0.01)	8	1.03
PIKO	2	0.34 (0.02)	5	0.32 (0.01)	10	1.06
PIKO	3	0.33 (0.02)	3	0.24 (0.01)	12	1.38
PIKO	4			0.16 (0.01)	4	
PIKO	5			0.13 (0.03)	2	
PILU	0			0.38 (0.01)	11	
PILU	1	0.38 (0.01)	21	0.36 (0.01)	7	1.06
PILU	2	0.38 (0.01)	69	0.34 (0.01)	92	1.12
PILU	3	0.40 (0.02)	17	0.26 (0.01)	153	1.54
PILU	4			0.13 (0.01)	58	
PILU	5			0.08 (0.00)	52	
PINE	1	0.37 (0.02)	5	0.37 (0.03)	5	1.00
PINE	2	0.36 (0.02)	4	0.27 (0.02)	9	1.33
PINE	3	0.35 (0.05)	5	0.19 (0.02)	8	1.84
PINE	4	0.35 (0.03)	6	0.19 (0.03)	7	1.84
PINE	5			0.22 ()	1	
PIOB	1	0.36 (0.02)	4	0.37 (0.01)	10	0.97
PIOB	2	0.39 (0.01)	4	0.33 (0.02)	10	1.18
PIOB	3			0.25 (0.01)	14	
PIOB	4			0.13 (0.01)	13	
PIOB	5			0.10 (0.01)	8	
PISI2	1	0.33 (0.01)	8	0.33 (0.01)	8	1.00
PISI2	2	0.34 (0.00)	7	0.30 (0.01)	8	1.13
PISI2	3	0.30 (0.00)	2	0.23 (0.02)	8	1.30
PISI2	4			0.14 (0.01)	8	
PISI2	5			0.10 (0.01)	8	
PISY	1	0.37 (0.01)	23	0.36 (0.01)	20	1.03
PISY	2	0.36 (0.01)	19	0.32 (0.01)	31	1.13
PISY	3	0.31 (0.03)	4	0.27 (0.01)	47	1.15
PISY	4			0.18 (0.01)	32	
PISY	5			0.12 (0.01)	29	
POTR	1	0.37 (0.02)	5	0.36 (0.01)	7	1.03
POTR	2	0.29 (0.02)	6	0.28 (0.02)	6	1.04
POTR	3	0.21 (0.03)	5	0.16 (0.01)	7	1.31
POTR	4			0.07 (0.01)	6	
POTR2	1			0.35 (0.01)	8	
POTR2	2	0.25 ()	1	0.29 (0.02)	12	0.86
POTR2	3	0.24 ()	1	0.25 (0.02)	11	0.96
POTR2	4			0.14 (0.01)	3	
TSHE	1	0.39 (0.01)	6	0.42 (0.01)	8	0.93
TSHE	2	0.36 (0.02)	6	0.35 (0.03)	5	1.03
TSHE	3	0.29 (0.02)	6	0.28 (0.02)	9	1.04
TSHE	4	0.17 (0.02)	6	0.17 (0.03)	7	1.00
TSHE	5			0.12 ()	1	

Note: Values are means with standard errors in parentheses. “n” is the number of SD or DD.

Appendix B

Average density reduction factor for standing dead (SD) and downed dead (DD) trees and their associated ratio (SD/DD decay reduction factor) for all study species

Species code	Decay class	SD	n	DD	n	Ratio SD/DD
ABSI	1	0.95 (0.06)	7			
ABSI	2	1.06 (0.06)	4	0.97 (0.05)	4	1.09
ABSI	3	1.03 ()	1	0.79 (0.08)	7	1.30
ABSI	4			0.66 (0.07)	10	
ABSI	5			0.55 (0.08)	7	
BECO	1	1.00 (0.01)	5	0.93 (0.01)	8	1.08
BECO	2			0.62 (0.07)	3	
BECO	3	0.44 (0.01)	2	0.34 (0.02)	8	1.29
BECO	4			0.22 (0.01)	2	
BECO	5			0.16 (0.00)	2	
BEPE	1	1.01 (0.01)	21	0.98 (0.02)	25	1.03
BEPE	2	0.81 (0.03)	19	0.77 (0.02)	28	1.05
BEPE	3	0.56 (0.07)	6	0.53 (0.04)	29	1.06
BEPE	4	0.43 (0.05)	2	0.30 (0.03)	41	1.43
BEPE	5			0.23 (0.02)	29	
LADA	1	0.88 (0.01)	2	0.90 (0.02)	13	0.98
LADA	2	0.92 (0.05)	8	0.77 (0.03)	13	1.19
LADA	3			0.66 (0.04)	14	
LADA	4			0.37 (0.03)	9	
LADA	5			0.22 (0.05)	4	
LASI	1	0.92 (0.02)	12	0.94 (0.03)	16	0.98
LASI	2	0.95 (0.03)	11	0.82 (0.02)	13	1.16
LASI	3	0.95 (0.02)	12	0.70 (0.04)	16	1.36
LASI	4			0.30 (0.02)	16	
LASI	5			0.22 (0.02)	16	
LITU	0			0.97 (0.00)	2	
LITU	1	0.91 (0.03)	6	0.76 (0.12)	3	1.20
LITU	2	0.85 (0.02)	5	0.68 (0.04)	9	1.25
LITU	3			0.48 (0.07)	5	
LITU	4			0.28 (0.05)	3	
PIAB	1	1.01 (0.09)	4	0.88 (0.03)	5	1.15
PIAB	2	1.01 (0.04)	5	0.73 (0.03)	6	1.38
PIAB	3			0.57 (0.05)	7	
PIAB	4			0.36 (0.12)	3	
PIAJ	1	1.07 (0.02)	8	0.97 (0.03)	11	1.10
PIAJ	2	1.11 (0.02)	3	0.92 (0.05)	11	1.21
PIAJ	3	1.03 ()	1	0.68 (0.06)	15	1.51
PIAJ	4			0.43 (0.05)	10	
PIAJ	5			0.34 (0.02)	6	
PIBA2	1	0.95 (0.04)	7	0.95 (0.03)	5	1.00
PIBA2	2	0.92 (0.03)	5	0.87 (0.03)	7	1.06
PIBA2	3	0.78 (0.09)	6	0.53 (0.04)	6	1.47
PIBA2	4			0.29 (0.03)	7	
PICO	1	0.98 (0.01)	27	0.95 (0.02)	18	1.03
PICO	2	1.04 (0.03)	8	0.92 (0.02)	15	1.13

