United States Department of Agriculture

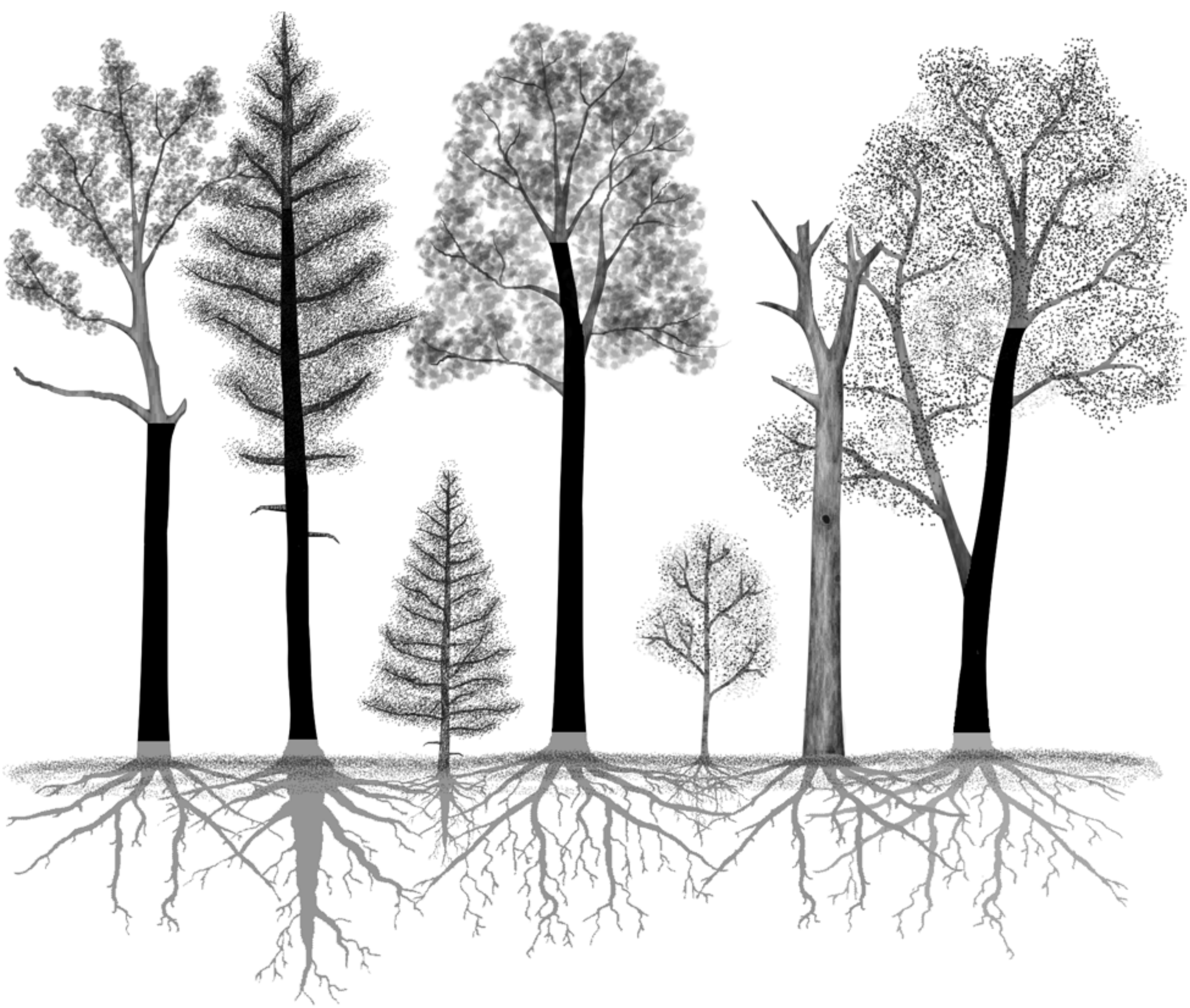
Forest Service

Northeastern Research Station

General Technical Report NE-298

Forest Volume-to-Biomass Models and Estimates of Mass for Live and Standing Dead Trees of U.S. Forests

James E. Smith
Linda S. Heath
Jennifer C. Jenkins



Abstract

We present methods and equations for nationally consistent estimates of tree-mass density at the stand level (Mg/ha) as predicted by growing-stock volumes reported in USDA Forest Service surveys for forests of the conterminous United States. Developed for use in FORCARB, a carbon budget model for U.S. forests, the equations also are useful for converting stand-, plot-, and regional-level forest merchantable volumes to estimates of total mass. Tree biomass is about 50 percent carbon, so carbon estimates can be derived from estimates of biomass by multiplying by 0.5. We include separate equations for live and standing dead trees. Similarly, separate equations predict the components of aboveground only vs. full trees (including coarse roots) and hardwood vs. softwood species. Equations are developed for broad forest types by region and are applicable to large-scale forest-inventory data. Example estimates are provided for regional tree-mass totals using summary forest statistics for the United States.

The Authors

JAMES E. SMITH, jsmith11@fs.fed.us, and LINDA S. HEATH, lheath@fs.fed.us, are research plant physiologist and research forester/project leader, respectively, with the Northeastern Research Station at Durham, New Hampshire; JENNIFER C. JENKINS, jjenkins@fs.fed.us, is a research forester with the Northeastern Research Station at Burlington, Vermont.

Manuscript received for publication 19 April 2002

Published by:

USDA FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073-3294

January 2003

For additional copies:

USDA Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640
Fax: (740)368-0152

Visit our homepage at: **http://www.fs.fed.us/ne**

Forest Volume-to-Biomass Models and Estimates of Mass for Live and Standing Dead Trees of U.S. Forests

James E. Smith, Linda S. Heath, and Jennifer C. Jenkins

Acknowledgments

We thank Richard Birdsey, Paul Van Deusen, Sarah Duke, Steve Prisley, and Harry Valentine for helpful comments on drafts of this manuscript. Eric Fiegenbaum provided the cover artwork. This work was partly supported by the USDA Forest Service's Northern Global Change Program and the RPA Assessment Management Group.

1 megagram (Mg) or metric tonne = 1,000 kg or 1 x 10^6 g
1 metric tonne = 1.102 U.S. ton, or 2,205 lb
1 megatonne (Mt) = 1 x 10^6 tonne, or teragram (Tg) or 1 x 10^{12} g
1 gigatonne (Gt) = 1 x 10^9 tonne, or petagram (Pg) or 1 x 10^{15} g
1 hectare (ha) = 2.471 acres, or 10,000 m^2
1 cubic meter (m^3) = 35.31 ft^3
100 m^3/ha = 1429 ft^3/acre
100 Mg/ha = 44.6 U.S. tons/acre, or 89,200 lb/acre

Introduction

The potential for U.S. forests to sequester carbon dioxide from the troposphere is well established. A large portion of assimilated carbon accumulates as tree biomass. The effect of this accumulation on atmospheric levels of greenhouse gasses and the role of forests in this process remain the subjects of national[1] and international research discussions (Watson and others 2000). Thus, the need for a nationwide carbon budget of U.S. forests extends beyond the current year's carbon gains, losses, and net inventory. Information needed for policy development includes estimates of past trends and projected future scenarios. The mass estimators presented in this report are part of an effort to improve carbon budget estimates for U.S. forests. The value of biomass equations for this effort is based on the link between individual-tree and whole-stand biomass estimates (Clutter and others 1983; Parresol 1999), coupled with the assumption that mass of wood is about 50 percent carbon (Birdsey 1992).

The few regional- to national-scale budgets of biomass or carbon mass developed for the United States are based largely on forest structure as described by previous versions of the USDA Forest Service's Forest Inventory and Analysis Database (FIADB; Miles and others 2001) developed by the Forest Inventory and Analysis (FIA) program. Currently, the database contains only recent data (within about the last 10 years), though extensive statistically based continuous forest surveys date back to about 1950. These surveys are designed to estimate the amount of volume of growing stock, which is a phrase describing merchantable trees. Data from the surveys also have been used to estimate biomass or carbon. Cost and others (1990) summarized FIA data into national estimates of growing-stock biomass. Birdsey (1992) derived volume-to-biomass ratios by comparing the estimates of growing-stock biomass in Cost and others (1990) to equivalent growing-stock volumes in Powell and others (1993). Birdsey used these ratios to calculate forest carbon budgets that later served as the basis for FORCARB, a carbon budget model for U.S. forests (Plantinga and Birdsey 1993; Heath and Birdsey 1993; Birdsey and Heath 1995). Turner and others (1995) published carbon estimates largely based on FIA data and Birdsey's (1992) values for carbon density. Schroeder and others (1997) and Brown and others (1999) improved on the volume-to-biomass relationship by recognizing that volume-to-biomass ratios vary by tree size or, on an aggregated scale, forest structure. They developed large-scale biomass estimates for the Eastern United States based on FIA data and generalized biomass expansion factors for select eastern forest types. None of these previous studies provided estimates of biomass of standing dead trees, nor were the biomass estimates based on equations that reflect the species composition of U.S. forests.

Our objective was to develop equations for estimating the mass (Mg/ha) of live and standing dead trees as predicted by FIA growing-stock volume (m^3/ha) for forests of the 48 conterminous States. Thus, values calculated by the FIA can readily serve as inputs to the regression-based estimates. Although these equations were developed for use with FIA volumes as applied in the Aggregated TimberLand Assessment System (ATLAS) model (Mills and Kincaid 1992), they also can be applied to statistics for large regions and broad classifications of forest types as presented in periodic national inventory compilations (see Smith and others 2001, Powell and others 1993, and Waddell and others 1989). Because the equations are based on current FIA datasets at a vegetation-type scale, they might be less precise for specific sites or for inventories with growing-stock definitions that differ from those of FIA. Similar cautions extend to applying regional-scale historical data or long-term projections. We used the equations to develop national-level estimates of tree mass and compare them with those produced following the methods of Birdsey (1992) and Brown and others (1999).

These equations are part of a larger project to develop estimates of forest carbon using FORCARB, which also accounts for carbon in forest products (Heath and others 1996; Skog and Nicholson 1998). An understanding of how the carbon budget numbers were obtained and how alternate scenarios or interpretations of data affect results is useful for policy development or negotiations. FORCARB was used to produce projections for the 2001 U.S. Submission to the United Nations Framework Convention on Climate Change on Land Use, Land Use Change, and Forestry (U.S. State Dep. 2000), and most recently to examine uncertainty in U.S. forest carbon budgets (Smith and Heath 2000, 2001; Heath and Smith 2000). With such intended applications, our models are fundamental, tractable, and transparent—with few inputs, widely applicable, and obvious relationships among the parts.

[1]See U.S. Global Change Research Information Office Internet site: http://www.gcrio.org/index.shtml (accessed March 28, 2002).

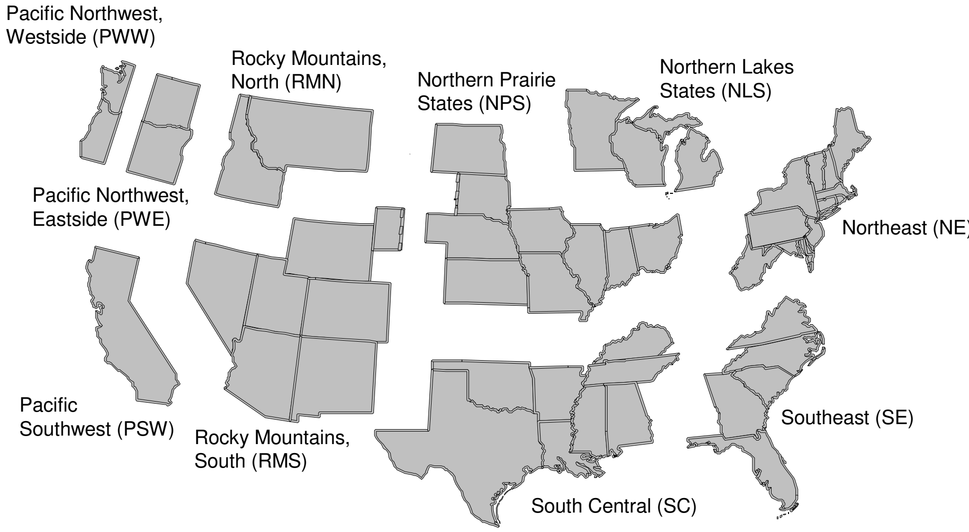


Figure 1.—Regions of the United States used in classifying forest types.