continued

Appendix B.—continued

Species code	Decay class	SD	n	DD	n	Ratio SD/DD
PICO	3	1.02 (0.01)	7	0.80 (0.05)	15	1.28
PICO	4			0.43 (0.03)	7	
PICO	5			0.42 (0.02)	9	
PIKO	1	0.92 (0.01)	4	0.90 (0.02)	8	1.02
PIKO	2	0.88 (0.05)	5	0.81 (0.03)	10	1.09
PIKO	3	0.86 (0.05)	3	0.62 (0.03)	12	1.39
PIKO	4			0.41 (0.03)	4	
PIKO	5			0.34 (0.07)	2	
PILU	0			1.06 (0.03)	11	
PILU	1	1.06 (0.02)	21	1.01 (0.04)	7	1.05
PILU	2	1.06 (0.02)	69	0.93 (0.01)	92	1.14
PILU	3	1.11 (0.04)	17	0.73 (0.02)	153	1.52
PILU	4			0.37 (0.01)	58	
PILU	5			0.23 (0.01)	52	
PINE	1	0.76 (0.05)	5	0.75 (0.06)	5	1.01
PINE	2	0.74 (0.03)	4	0.55 (0.04)	9	1.35
PINE	3	0.72 (0.09)	5	0.40 (0.03)	8	1.80
PINE	4	0.72 (0.07)	6	0.39 (0.06)	7	1.85
PINE	5			0.46 ()	1	
PIOB	1	0.97 (0.04)	4	0.98 (0.03)	10	0.99
PIOB	2	1.03 (0.03)	4	0.87 (0.05)	10	1.18
PIOB	3			0.66 (0.03)	14	
PIOB	4			0.35 (0.03)	13	
PIOB	5			0.26 (0.02)	8	
PISI2	1	0.86 (0.02)	8	0.85 (0.02)	8	1.01
PISI2	2	0.89 (0.01)	7	0.77 (0.03)	8	1.16
PISI2	3	0.78 (0.01)	2	0.58 (0.04)	8	1.34
PISI2	4			0.36 (0.03)	8	
PISI2	5			0.27 (0.02)	8	
PISY	1	0.99 (0.02)	23	0.96 (0.02)	20	1.03
PISY	2	0.98 (0.02)	19	0.87 (0.02)	31	1.13
PISY	3	0.83 (0.08)	4	0.71 (0.02)	47	1.17
PISY	4			0.48 (0.04)	32	
PISY	5			0.33 (0.02)	29	
POTR	1	0.97 (0.04)	5	0.93 (0.03)	7	1.04
POTR	2	0.75 (0.05)	6	0.72 (0.04)	6	1.04
POTR	3	0.54 (0.07)	5	0.41 (0.03)	7	1.32
POTR	4			0.18 (0.01)	6	
POTR2	1			0.95 (0.02)	8	
POTR2	2	0.66 ()	1	0.78 (0.05)	12	0.85
POTR2	3	0.63 ()	1	0.66 (0.07)	11	0.95
POTR2	4			0.36 (0.03)	3	
TSHE	1	0.90 (0.03)	6	0.96 (0.02)	8	0.94
TSHE	2	0.83 (0.04)	6	0.80 (0.06)	5	1.04
TSHE	3	0.66 (0.05)	6	0.64 (0.05)	9	1.03
TSHE	4	0.38 (0.05)	6	0.40 (0.06)	7	0.95
TSHE	5			0.27 ()	1	

Note: Values are means with standard errors in parentheses. “n” is the number of SD or DD.

Appendix C

Standing dead tree absolute density and its uncertainty for each decay class by species present in the U.S. FIA inventory

Genus	Species	Code	den0	den1	unc1	cod1	den2	unc2	cod2	den3	unc3	cod3	den4	unc4	cod4
Abies	*amabilis*	ABAM	0.400	0.356	0.020	B	0.382	0.014	B	0.301	0.060	B	0.239	0.336	C
Abies	*balsamea*	ABBA	0.340	0.356	0.024	B	0.414	0.014	B	0.412	0.058	B	0.286	0.336	C
Abies	*bracteata*	ABBR	0.360	0.367	0.024	B	0.354	0.029	B	0.301	0.060	B	0.239	0.336	C
Abies	*concolor*	ABCO	0.370	0.337	0.012	B	0.319	0.013	B	0.172	0.057	B	0.232	0.336	C
Abies	*fraseri*	ABFR	0.340	0.367	0.024	B	0.354	0.029	B	0.301	0.060	B	0.239	0.336	C
Abies	*grandis*	ABGR	0.350	0.338	0.010	B	0.338	0.013	B	0.320	0.057	B	0.239	0.336	C
Abies	*lasiocarpa*	ABLA	0.310	0.367	0.014	B	0.331	0.025	B	0.331	0.057	B	0.255	0.336	C
Abies	*magnifica*	ABMA	0.360	0.473	0.012	B	0.435	0.023	B	0.213	0.057	B	0.240	0.336	C
Abies	*magnifica* var. *shastensis*	ABMA2	0.360	0.367	0.024	B	0.354	0.029	B	0.301	0.060	B	0.239	0.336	C
Abies	*procera*	ABPR	0.370	0.364	0.010	B	0.309	0.012	B	0.334	0.057	B	0.252	0.336	C
Abies	*species*	ABIE	0.340	0.367	0.024	B	0.354	0.029	B	0.301	0.060	B	0.239	0.336	C
Acacia	*species*	ACSP2	0.600	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Acer	*barbatum*	ACBA	0.540	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Acer	*glabrum*	ACGL	0.440	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Acer	*grandidentatum*	ACGR	0.440	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Acer	*macrophyllum*	ACMA	0.440	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Acer	*negundo*	ACNE	0.440	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Acer	*nigrum*	ACNI	0.520	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Acer	*pensylvanicum*	ACPE	0.440	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Acer	*rubrum*	ACRU	0.490	0.462	0.030	B	0.286	0.047	B	0.208	0.085	B	0.297	0.336	C
Acer	*saccharinum*	ACSA2	0.440	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Acer	*saccharum*	ACSA	0.560	0.720	0.028	B	0.497	0.052	B	0.340	0.085	B	0.306	0.336	C
Acer	*species*	ACER	0.490	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Acer	*spicatum*	ACSP	0.440	0.568	0.048	B	0.415	0.053	B	0.295	0.087	B	0.297	0.336	C
Aesculus	*californica*	AECA	0.380	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Aesculus	*species*	AESP	0.330	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Ailanthus	*altissima*	AIAL	0.370	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Aleurites	*fordii*	ALFO	0.470	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Alnus	*rubra*	ALRU	0.370	0.409	0.021	B	0.359	0.047	B	0.207	0.084	B	0.181	0.336	C
Alnus	*species*	ALSP	0.370	0.409	0.092	B	0.359	0.096	B	0.207	0.098	B	0.181	0.337	C
Amelanchier	*species*	AMSP	0.660	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C