Methods

The estimates of tree-mass density presented here and incorporated in FORCARB are based on tree- and plot-level data in the FIADB (Miles and others 2001) and the individual-tree biomass equations of Jenkins and others (in press). Estimates are formed in two steps: (1) summaries of tree mass are developed at the FIA plot level, and (2) regressions are developed to estimate plot-level tree mass as functions of growing-stock volume. The individual-tree biomass equations are applied to determine mass for each tree recorded on an FIA inventory plot. Tree mass and merchantable volume of growing stock are summed for each plot and expressed as densities (Mg/ha and m^3/ha for mass and volume, respectively). The paired mass and volume densities are then incorporated in regressions with growing-stock volume as the independent variable.

Plot summary pairs and corresponding regression equations are classified and sorted by various categories, a requirement for their subsequent inclusion in FORCARB. Region and forest type are the highest levels of classification. The 48 conterminous states are divided into 10 regions (Fig. 1), each of which includes six to eight forest types. Relationships between classifications used in ATLAS and FORCARB and those of the FIADB are described in Table 1. Additional classifications include live or standing dead trees; aboveground only or whole trees (including coarse roots); and live softwood or hardwood tree species.

A consequence of these classification schemes is a proliferation in the number of estimators of tree-mass density in FORCARB simulations. Use of the regression estimates was an important consideration in developing the procedures described in this report. We standardized inputs (independent variable) to a single summary value available for all FIADB plots, and limited the form of the regression models to one for live trees and another for standing dead trees.

Forest-Inventory Design and Data Description

Unlike the U.S. census, which uses complete enumeration (every individual is counted), the FIA inventory design relies on a sampling scheme to estimate growing-stock volumes at a designated level of precision. Sampling is conducted in different phases, allowing cost-efficient data collection. In the past, these surveys were conducted periodically by state, usually every 5 to 7 years in the South and every 10 to 15 years in other regions. The data used in this study are from the most recent summary for each state (Table 2). Although FIA has adopted an annualized inventory with three sampling phases, the current data are from inventories of two phases based on double-sampling for stratification (Schreuder and others 1993). In the first phase, sample points on aerial photographs are interpreted and classified by land use and type of vegetation or land cover on an area of known size. These areas are taken from U.S. Bureau of Census reports and other sources. Depending on the individual state, additional classifications might include productivity, estimated volume, or stand age. In the second phase, a sample of points from the first phase is chosen for crews to visit in the field. Until FIA recently adopted a national plot design, many designs were used in the second phase of past inventories. Detailed observations are made on forest plots, particularly those that meet a productivity standard and are labeled as timberland. The data from

Table 1.—Forest types classified for mass estimates of trees in this report (based on the FIADB forest-type groups)

Region[a]	Forest type	FIADB forest-type group
NE	Aspen-Birch	Aspen-Birch
	MBB/Other HW	Oak-Gum-Cypress, Elm-Ash-Cottonwood, and Maple-Beech-Birch
	Oak-Hickory	Oak-Hickory
	Oak-Pine	Oak-Pine
	Other Pine	Longleaf-Slash Pine, Loblolly-Shortleaf Pine, and pines other than White-Red-Jack
	Spruce-Fir	Spruce-Fir and other non-pine conifers
	WRJ-Pine	White-Red-Jack Pine
	Nonstocked	Nonstocked
NLS	Aspen-Birch	Aspen-Birch
	Lowland HW	Oak-Gum-Cypress and Elm-Ash-Cottonwood
	MBB	Maple-Beech-Birch
	Oak-Hickory	Oak-Hickory
	Pine	All pine groups and Oak-Pine
	Spruce-Fir	Spruce-Fir
	Nonstocked	Nonstocked
NPS	Conifer	All conifer groups
	Lowland HW	Oak-Gum-Cypress, Elm-Ash-Cottonwood, and Aspen-Birch
	MBB	Maple-Beech-Birch
	Oak-Hickory	Oak-Hickory
	Oak-Pine	Oak-Pine
	Nonstocked	Nonstocked
SC, SE	Bottomland HW	Oak-Gum-Cypress, Elm-Ash-Cottonwood, and Aspen-Birch
	Natural Pine	Longleaf-Slash Pine and Loblolly-Shortleaf Pine, naturally occurring
	Oak-Pine	Oak-Pine
	Other Conifer	Other conifer groups
	Planted Pine	Longleaf-Slash Pine and Loblolly-Shortleaf Pine, planted
	Upland HW	Oak-Hickory and Maple-Beech-Birch
	Nonstocked	Nonstocked
PSW	Douglas-fir	Douglas-fir and Hemlock-Sitka Spruce
	Fir-Spruce	Fir-Spruce-Mountain Hemlock
	Hardwoods	Hardwoods
	Other Conifer	Ponderosa Pine, Lodgepole Pine, and other conifer groups
	Pinyon-Juniper	Pinyon-Juniper
	Redwood	Redwood
	Nonstocked	Nonstocked
PWE	Douglas-fir	Douglas-fir, Western Larch, and Redwood
	Fir-Spruce	Fir-Spruce-Mountain Hemlock and Hemlock-Sitka Spruce
	Hardwoods	Hardwoods
	Lodgepole Pine	Lodgepole Pine
	Ponderosa Pine	Ponderosa Pine and Western White Pine
	Pinyon-Juniper	Pinyon-Juniper

Continued

Table 1.—continued.

Region[a]	Forest type	FIADB forest-type group
	Nonstocked	Nonstocked
PWW	Douglas-fir	Douglas-fir and Redwood
	Fir-Spruce	Fir-Spruce-Mountain Hemlock
	Other Conifer	Ponderosa Pine, Western White Pine, Lodgepole Pine, and other conifer groups
	Other Hardwoods	Other hardwoods
	Red Alder	Alder-Maple
	Western Hemlock	Hemlock-Sitka Spruce
	Nonstocked	Nonstocked
RMN, RMS	Douglas-fir	Douglas-fir, Western White Pine, Hemlock-Sitka Spruce, Western Larch, and Redwood
	Fir-Spruce	Fir-Spruce-Mountain Hemlock
	Hardwoods	Hardwoods
	Lodgepole Pine	Lodgepole Pine
	Other Conifer	Other conifer groups
	Ponderosa Pine	Ponderosa Pine
	Pinyon-Juniper	Pinyon-Juniper
	Nonstocked	Nonstocked

[a]NE=Northeast; NLS=Northern Lake States; NPS=Northern Prairie States; SC=South Central; SE=Southeast; PSW=Pacific Southwest; PWE=Pacific Northwest Eastside; PWW=Pacific Northwest Westside; RMN=Rocky Mountains North; RMS=Rocky Mountains South.

both phases are used to determine the area that each ground plot represents. Allowable tolerances are specified for the measurements; for example, diameters are measured to the nearest 0.1 inch. The designated maximum allowable sample error for area is 3 percent per 1 million acres of timberland. For more information, see the documentation accompanying the FIADB (Miles and others 2001) and the "Forest Inventory and Analysis National Core Field Guide."[2]

In this section we describe how we used the FIADB to estimate plot-level tree-mass density based on generalized individual-tree biomass equations, and subsequently to develop regression-based estimates of mean tree-mass density. We first describe our interest in selected variables and our rationale for organizing the data into separate forest groups. Where useful, we provide specific variable names as found in the FIADB as of March 2002, for example, STDAGE (stand age). FIA data are collected in English units; we converted them to metric units.

For our purposes, the FIADB includes data at two levels of organization: FIA inventory plot and individual tree. Plot information includes location (state and county), landowner classification, current forest type, stand origin (plantation or natural regeneration), site productivity classification, estimated stand age, current and past land-use classification, area (in acres) that each plot represents, and years between remeasurements. Individual-tree information — for all trees larger than 1 inch in diameter at breast height (d.b.h.) — includes species, diameter, status (live or dead), whether growing stock or cull, growing-stock volume if applicable, and number per acre represented by each individual. Plot volumes are calculated by summing individual-tree growing-stock volumes on the plot and expressed as volume per unit area (m^3/ha).

We classify forests according to region and forest type with a goal to gain added flexibility in applying results. We wanted forest groupings consistent with: (1) classifications used in the FIADB, (2) timber units used in ATLAS (Mills and Kincaid 1992; Haynes and others

[2]U.S. Department of Agriculture, Forest Service. 2001. **Forest inventory and analysis national core field guide, volume 1: field data collection procedures for phase 2 plots, version 1.5.** Internal report on file at: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis, 201 14th St., Washington, DC.

1995), (3) forest-type groups listed in Forest Service statistical reports, for example, Smith and others (2001), and (4) other components of FORCARB. The variables for state (STATECD) and FIA inventory unit (UNITCD) are used to define the 10 regions (Fig. 1). Forest types (FORTYPCD) are grouped to reflect species composition and other aspects of stand structure that influence overall biomass. The principal goals in grouping forest types for this analysis were to maintain a small set of types to represent each region and conform to types used in ATLAS' timber projections.

We considered additional forest groupings by ownership (OWNCD or OWNGRPCD) and productivity (SITECLCD). Decisions about whether to include such additional classifications were based on preliminary analyses of the data rather than required links to other models as with region and forest type. Preliminary analysis of covariance identified some forest types as showing an effect of ownership on the relationship between volume of growing stock and tree-mass density. These ownerships are classified as "public" or "private" lands and included in the classification scheme described in Table 1. Analyses also revealed slight interactions between productivity and the initial slope of this same biomass-to-volume relationship. However, this effect was inconsistent across forest types of the two areas where productivity is an important variable in simulation models—the South and the Pacific Northwest. Thus, no estimates in this report are classified by productivity.

Some older inventories identified and measured only live or merchantable dead (salvageable) trees on new plots; that is, all standing dead trees were not necessarily included in the initial survey for a plot. To avoid plots where standing dead trees might be underrepresented, we used only remeasured plots (KINDCD=2) or recently completed surveys, which were more likely to include standing dead trees. Current surveys include the identification and measurement of all trees. We used all measured plots (KINDCD=1 through 3) on surveys since 1999.

Estimating Mass for Individual Trees

Mass estimates are provided for individual trees (DRYBIOT) in the FIADB. However, we applied the nationally consistent set of individual-tree biomass estimates of Jenkins and others (in press) because FIA biomass estimates may differ considerably by FIA unit. We also wanted to extend mass estimates to standing dead trees and coarse tree roots. The 10 equations are designed to estimate all tree species in U.S. forests: five softwood species groups, four hardwood species groups, and one group for woodland species. These equations estimate

Table 2.—Most recent statewide forest inventories included in FIADB and used in this analysis

State	Date of inventory
Alabama	2000
Arizona	1999
Arkansas	1995
California	1994
Colorado	1983
Connecticut	1998
Delaware	1999
Florida	1995
Georgia	1997
Idaho	1991
Illinois	1998
Indiana	1998
Iowa	1999
Kansas	1994
Kentucky	1988
Louisiana	1991
Maine	1995
Maryland	1999
Massachusetts	1998
Michigan	1993
Minnesota	1990
Mississippi	1994
Missouri	1999
Montana	1989
Nebraska	1994
Nevada	1989
New Hampshire	1997
New Jersey	1999
New Mexico	1999
New York	1993
North Carolina	1990
North Dakota	1995
Ohio	1993
Oklahoma	1993
Oregon	1995
Pennsylvania	1989
Rhode Island	1998
South Carolina	1999
South Dakota	1995
Tennessee	1999
Texas	1992
Utah	1995
Vermont	1997
Virginia	1992
Washington	1991
West Virginia	1989
Wisconsin	1996
Wyoming	1984

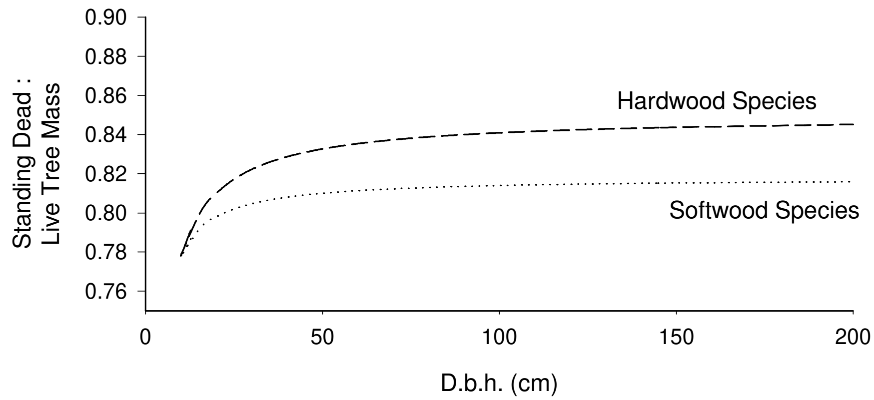


Figure 2.—Ratios of standing dead mass to live tree mass for individual trees, by d.b.h. and classification as softwood or hardwood.

total aboveground (that is, above the root collar) biomass for trees of 1 inch or larger in d.b.h. Additional equations are provided for estimating the ratio of components to total aboveground biomass. The component equations are for foliage, coarse roots, stem bark, and stem wood.