continued

Appendix C.—continued

Genus	Species	Code	den0	den1	unc1	cod1	den2	unc2	cod2	den3	unc3	cod3	den4	unc4	cod4
Quercus	*durandii*	QUDU	0.600	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*ellipsoidalis*	QUEL	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*emoryi*	QUEM	0.700	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*engelmannii*	QUEN	0.700	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*falcata* var. *falcata*	QUFA	0.520	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*falcata* var. *pagodaefolia*	QUFA2	0.610	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*gambelii*	QUGA	0.640	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*garryana*	QUGA2	0.640	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*hypoleucoides*	QUHY	0.700	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*ilicifolia*	QUIL	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*imbricaria*	QUIM	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*incana*	QUIN	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*kelloggii*	QUKE	0.510	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*laevis*	QULA	0.520	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*laurifolia*	QULA2	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*lobata*	QULO	0.640	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*lyrata*	QULY	0.570	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*macrocarpa*	QUMA	0.580	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*marilandica*	QUMA2	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*michauxii*	QUMI	0.600	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*muehlenbergii*	QUMU	0.600	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*nigra*	QUNI	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*nuttalli*	QUNU	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*oblongifolia*	QUOB	0.700	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*palustris*	QUPA	0.580	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*phellos*	QUPH	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*prinus*	QUPR	0.570	0.773	0.061	B	0.538	0.063	B	0.309	0.085	B	0.405	0.336	C
Quercus	*rubra*	QURU	0.560	0.578	0.032	B	0.333	0.051	B	0.406	0.090	B	0.393	0.336	C
Quercus	*shumardii*	QUSH	0.560	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*species*	QUSP	0.580	0.599	0.024	B	0.508	0.048	B	0.334	0.085	B	0.329	0.336	C
Quercus	*stellata*	QUST	0.600	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*velutina*	QUVE	0.560	0.648	0.056	B	0.399	0.056	B	0.476	0.095	B	0.405	0.336	C

continued

Appendix C.—continued

Genus	Species	Code	den0	den1	unc1	cod1	den2	unc2	cod2	den3	unc3	cod3	den4	unc4	cod4
Quercus	*virginiana*	QUVI	0.800	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Quercus	*wislizeni*	QUWI	0.700	0.648	0.056	B	0.495	0.062	B	0.401	0.092	B	0.405	0.336	C
Robinia	*neomexicana*	RONE	0.660	0.769	0.170	B	0.616	0.154	B	0.341	0.119	B	0.356	0.338	C
Robinia	*pseudoacacia*	ROPS	0.660	0.769	0.031	B	0.616	0.053	B	0.341	0.119	B	0.356	0.338	C
Salix	*species*	SASP	0.360	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Sapium	*sebiferum*	SASE	0.470	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Sassafras	*albidum*	SAAL	0.420	0.458	0.024	B	0.427	0.047	B	0.355	0.084	B	0.356	0.338	C
Sequoia	*sempervirens*	SESE	0.340	0.377	0.041	B	0.366	0.079	B	0.365	0.065	B	0.272	0.336	C
Sequoiadendron	*giganteum*	SEGI	0.340	0.377	0.041	B	0.366	0.079	B	0.365	0.065	B	0.272	0.336	C
Sorbus	*americana*	SOAM	0.420	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Tamarix	*species*	TASP	0.400	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Taxodium	*distichum* var. *nutans*	TADI	0.420	0.377	0.041	B	0.366	0.079	B	0.365	0.065	B	0.272	0.336	C
Taxus	*brevifolia*	TABR	0.600	0.377	0.041	B	0.366	0.079	B	0.365	0.065	B	0.272	0.336	C
Thuja	*occidentalis*	THOC	0.290	0.326	0.016	B	0.298	0.102	B	0.447	0.059	B	0.240	0.336	C
Thuja	*plicata*	THPL	0.310	0.315	0.016	B	0.298	0.102	B	0.352	0.057	B	0.222	0.336	C
Tilia	*americana*	TIAM	0.320	0.430	0.023	B	0.366	0.045	B	0.269	0.084	B	0.356	0.338	C
Tilia	*heterophylla*	TIHE	0.320	0.430	0.097	B	0.366	0.098	B	0.269	0.107	B	0.356	0.338	C
Tilia	*species*	TISP	0.320	0.430	0.097	B	0.366	0.098	B	0.269	0.107	B	0.356	0.338	C
Torreya	*californica*	TOCA	0.340	0.377	0.041	B	0.366	0.079	B	0.365	0.065	B	0.272	0.336	C
Tsuga	*canadensis*	TSCA	0.400	0.394	0.025	B	0.370	0.080	B	0.462	0.063	B	0.299	0.336	C
Tsuga	*heterophylla*	TSHE	0.440	0.390	0.010	A	0.360	0.020	A	0.290	0.020	A	0.170	0.024	A
Tsuga	*mertensiana*	TSME	0.420	0.376	0.025	B	0.370	0.080	B	0.400	0.066	B	0.299	0.336	C
Tsuga	*species*	TSSP	0.380	0.376	0.025	B	0.370	0.080	B	0.400	0.066	B	0.299	0.336	C
Ulmus	*alata*	ULAL	0.570	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Ulmus	*americana*	ULAM	0.460	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Ulmus	*crassifolia*	ULCR	0.570	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Ulmus	*pumila*	ULPU	0.460	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Ulmus	*rubra*	ULRU	0.480	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Ulmus	*serotina*	ULSE	0.570	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Ulmus	*species*	ULSP	0.500	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Ulmus	*thomasii*	ULTH	0.570	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Umbellularia	*californica*	UMCA	0.510	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C
Vaccinium	*arboreum*	VAAR	0.470	0.565	0.126	B	0.464	0.119	B	0.341	0.119	B	0.356	0.338	C

continued

Appendix C.—continued

Standing Dead Absolute Density Predictions Metadata (Appendix C)