Live trees

Live trees are identified as STATUSCD=1. Once identified as a live tree larger than 1 inch d.b.h. in an FIA plot, the only variables needed to estimate individual-tree mass are diameter (DIA) and species (SPCD). The value of DIA usually is measured at breast height except for woodland species, which generally are measured at the root collar. The individual-tree biomass equations provide estimates of the mass (kg) of individual live trees.

Mass per unit area is then determined by multiplying by the number of trees per acre (TPACURR). Mass is summed across all trees per plot and the sum is converted to metric units. The mass density of live trees at the plot level is expressed as Mg/ha. Growing-stock volume as estimated per tree by FIA (VOLCFNET where TREECLCD=2) also is summed for each plot and expressed as m^3/ha. The paired values (volume, mass density) from each FIA plot were the source of the observations used in the regressions we developed. The same process of estimating volume-density and mass-density pairs per FIA plot can be repeated for both aboveground and total-tree estimates. Similarly, hardwood-only or softwood-only estimates are developed with mass and volume pairs representing only the hardwood or softwood portion of the live trees on a plot.

Standing dead trees

Trees identified in the FIADB as STATUSCD=2 are standing dead trees. For the same diameter, these are likely to have less mass than live trees, which were the basis for the individual-tree biomass equations. We adjust tree mass to reflect an expected difference between live and dead trees of the same d.b.h. by reducing the mass of some parts of dead trees. We do not have specific information on mass of standing dead trees, which can encompass a wide range of structural damage and decay, so we use the component equations of Jenkins and others (in press) to reduce the mass of standing dead relative to live by the following amounts: 10 percent of stem wood and bark; 100 percent of leaves; 33 percent of branches; and 20 percent of coarse roots. Separate component equations are for hardwood and softwood species and are based on d.b.h. The net effect of the component reductions is illustrated in Figure 2 by the ratios of standing dead to live mass according to d.b.h. and species group (softwood or hardwood).

Adjusting for cull trees

The biomass of cull trees (TREECLCD=3 or 4) is likely to differ from that of trees of similar diameter classified as growing stock (TREECLCD=2). The biomass of live cull trees represents more than 10 percent of live-tree biomass in the East (estimated from FIADB). Cull status is assigned to a tree if it is a nonmerchantable species or if a significant portion of the bole of a merchantable species is unusable as timber. Cull status suggests that diameter-to-biomass relationships likely differ from those of the individual-tree biomass equations. We did not have specific estimates of biomass for cull trees, so we developed generalized adjustments to the individual-tree biomass equations by examining the apparent effect of cull classification on volume; that is, we developed ratios for estimating the woody mass of cull trees that were proportional to ratios of cull volumes to growing-stock volumes.

Biomass correction factors for cull trees are based on analysis of the Eastwide and Westwide inventory databases (Hansen and others 1992; Woudenberg and Farrenkopf 1995), which provided the format for FIA inventory data prior to the FIADB. Cull trees are distributed across similar diameter ranges as growing-stock trees with proportionally more rough cull at smaller diameters. We focused on trees less than 40 cm d.b.h. because most trees are in this size range. The ratio of volume for cull to volume for growing stock changed slightly with diameter, but we used average ratios over the range of 25 to 40 cm. We plotted values for the net volume of wood in the central stem (the variable NETCFVL in the Eastwide and Westwide databases) as functions of d.b.h. for growing stock, rough cull, and rotten cull for the broad classifications of hardwood vs. softwood, and for the Eastern vs. Western United States. Volumes of cull trees are consistently less than those for growing stock.

The tree classification rough cull (TREECLCD=3) can be based on form defect or identity as a noncommercial species. No adjustments were made in applying the individual-tree biomass equations to rough cull of noncommercial species. We did adjust mass for such trees where the classification was based on form defect. The adjustment was based on the assumption that defect may reduce the volume of rough cull proportionally more than biomass. The ratio of volume for rough cull to volume for growing stock obtained from FIA tree data was 0.74 and 0.64 for hardwoods and softwoods in the East, respectively. The ratio of volume for rough-cull trees to volume for growing stock was 0.64 and 0.42 for hardwoods and softwoods in the West. We assumed that 25 percent of the volume reduction of cull trees (that is, compared to volume for regular growing stock) reduced the biomass of the tree, and adjusted the estimated biomass for the cull trees by this factor. For example, in the East, volume was 26 percent lower for rough-cull hardwoods relative to growing-stock volume. We apply 25 percent of this reduction (0.26 x 0.25 = 0.06) to the mass of a cull tree by reducing the estimated mass of a noncull live tree by 6 percent. The net effect of these assumptions was reductions in bole mass of 6 and 9 percent for hardwoods and softwoods in the East, respectively, and of 9 and 14 percent for hardwoods and softwoods in the West.

The tree classification of rotten cull (TREECLCD=4) is based on threshold levels of rot in bole wood. We adjusted mass for rotten cull by applying assumptions about the extent of rot to ratios of volume in rotten culls to volume in growing stock. This was similar to the way in which we adjusted mass for rough cull. The ratio of volume for rotten-cull trees to volume for growing stock obtained from FIA tree data was 0.42 and 0.30 for hardwoods and softwoods in the East, respectively, and 0.40 and 0.22 for hardwoods and softwoods in the West. We assumed that more than 50 percent of the volume reduction had some degree of rot. Of this volume reduction, we assumed 75 percent was rotten wood that was assumed to have lost 45 percent of its mass, or specific gravity, depending on the state of decay (Heath and Chojnacky 2001). Multiplying these factors produced an adjustment factor for the estimated biomass for rotten-cull trees. For example, volume was 58 percent lower for rotten-cull hardwoods in the East (relative to volume of growing stock). If 75 percent of this volume was missing 45 percent of its intact mass, overall bole-wood mass was reduced by 20 percent (0.58 x 0.75 x 0.45 = 0.20). Total-tree mass was adjusted by reducing wood mass by 20 percent. The net effect of these assumptions was reductions in bole-wood mass of 20 and 24 percent for hardwoods and softwoods in the East, respectively, and 20 and 26 percent for hardwoods and softwoods in the West.