Fieldname	Definition	Code/Units	Method
genus	Sample genus		
species	Sample species		
code	Genus-species code		
den0	Green density (decay class “0”)	g/cm^3	
den1	Density of decay class 1 snag	g/cm^3	
unc1	Uncertainty of den1		
cod1	Uncertainty code for den1 (A, B, C)	A	Species sampled
cod1	Uncertainty code for den1 (A, B, C)	B	Genera sampled
cod1	Uncertainty code for den1 (A, B, C)	C	Species and genus not sampled
den2	Density of decay class 2 snag	g/cm^3	
unc2	Uncertainty of den2		
cod2	Uncertainty code for den2 (A, B, C)	A	Species sampled
cod2	Uncertainty code for den2 (A, B, C)	B	Genera sampled
cod2	Uncertainty code for den2 (A, B, C)	C	Species and genus not sampled
den3	Density of decay class 3 snag	g/cm^3	
unc3	Uncertainty of den3		
cod3	Uncertainty code for den3 (A, B, C)	A	Species sampled
cod3	Uncertainty code for den3 (A, B, C)	B	Genera sampled
cod3	Uncertainty code for den3 (A, B, C)	C	Species and genus not sampled
den4	Density of decay class 4 snag	g/cm^3	
unc4	Uncertainty of den4		
cod4	Uncertainty code for den4 (A, B, C)	A	Species sampled
cod4	Uncertainty code for den4 (A, B, C)	B	Genera sampled
cod4	Uncertainty code for den4 (A, B, C)	C	Species and genus not sampled

Appendix D

Standing dead tree relative density and its uncertainty for each decay class by species present in the U.S. FIA inventory

Genus	Species	Code	den0	rel1	unc1	cod1	rel2	unc2	cod2	rel3	unc3	cod3	rel4	unc4	cod4
Abies	*amabilis*	ABAM	0.400	0.936	0.044	B	0.955	0.022	B	0.803	0.107	B	0.574	0.216	C
Abies	*balsamea*	ABBA	0.340	1.040	0.062	B	1.150	0.023	B	1.101	0.064	B	0.710	0.219	C
Abies	*bracteata*	ABBR	0.360	1.018	0.056	B	0.975	0.091	B	0.803	0.107	B	0.574	0.216	C
Abies	*concolor*	ABCO	0.370	0.996	0.021	B	0.873	0.018	B	0.625	0.054	B	0.541	0.213	C
Abies	*fraseri*	ABFR	0.340	1.018	0.056	B	0.975	0.091	B	0.803	0.107	B	0.574	0.216	C
Abies	*grandis*	ABGR	0.350	1.013	0.011	B	0.966	0.021	B	0.855	0.054	B	0.574	0.216	C
Abies	*lasiocarpa*	ABLA	0.310	1.040	0.030	B	1.068	0.073	B	1.000	0.056	B	0.696	0.214	C
Abies	*magnifica*	ABMA	0.360	1.040	0.017	B	1.080	0.051	B	0.626	0.054	B	0.467	0.213	C
Abies	*magnifica* var. *shastensis*	ABMA2	0.360	1.018	0.056	B	0.975	0.091	B	0.803	0.107	B	0.574	0.216	C
Abies	*procera*	ABPR	0.370	1.035	0.013	B	0.836	0.013	B	0.845	0.054	B	0.575	0.213	C
Abies	*species*	ABIE	0.340	1.018	0.056	B	0.975	0.091	B	0.803	0.107	B	0.622	0.217	C
Acacia	*species*	ACSP2	0.600	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Acer	*barbatum*	ACBA	0.540	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Acer	*glabrum*	ACGL	0.440	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Acer	*grandidentatum*	ACGR	0.440	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Acer	*macrophyllum*	ACMA	0.440	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Acer	*negundo*	ACNE	0.440	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Acer	*nigrum*	ACNI	0.520	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Acer	*pensylvanicum*	ACPE	0.440	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Acer	*rubrum*	ACRU	0.490	1.002	0.049	B	0.773	0.056	B	0.618	0.086	B	0.450	0.221	C
Acer	*saccharinum*	ACSA2	0.440	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Acer	*saccharum*	ACSA	0.560	0.956	0.028	B	0.761	0.055	B	0.526	0.077	B	0.450	0.213	C
Acer	*species*	ACER	0.490	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Acer	*spicatum*	ACSP	0.440	0.979	0.035	B	0.766	0.194	B	0.565	0.160	B	0.450	0.221	C
Aesculus	*californica*	AECA	0.380	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Aesculus	*species*	AESP	0.330	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ailanthus	*altissima*	AIAL	0.370	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Aleurites	*fordii*	ALFO	0.470	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C