To summarize, adjusting the tree mass estimates from the individual-tree biomass equations to account for cull-tree mass depends on our assumptions. The assumptions that likely had the greatest effect were that: 1) cull trees have a lower bole mass than a tree of the same diameter, and 2) differences in volume between rotten cull and growing stock were represented by woody mass that was 75 percent rotten. The low precision in values subtracted from bole mass reflects the level of information available. However, these differences in individual-tree mass have little impact on total-tree biomass at regional and national level summaries because they represent only several percent of density of the mass of all trees.

Equations for Estimating Density of Forest-Tree Mass

Applying the individual-tree biomass equations to FIA trees and summarizing to the plot produces paired values of growing-stock volume density (m^3/ha) and tree-mass density (Mg/ha) on each plot. After sorting the plot-level summary data according to region and forest classification, we developed regression-based estimates of mass density as predicted by growing-stock volume. Stand age was considered as a candidate predictor variable for regression. However, the poor relationship shown in Figure 3 for some northeastern hardwoods is typical of many forest types. Thus, stand age was dropped from consideration.

As mentioned earlier, preliminary regression analyses were performed to help establish a classification scheme for forest types. Second-order polynomial regressions were useful in classifying forest types, particularly in identifying effects of ownership and productivity. The polynomial model worked initially because we were interested only in the initial slope of the relationship. We

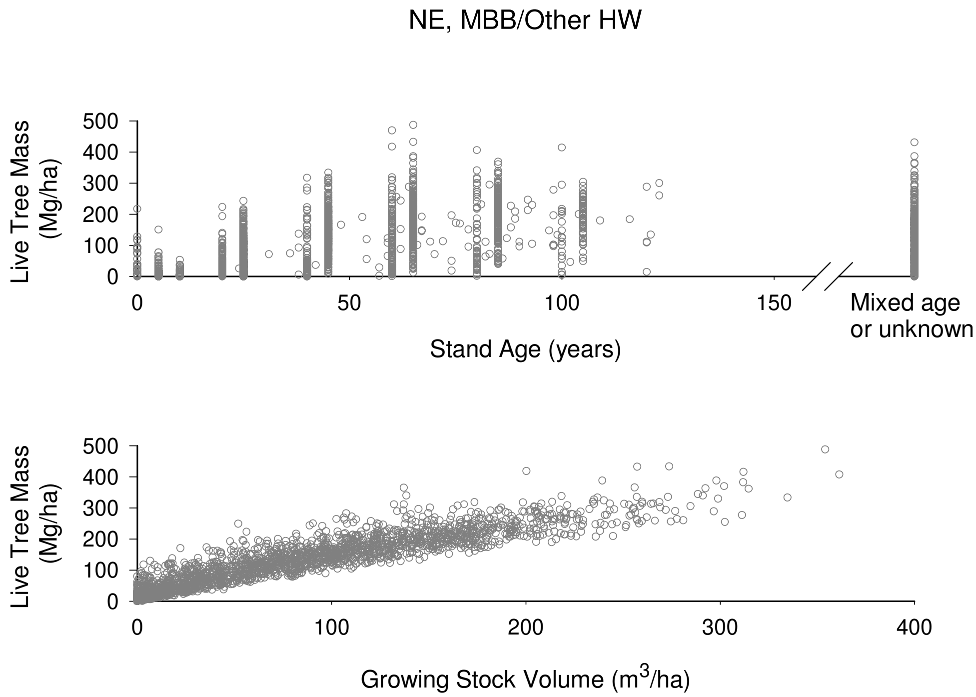


Figure 3.—Mean live-tree mass density per FIA plot as function of stand age (upper graph) and growing-stock volume (lower graph) for NE MBB/Other HW forests. The same set of FIA inventory plots contributed to each graph. However, 23 percent of points were classified as mixed or unknown age in the upper graph.

restricted analyses to points below the 75th percentile of growing-stock volumes. Analyses of covariance with the second-order polynomial model and ownership or productivity as the class variable identified the importance of ownership for some forest types (Table 1). However, the sign and the magnitude of the quadratic effect coefficient often produced unrealistic estimates relative to other important assumptions about the volume and biomass relationship. Thus, this regression form was not useful for further development of stand-level estimates, so we adopted a different equation form for the analyses.

Live trees

Several candidate linear and nonlinear models were considered for the regression estimates of live-tree mass density. A form of the Chapman-Richards growth equation (Clutter and others 1983) was selected primarily because of its flexibility in the shape of the initial portion of the curve and the continuous decrease in slope at greater volumes. Although this relationship usually describes net growth (for example, of populations), it was suitable for our purpose. We added an intercept term because the usual form of the Chapman-Richards equation is forced through the origin, but tree biomass is expected to remain greater than zero as growing-stock volume approaches zero. The addition of the intercept meant that four coefficients were estimated. Nonlinear regression (Proc NLIN in SAS) was used to determine values for these coefficients. Estimates of regression coefficients showed that the coefficient determining the shape of the initial portion of the curve was unimportant. Thus, the regression was changed to essentially an exponential model with a non-zero intercept, and mean mass density of live trees is estimated by:

$$\text{Live-tree mass density} = F \cdot (G + (1-e^{(-volume/H)}))$$

where volume is in m^3/ha and coefficients F, G, and H are estimated using nonlinear regression. Because some fixed-radius FIA plots are assigned to more than one condition class (CONDID), the number of trees per area represented by each tree can vary within a plot. Thus, the proportion of plot in each condition (CONDPROP) is used as a weighting variable in the regressions.

In addition to estimates of total (hardwood plus softwood) tree mass, we develop separate estimates for live-tree mass of hardwood and softwood species within each forest type based on their respective growing stock. We estimate absolute mass density of hardwoods and softwoods rather than model hardwoods and softwoods as a percentage of total mass. We chose this method over modeling percentages to avoid regressions with skewed data, as would be expected with high or low percentages. A disadvantage of estimating components with separate independent and dependent variables is that individual predictions of hardwood and softwood mass may not sum to total mass, which is estimated separately.

Standing dead trees

Mean mass density of standing dead trees is estimated by fitting nonlinear regressions to the FIA plot-level ratio of the mass of standing dead to predicted live-tree mass (Fig. 4). A three-parameter Weibull function is used to model this ratio, which generally decreases with increasing live growing stock-volume. Regression procedures and weighting are the same as for estimating live mass. The basic form of the equation is:

$$\text{Dead-tree mass density} = (\text{Estimated live-tree mass density}) \cdot A \cdot e^{(-((\text{volume}/B)^\wedge C))}$$

where live-tree mass density is in Mg/ha, volume is in m^3/ha, and coefficients A, B, and C are estimated using nonlinear regression.

Applying the estimates

Interest in biomass and carbon mass often focuses on specific subsets of the entire forest system (Birdsey 1992; Watson and others 2000). Hence, we developed estimates of specific subsets of total-tree mass. This approach was extended to provide estimates for both the entire tree — including coarse roots — and the aboveground portion only. Similarly, hardwood or softwood live-tree mass density can be estimated separately from hardwood or softwood growing-stock volume. Carbon mass or carbon dioxide equivalents often are the quantities of interest where tree-mass estimates extend beyond converting from merchantable-wood volumes. Carbon mass is about 50 percent of wood dry weight; more precise values for carbon content depend on the identity of the species and tissue or part of the tree.

Several units are used in reporting estimates of forest carbon, so the results can be confusing. The use of metric units internationally but English units in the United States has resulted in hybrid measures, for example, metric tons/acre. For clarity, values taken from the FIADB are in the original units, for example, inches for d.b.h. Our analysis was conducted in metric units so our results generally are expressed in those units. International discussions of greenhouse gas inventories (Watson and others 2000) in which the United States has participated for many years report carbon mass in tonnes (t) and megagrams (Mg), which are identical values (also defined as 10^3 kg and 10^6 g, respectively). Larger aggregate values of mass are reported as teragrams (10^{12} g) and petagrams (10^{15} g). Area is in hectares (10,000 m^2).

Results and Discussion

Model Parameters

Coefficients for estimating mean tree-mass densities are provided in Tables 3 through 10 (pages 12-31) by stand component, region, and forest type. In the Appendix, examples from Tables 3 and 4 are illustrated in Figures 5 through 62. The mass of live and dead trees can be estimated for the full tree (including coarse roots) or aboveground only. All the forest types listed in Table 1 are represented in Tables 3-10. However, some sets of coefficients are not based on type-specific regressions. Estimates for the Nonstocked and Pinyon/Juniper forest types are simply means from the FIA plots. Pinyon/Juniper averages are based on all FIA plots of that type across the West. Type-specific regression estimates were not possible for several forest types. For example, nonlinear procedures failed to fit coefficients for hardwood tree mass in a publicly owned lodgepole pine forest in the Pacific Northwest Eastside (PWE) region. We substituted regression-based estimates of hardwood components in all softwood forests of PWE. See table footnotes for cases in which regional summary values were substituted for type-specific regression equations.

Estimates of some components of forest-tree mass are based on regressing over data points that tend to be grouped near the origin. For example, this occurs in hardwood species of western pine forests or softwoods in northern hardwood forests. In such cases, the regressions are applicable over a limited range of growing-stock volumes. For this reason, the tables of coefficients also provide an indication of the upper end of the range of growing stock volume that contributed to the coefficient estimates. We also provide the mean square error of the regression models and the number of FIA plot summaries that contributed to each regression.

The use of remeasured FIA plots and the substitution of estimates from other forest types when necessary can affect estimates of mass density. This effect is most likely for mass density of standing dead trees because fewer regressions for standing dead trees successfully estimated parameters without pooling forest types within a region. The effect of these assumptions in our model will be a major part of any difference between our estimates and the direct application of the individual-tree biomass equations of Jenkins and others (in press) to FIADB tree data. However, dead mass is a small part of overall tree

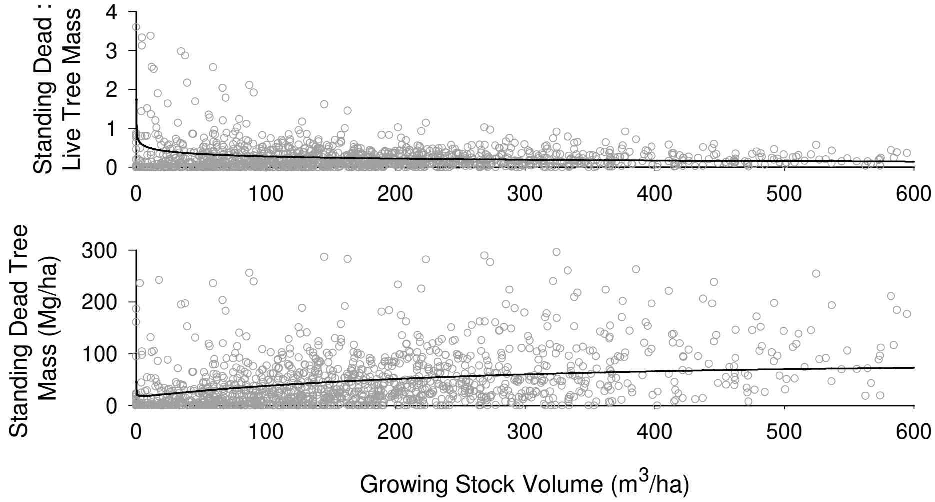


Figure 4.—Estimates of the ratio of the mass of standing dead tree to predicted live-tree mass (upper graph) and estimate of standing dead tree mass (lower graph) for RMS Fir-Spruce forests (individual points are plot-level density summaries).

mass, as illustrated in Figure 4 and Appendix Figures 5 through 62.

Comparing Alternate Estimates of Total-Tree Biomass

We maintained many separate and distinct forest types when developing our estimates. This is possible largely because of the set of individual-tree biomass equations. Both species composition and other characteristics of stand structure, such as tree size and stem density, can affect tree-mass density. The equations in Tables 3-10 are based on linked datasets and regression models, so they can be updated easily as the FIADB is updated. We structured our classifications to conform to commonly used forest types and regions such as are used in timber projection models. A key point was maintaining flexibility for application back to historical data and forward to forest projections.

We compared estimates of average biomass density among four relatively separate sets of estimates (Table 11, page 32). All forest types were classified as hardwood or softwood to facilitate comparison; Nonstocked and Pinyon/Juniper types were excluded from this summary. These values are described as average tree-mass density because total biomass was estimated for large areas by forest type and then divided by the total area. Estimates were developed from: 1) our analysis, 2) the biomass information included as part of the FIADB, 3) summaries developed by Birdsey (1992), and 4) the biomass expansion factors developed by Brown and others (1997, 1999).