continued

Appendix D.—continued

Genus	Species	Code	den0	rel1	unc1	cod1	rel2	unc2	cod2	rel3	unc3	cod3	rel4	unc4	cod4
Alnus	*rubra*	ALRU	0.370	1.030	0.013	B	0.903	0.051	B	0.535	0.074	B	0.393	0.213	C
Alnus	*species*	ALSP	0.370	1.030	0.135	B	0.903	0.228	B	0.535	0.153	B	0.393	0.219	C
Amelanchier	*species*	AMSP	0.660	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Arbutus	*menziesii*	ARME	0.580	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Asimina	*triloba*	ASTR	0.470	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Betula	*alleghaniensis*	BEAL	0.550	1.032	0.135	B	0.713	0.181	B	0.336	0.075	B	0.402	0.213	C
Betula	*lenta*	BELE	0.600	1.040	0.070	B	0.756	0.077	B	0.500	0.084	B	0.439	0.220	C
Betula	*lutea*	BELU	0.600	1.040	0.044	B	0.671	0.048	B	0.400	0.076	B	0.439	0.220	C
Betula	*nigra*	BENI	0.560	1.032	0.135	B	0.713	0.181	B	0.511	0.148	B	0.439	0.220	C
Betula	*occidentalis*	BEOC	0.530	1.032	0.135	B	0.713	0.181	B	0.511	0.148	B	0.439	0.220	C
Betula	*papyrifera*	BEPA	0.480	1.016	0.052	B	0.713	0.181	B	0.777	0.120	B	0.439	0.220	C
Betula	*papyrifera var. commutata*	BEPA2	0.480	1.032	0.135	B	0.713	0.181	B	0.511	0.148	B	0.439	0.220	C
Betula	*populifolia*	BEPO	0.450	1.032	0.135	B	0.713	0.181	B	0.511	0.148	B	0.439	0.220	C
Betula	*species*	BESP	0.480	1.032	0.135	B	0.713	0.181	B	0.511	0.148	B	0.439	0.220	C
Bumelia	*lanuginosa*	BULA	0.470	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Calocedrus	*decurrens*	CADE3	0.370	1.040	0.074	B	0.972	0.035	B	1.011	0.059	B	0.596	0.218	C
Carpinus	*caroliniana*	CACA	0.580	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Carya	*aquatica*	CAAQ	0.610	0.988	0.069	B	0.705	0.064	B	0.404	0.080	B	0.396	0.219	C
Carya	*cordiformis*	CACO	0.600	1.040	0.075	B	0.661	0.056	B	0.440	0.077	B	0.396	0.219	C
Carya	*glabra*	CAGL	0.660	0.988	0.069	B	0.705	0.064	B	0.404	0.080	B	0.396	0.219	C
Carya	*illinoensis*	CAIL	0.600	0.988	0.069	B	0.705	0.064	B	0.404	0.080	B	0.396	0.219	C
Carya	*laciniosa*	CALA	0.620	0.988	0.069	B	0.705	0.064	B	0.404	0.080	B	0.396	0.219	C
Carya	*myristicaeformis*	CAMY	0.560	0.988	0.069	B	0.705	0.064	B	0.404	0.080	B	0.396	0.219	C
Carya	*ovata*	CAOV	0.640	0.895	0.062	B	0.808	0.073	B	0.510	0.081	B	0.396	0.219	C
Carya	*species*	CASP	0.620	1.040	0.033	B	0.727	0.035	B	0.334	0.074	B	0.396	0.213	C
Carya	*texana*	CATE	0.540	0.988	0.069	B	0.705	0.064	B	0.404	0.080	B	0.396	0.219	C
Carya	*tomentosa*	CATO	0.640	0.977	0.056	B	0.627	0.038	B	0.332	0.078	B	0.396	0.219	C
Castanea	*dentata*	CADE	0.400	0.936	0.043	B	0.940	0.046	B	0.668	0.082	B	0.525	0.223	C
Castanea	*ozarkensis*	CAOZ	0.400	0.936	0.123	B	0.940	0.237	B	0.676	0.185	B	0.525	0.223	C

continued

Appendix D.—continued

Genus	Species	Code	den0	rel1	unc1	cod1	rel2	unc2	cod2	rel3	unc3	cod3	rel4	unc4	cod4
Castanea	*pumila*	CAPU	0.400	0.936	0.123	B	0.940	0.237	B	0.676	0.185	B	0.525	0.223	C
Castanopsis	*species*	CAST	0.420	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Catalpa	*species*	CATA	0.380	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Celtis	*laevigata*	CELA	0.470	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Celtis	*occidentalis*	CEOC	0.490	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Celtis	*species*	CESP	0.490	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Cercis	*canadensis*	CECA	0.580	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Cercocarpus	*intricatus*	CEIN	1.000	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Cercocarpus	*ledifolius*	CELE	1.000	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Cercocarpus	*montanus*	CEMO	1.000	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Chamaecyparis	*lawsoniana*	CHLA	0.390	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Chamaecyparis	*nootkatensis*	CHNO	0.420	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Chamaecyparis	*thyoides*	CHTH	0.310	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Cladrastis	*lutea*	CLLU	0.520	0.982	0.129	B	0.844	0.199	B	0.775	0.163	B	0.525	0.223	C
Cornus	*florida*	COFL	0.640	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Cornus	*nuttallii*	CONU	0.580	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Cornus	*species*	COSP	0.640	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Cotinus	*obovaus*	COOB	0.470	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Crataegus	*species*	CRSP	0.620	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Cupressus	*species*	CUSP	0.440	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Diospyros	*virginiana*	DIVI	0.640	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Eucalyptus	*species*	EUSP	0.670	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Fagus	*grandifolia*	FAGR	0.560	1.015	0.056	B	0.663	0.041	B	0.508	0.076	B	0.533	0.213	C
Fraxinus	*americana*	FRAM	0.550	0.899	0.061	B	0.562	0.049	B	0.604	0.079	B	0.525	0.223	C
Fraxinus	*latifolia*	FRLA	0.500	0.899	0.118	B	0.622	0.159	B	0.575	0.162	B	0.525	0.223	C
Fraxinus	*nigra*	FRNI	0.450	0.899	0.118	B	0.622	0.159	B	0.575	0.162	B	0.525	0.223	C
Fraxinus	*pennsylvanica*	FRPE	0.530	0.899	0.118	B	0.622	0.159	B	0.575	0.162	B	0.525	0.223	C
Fraxinus	*profunda*	FRPR	0.540	0.899	0.118	B	0.622	0.159	B	0.575	0.162	B	0.525	0.223	C
Fraxinus	*quadrangulata*	FRQU	0.530	0.899	0.118	B	0.622	0.159	B	0.575	0.162	B	0.525	0.223	C
Fraxinus	*species*	FRSP	0.540	0.899	0.118	B	0.622	0.159	B	0.575	0.162	B	0.525	0.223	C

continued

Appendix D.—continued

Genus	Species	Code	den0	rel1	unc1	cod1	rel2	unc2	cod2	rel3	unc3	cod3	rel4	unc4	cod4
Gleditsia	*aquatica*	GLAQ	0.600	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Gleditsia	*triacanthos*	GLTR	0.600	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Gordonia	*lasianthus*	GOLA	0.370	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Gymnocladus	*dioicus*	GYDI	0.500	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Halesia	*species*	HASP	0.320	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ilex	*opaca*	ILOP	0.500	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Juglans	*cinerea*	JUCI	0.360	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Juglans	*species*	JUSP	0.510	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Julglans	*nigra*	JUNI	0.510	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Juniperus	*monosperma*	JUMO	0.450	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Juniperus	*occidentalis*	JUOC	0.440	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Juniperus	*species*	JUSP2	0.440	0.982	0.129	B	0.844	0.199	B	0.775	0.163	B	0.525	0.223	C
Larix	*laricina*	LALA	0.490	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Larix	*lyallii*	LALY	0.480	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Larix	*occidentalis*	LAOC	0.480	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Larix	*species*	LASP	0.440	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Liquidambar	*styraciflua*	LIST	0.460	1.017	0.013	B	0.778	0.039	B	0.526	0.075	B	0.525	0.223	C
Liriodendron	*tulipifera*	LITU	0.410	0.910	0.030	A	0.850	0.020	A	0.554	0.075	B	0.501	0.214	C
Lithocarpus	*densiflorus*	LIDE	0.580	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Maclura	*pomifera*	MAPO	0.760	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Magnolia	*acuminata*	MAAC	0.450	0.884	0.026	B	0.862	0.074	B	0.530	0.080	B	0.525	0.223	C
Magnolia	*species*	MASP	0.450	0.884	0.116	B	0.862	0.218	B	0.530	0.152	B	0.525	0.223	C
Malus	*species*	MASP2	0.610	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Melia	*azedarach*	MEAZ	0.470	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Morus	*alba*	MOAL	0.590	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Morus	*rubra*	MORU	0.590	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Morus	*species*	MOSP	0.590	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Nyssa	*aquatica*	NYAQ	0.460	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Nyssa	*ogeche*	NYOG	0.460	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Nyssa	*sylvatica*	NYSY	0.460	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C

continued

Appendix D.—continued

Genus	Species	Code	den0	rel1	unc1	cod1	rel2	unc2	cod2	rel3	unc3	cod3	rel4	unc4	cod4
Olneya	*tesota*	OLTE	1.000	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ostrya	*virginiana*	OSVI	0.630	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Oxydendrum	*arboreum*	OXAR	0.500	1.040	0.104	B	0.877	0.043	B	0.714	0.084	B	0.525	0.223	C
Paulownia	*tomentosa*	PATO	0.380	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Persea	*borbonia*	PEBO	0.510	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Picea	*abies*	PIAB	0.370	1.010	0.083	A	1.010	0.040	A	0.991	0.159	B	0.605	0.218	C
Picea	*breweriana*	PIBR	0.330	1.038	0.074	B	0.987	0.270	B	0.991	0.159	B	0.605	0.218	C
Picea	*engelmannii*	PIEN	0.330	0.953	0.068	B	0.899	0.021	B	0.991	0.159	B	0.504	0.213	C
Picea	*glauca*	PIGL2	0.370	1.038	0.074	B	0.987	0.270	B	0.991	0.159	B	0.605	0.218	C
Picea	*lutzii*	PILU	0.360	1.060	0.020	A	1.060	0.020	A	1.110	0.040	A	0.564	0.213	C
Picea	*mariana*	PIMA	0.380	1.038	0.074	B	0.987	0.270	B	0.991	0.159	B	0.605	0.218	C
Picea	*pungens*	PIPU	0.380	1.038	0.074	B	0.987	0.270	B	0.991	0.159	B	0.605	0.218	C
Picea	*rubens*	PIRU	0.380	1.040	0.058	B	0.987	0.270	B	1.107	0.107	B	0.605	0.218	C
Picea	*sitchensis*	PISI	0.370	1.040	0.013	B	0.998	0.022	B	0.984	0.055	B	0.676	0.213	C
Picea	*species*	PICE	0.380	1.038	0.074	B	0.987	0.270	B	0.991	0.159	B	0.605	0.218	C
Pinus	*albicaulis*	PIAL	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*aristata*	PIAR	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*arizonica*	PIAR2	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*attenuata*	PIAT	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*balfouriana*	PIBA	0.370	0.916	0.061	A	0.876	0.095	A	1.018	0.155	A	0.598	0.215	C
Pinus	*banksiana*	PIBA2	0.420	0.953	0.040	A	0.920	0.030	A	0.780	0.091	A	0.598	0.215	C
Pinus	*clausa*	PICL	0.460	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*contorta*	PICO	0.400	0.980	0.010	A	1.040	0.030	A	1.020	0.010	A	0.727	0.213	C
Pinus	*coulteri*	PICO2	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*discolor*	PIDI	0.500	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*echinata*	PIEC	0.470	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*edulis*	PIED	0.500	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*elliotti*	PIEL	0.540	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*engelmannii*	PIEN2	0.370	0.953	0.057	B	0.950	0.075	B	0.991	0.089	B	0.598	0.215	C
Pinus	*flexilis*	PIFL	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C

continued

Appendix D.—continued

Genus	Species	Code	den0	rel1	unc1	cod1	rel2	unc2	cod2	rel3	unc3	cod3	rel4	unc4	cod4
Pinus	*glabra*	PIGL	0.410	1.038	0.062	B	0.987	0.078	B	0.991	0.095	B	0.605	0.215	C
Pinus	*jeffreyi*	PIJE	0.370	0.904	0.025	B	0.960	0.037	B	0.883	0.062	B	0.645	0.214	C
Pinus	*lambertiana*	PILA	0.340	1.040	0.038	B	0.906	0.014	B	0.735	0.054	B	0.517	0.213	C
Pinus	*leiophylla*	PILE	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*monophylla*	PIMO	0.500	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*monticola*	PIMO3	0.350	1.022	0.012	B	0.996	0.015	B	1.170	0.055	B	0.598	0.215	C
Pinus	*muricata*	PIMU	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*nigra*	PINI	0.410	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*palustris*	PIPA	0.540	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*ponderosa*	PIPO	0.380	0.925	0.011	B	1.007	0.020	B	1.154	0.061	B	0.481	0.213	C
Pinus	*pungens*	PIPU2	0.490	1.038	0.062	B	0.987	0.078	B	0.991	0.095	B	0.605	0.215	C
Pinus	*radiata*	PIRA	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*resinosa*	PIRE	0.410	0.862	0.052	B	0.950	0.075	B	0.876	0.088	B	0.520	0.214	C
Pinus	*rigida*	PIRI	0.470	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*sabiniana*	PISA	0.370	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*serotina*	PISE	0.510	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*strobiformis*	PIST2	0.350	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*strobus*	PIST	0.340	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Pinus	*sylvestris*	PISY	0.380	0.990	0.020	A	0.980	0.020	A	0.830	0.080	A	0.598	0.215	C
Pinus	*taeda*	PITA	0.470	0.862	0.014	B	0.784	0.012	B	0.732	0.053	B	0.601	0.213	C
Pinus	*virginiana*	PIVI	0.450	0.953	0.057	B	0.950	0.075	B	0.927	0.091	B	0.598	0.215	C
Planera	*aquatica*	PLAQ	0.530	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Platanus	*occidentalis*	PLOC	0.460	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Populus	*alba*	POAL	0.370	1.006	0.132	B	0.793	0.201	B	0.868	0.229	B	0.613	0.227	C
Populus	*angustifolia*	POAN	0.340	1.006	0.132	B	0.793	0.201	B	0.868	0.229	B	0.613	0.227	C
Populus	*balsamifera*	POBA	0.310	1.006	0.132	B	0.793	0.201	B	0.868	0.229	B	0.613	0.227	C
Populus	*deltoides*	PODE	0.370	1.006	0.132	B	0.793	0.201	B	0.868	0.229	B	0.613	0.227	C
Populus	*fremontii*	POFR	0.340	1.006	0.132	B	0.793	0.201	B	0.868	0.229	B	0.613	0.227	C
Populus	*grandidentata*	POGR	0.360	0.970	0.063	B	0.793	0.201	B	0.878	0.092	B	0.613	0.227	C
Populus	*heterophylla*	POHE	0.370	1.006	0.132	B	0.793	0.201	B	0.868	0.229	B	0.613	0.227	C

continued

Appendix D.—continued

Genus	Species	Code	den0	rel1	unc1	cod1	rel2	unc2	cod2	rel3	unc3	cod3	rel4	unc4	cod4
Populus	*sargentii*	POSA	0.370	1.006	0.132	B	0.793	0.201	B	0.868	0.229	B	0.613	0.227	C
Populus	*species*	POSP	0.370	1.040	0.136	B	0.793	0.201	B	0.860	0.227	B	0.613	0.227	C
Populus	*tremuloides*	POTR	0.390	0.970	0.040	A	0.750	0.050	A	0.540	0.070	A	0.613	0.227	C
Prosopis	*species*	PRSP	0.580	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Prunus	*americana*	PRAM	0.470	1.040	0.136	B	1.045	0.263	B	0.708	0.192	B	0.525	0.223	C
Prunus	*nigra*	PRNI	0.470	1.040	0.136	B	1.045	0.263	B	0.708	0.192	B	0.525	0.223	C
Prunus	*pensylvanica*	PRPE	0.360	1.040	0.031	B	1.011	0.041	B	0.636	0.076	B	0.525	0.223	C
Prunus	*serotina*	PRSE	0.470	1.040	0.073	B	1.080	0.059	B	0.780	0.103	B	0.525	0.223	C
Prunus	*species*	PRSP2	0.470	1.040	0.136	B	1.045	0.263	B	0.708	0.192	B	0.525	0.223	C
Prunus	*virginiana*	PRVI	0.360	1.040	0.136	B	1.045	0.263	B	0.708	0.192	B	0.525	0.223	C
Pseudotsuga	*menziesii*	PSME	0.450	0.892	0.015	B	0.831	0.017	B	0.591	0.054	B	0.433	0.213	C
Quercus	*agrifolia*	QUAG	0.700	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*alba*	QUAL	0.600	1.012	0.032	B	0.806	0.035	B	0.591	0.078	B	0.398	0.214	C
Quercus	*arizonica, grisea*	QUAR	0.700	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*bicolor*	QUBI	0.640	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*chrysolepis*	QUCH	0.700	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*coccinea*	QUCO	0.600	0.990	0.052	B	0.904	0.047	B	0.781	0.078	B	0.591	0.216	C
Quercus	*douglasii*	QUDO	0.510	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*durandii*	QUDU	0.600	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*ellipsoidalis*	QUEL	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*emoryi*	QUEM	0.700	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*engelmannii*	QUEN	0.700	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*falcata* var. *falcata*	QUFA	0.520	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*falcata* var. *pagodaefolia*	QUFA2	0.610	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*gambelii*	QUGA	0.640	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*garryana*	QUGA2	0.640	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*hypoleucoides*	QUHY	0.700	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*ilicifolia*	QUIL	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*imbricaria*	QUIM	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C

continued

Appendix D.—continued

Genus	Species	Code	den0	rel1	unc1	cod1	rel2	unc2	cod2	rel3	unc3	cod3	rel4	unc4	cod4
Quercus	*incana*	QUIN	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*kelloggii*	QUKE	0.510	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*laevis*	QULA	0.520	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*laurifolia*	QULA2	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*lobata*	QULO	0.640	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*lyrata*	QULY	0.570	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*macrocarpa*	QUMA	0.580	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*marilandica*	QUMA2	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*michauxii*	QUMI	0.600	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*muehlenbergii*	QUMU	0.600	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*nigra*	QUNI	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*nuttalli*	QUNU	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*oblongifolia*	QUOB	0.700	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*palustris*	QUPA	0.580	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*phellos*	QUPH	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*prinus*	QUPR	0.570	1.040	0.079	B	0.927	0.086	B	0.547	0.077	B	0.591	0.216	C
Quercus	*rubra*	QURU	0.560	1.031	0.044	B	0.859	0.074	B	0.731	0.093	B	0.591	0.216	C
Quercus	*shumardii*	QUSH	0.560	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*species*	QUSP	0.580	1.013	0.021	B	0.861	0.045	B	0.688	0.079	B	0.686	0.213	C
Quercus	*stellata*	QUST	0.600	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*velutina*	QUVE	0.560	1.020	0.051	B	0.700	0.072	B	0.858	0.118	B	0.591	0.216	C
Quercus	*virginiana*	QUVI	0.800	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Quercus	*wislizeni*	QUWI	0.700	1.020	0.051	B	0.841	0.084	B	0.705	0.106	B	0.591	0.216	C
Robinia	*neomexicana*	RONE	0.660	1.040	0.136	B	0.916	0.231	B	0.618	0.171	B	0.525	0.223	C
Robinia	*pseudoacacia*	ROPS	0.660	1.040	0.033	B	0.916	0.055	B	0.618	0.171	B	0.525	0.223	C
Salix	*species*	SASP	0.360	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Sapium	*sebiferum*	SASE	0.470	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Sassafras	*albidum*	SAAL	0.420	1.040	0.030	B	0.998	0.051	B	0.853	0.077	B	0.525	0.223	C
Sequoia	*sempervirens*	SESE	0.340	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Sequoiadendron	*giganteum*	SEGI	0.340	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C

continued

Appendix D.—continued

Genus	Species	Code	den0	rel1	unc1	cod1	rel2	unc2	cod2	rel3	unc3	cod3	rel4	unc4	cod4
Sorbus	*americana*	SOAM	0.420	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Tamarix	*species*	TASP	0.400	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Taxodium	*distichum var. nutans*	TADI	0.420	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Taxus	*brevifolia*	TABR	0.600	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Thuja	*occidentalis*	THOC	0.290	1.040	0.039	B	0.960	0.163	B	1.330	0.075	B	0.655	0.213	C
Thuja	*plicata*	THPL	0.310	1.040	0.074	B	0.960	0.326	B	1.064	0.058	B	0.656	0.213	C
Tilia	*americana*	TIAM	0.320	1.040	0.026	B	1.080	0.046	B	0.848	0.076	B	0.525	0.223	C
Tilia	*heterophylla*	TIHE	0.320	1.040	0.136	B	1.080	0.272	B	0.848	0.225	B	0.525	0.223	C
Tilia	*species*	TISP	0.320	1.040	0.136	B	1.080	0.272	B	0.848	0.225	B	0.525	0.223	C
Torreya	*californica*	TOCA	0.340	0.994	0.071	B	0.951	0.260	B	0.902	0.146	B	0.605	0.218	C
Tsuga	*canadensis*	TSCA	0.400	1.035	0.060	B	0.882	0.241	B	1.081	0.087	B	0.604	0.218	C
Tsuga	*heterophylla*	TSHE	0.440	0.900	0.030	A	0.830	0.040	A	0.661	0.050	A	0.380	0.050	A
Tsuga	*mertensiana*	TSME	0.420	0.953	0.052	B	0.882	0.241	B	0.906	0.079	B	0.604	0.218	C
Tsuga	*species*	TSSP	0.380	0.953	0.052	B	0.882	0.241	B	0.906	0.079	B	0.604	0.218	C
Ulmus	*alata*	ULAL	0.570	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ulmus	*americana*	ULAM	0.460	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ulmus	*crassifolia*	ULCR	0.570	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ulmus	*pumila*	ULPU	0.460	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ulmus	*rubra*	ULRU	0.480	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ulmus	*serotina*	ULSE	0.570	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ulmus	*species*	ULSP	0.500	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Ulmus	*thomasii*	ULTH	0.570	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Umbellularia	*californica*	UMCA	0.510	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C
Vaccinium	*arboreum*	VAAR	0.470	0.982	0.129	B	0.793	0.201	B	0.618	0.171	B	0.525	0.223	C

continued

Appendix D.—continued

Standing Dead Tree Relative Density Predictions Metadata (Appendix D)

Fieldname	Definition	Code/Units	Method
genus	genus		
species	species		
code	genus-species code		
den0	green density	g/cm^3	
rel1	relative density decay class 1	dimensionless	
unc1	uncertainty of rel1	dimensionless	
cod1	uncertaintly code for rel1	A	Species sampled
		B	Genera sampled
		C	Species and genus not sampled
rel2	relative density decay class 2	dimensionless	
unc2	uncertainty of rel2	dimensionless	
cod2	uncertaintly code for rel2	A	Species sampled
		B	Genera sampled
		C	Species and genus not sampled
rel3	relative density decay class 3	dimensionless	
unc3	uncertainty of rel3	dimensionless	
cod3	uncertaintly code for rel3	A	Species sampled
		B	Genera sampled
		C	Species and genus not sampled
rel4	relative density decay class 4	dimensionless	
unc4	uncertainty of rel4	dimensionless	
cod4	uncertaintly code for rel4	A	Species sampled
		B	Genera sampled
		C	Species and genus not sampled

Harmon, Mark E.; Woodall, Christopher W.; Fasth, Becky; Sexton, Jay; Yatkov, Misha. 2011. **Differences between standing and downed dead tree wood density reduction factors: A comparison across decay classes and tree species.** Res. Pap. NRS-15. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 40 p.

Woody detritus or dead wood is an important part of forest ecosystems and has become a routine facet of forest monitoring and inventory. Biomass and carbon estimates of dead wood depend on knowledge of species- and decay class-specific density or density reduction factors. While some progress has been made in determining these parameters for dead and downed trees (DD), there are very few estimates of these key parameters for standing dead trees (SD). We evaluated indicators of decay to relate subjective SD and DD decay classifications then compared SD and DD density and density reduction factors by decay class for a total of 19 tree species at nine sites in the United States and Russia. Results indicate that SD density declined with decay class for all examined species. By applying these results, a new set of SD density reduction factors was developed for 260 species inventoried by the U.S. Forest Service's Forest Inventory and Analysis program in forests of the United States.

KEY WORDS: standing dead trees, downed dead trees, carbon, biomass, decay reduction factor

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