Consistent sets of results were developed for making the comparisons in Table 11. All sets were based on the same dataset of plot and tree information extracted from the FIADB in March 2002. Estimates were for live trees, aboveground only; all live trees at least 1 inch d.b.h. were included. Estimates taken directly from the FIADB were based on the variable DRYBIOT. The estimates from Birdsey (1992) were derived by applying information in Tables 1.1 and 1.2 to plot-level summaries of hardwood and softwood growing-stock volume by forest type and region. Similarly, the estimates of Brown and others (1999) were by applying the three biomass expansion factors to plot-level summaries of growing-stock volume by forest type. Estimates of Birdsey (1992) and Brown and others (1999) were calibrated with some reference to Eastwide or Westwide data at different times. The same is true of preliminary analysis of our estimates.

There were similarities between our method and that of Schroeder and others (1997) and Brown and others (1999). Both included constraints on the regression line at greater volumes; that is, both featured asymptotic limits to increasing biomass at large growing-stock volumes. Additionally, both were based on a regression of estimated biomass on growing stock-volume. However, the regression models were slightly different. We estimate mass density directly from growing-stock volume. Schroeder and others (1997) and Brown and others (1999) included an additional step of calculating a biomass expansion factor; we believe that step is useful only when comparing ratios. The biomass expansion factors also were undefined at zero volume, while the direct relationship of volume to mass density provided an estimate of mass at zero volume. Finally, we developed equations for mass of live and dead trees for a number of forest types in the United States; previous literature focused on the live biomass of several eastern forest types.

Suitability of Equations and Spatial Scale

The estimates developed here are likely to be applied at a range of spatial scales that sometimes differ greatly from those of the FIA plots used as the bases for regressions. For example, biomass predictions based on the full set of FIA forest plots or plot-level RPA data (a component of the 1997 RPA forest dataset; Smith and others 2001) are at the same scale as the original regressions, so scaling is not a likely source of systematic error. By contrast, biomass predictions associated with the linked forest models ATLAS and FORCARB are applied to volume of growing stock aggregated over areas of tens to hundreds of thousand hectares—one to two orders of magnitude larger than the FIA plots used in developing the regressions.

Applying these equations at a different scale might result in systematic error (Rastetter and others 1992). Although both independent and dependent variables are expressed per unit area, the predictions are scale-dependent because volume and biomass densities can be averaged over different areas from one prediction to the next. For example, aggregating FIA plot summary values to county, unit, or state levels and then applying the equations may produce average volume-mass density paired values on the concave side of a regression fit to the FIA plot-scale values. This could result in lower estimates of biomass for many forest types. This form of bias is unlikely when these predictors are applied to ATLAS/FORCARB summary values because such aggregation in ATLAS is systematic rather than random. Forest volumes and areas are classified by age class prior to aggregation; thus, samples are effectively stratified. Specific information on aggregation of forest areas, for example, by ATLAS/FORCARB, can offset this potential bias through: 1) quantification of possible systematic error, and 2) modification of regression to reflect specific levels of aggregation. In fact, preliminary analyses indicate that applying our equations at scales greater than plot level, for example, UNIT or COUNTY, produces estimates that are within 5 percent of the actual value. This effect is from essentially random aggregation—any bias associated with stratified aggregation is likely to be considerably less. Thus, for most purposes, these equations can be applied at more aggregated spatial scales with only negligible error.

Continuing Research

The most immediate application of the estimates of tree-mass density is shown in Table 12 (page 33), which includes mass totals obtained from applying estimates to 1997 RPA forest data (Smith and others 2001). Current research is focused on extending these for more general applicability and links to other models or forest assessments. Carbon estimators based on alternate forest classification schemes as well as estimates of uncertainty in these values will be available in subsequent publications. We also are considering alternate approaches to modeling mass for standing dead trees. Specifically, gaps in recording or expanding tree data for dead trees need to be addressed – this likely would reduce bias for under representing dead stems.

Table 3.—Coefficients for estimating mass density of live trees (above- and belowground, Mg/ha) by type, region, and owner (as appropriate); *F*, *G*, and *H* are coefficients; *n* = number of FIA plots; *mse* = mean squared error of the prediction relative to individual plots; *volume limit* (m^3/ha) = 99th percentile of growing-stock volumes within each set of FIA plots (upper limit of independent variables in the regressions)[a]

Forest type	F	G	H	n	mse	Volume limit
		NE				
Aspen-Birch	508.5	0.0361	397.4	264	510	250
MBB/Other HW (Priv.)	425.3	0.0476	254.7	2302	936	273
MBB/Other HW (Publ.)	558.4	0.0276	374.7	362	1140	342
Oak-Hickory	488.2	0.0509	312.8	3314	1262	306
Oak-Pine	369.0	0.0490	245.5	304	656	268
Other Pine	715.5	0.0348	697.2	295	595	304
Spruce-Fir	306.4	0.0419	156.3	236	524	237
WRJ-Pine	415.6	0.0349	276.1	398	1056	354
Nonstocked	5.8	0.0000	0.0	14	19	10
		NLS				
Aspen-Birch	362.5	0.0524	270.1	8072	568	239
Lowland HW (Priv.)	505.2	0.0419	359.1	1322	858	223
Lowland HW (Publ.)	744.5	0.0229	555.0	662	570	281
MBB	350.0	0.0496	187.0	5871	1077	259
Oak-Hickory	364.8	0.0755	186.1	2049	1136	238
Pine	432.1	0.0346	373.2	2056	548	280
Spruce-Fir	391.9	0.0582	278.8	4926	647	217
Nonstocked	8.5	0.0000	0.0	83	466	119
		NPS				
Conifer	583.1	0.0482	577.4	256	569	236
Lowland HW	1192.0	0.0284	988.5	1030	1378	303
MBB	465.9	0.0725	321.6	1682	1223	252
Oak-Hickory	1012.1	0.0393	727.6	2516	1437	243
Oak-Pine	255.9	0.1240	157.6	172	1011	200
Nonstocked	22.9	0.0000	0.0	41	903	71
		SC				
Bottomland HW (Priv.)	314.5	0.1091	174.9	2092	1528	309
Bottomland HW (Publ.)	313.5	0.1022	147.9	295	1379	329
Natural Pine (Priv.)	358.3	0.0935	421.9	1620	811	321
Natural Pine (Publ.)	363.1	0.1133	480.0	448	838	373
Oak-Pine	282.3	0.0904	197.4	2000	922	265
Other Conifer	162.6	0.1869	85.5	72	792	208
Planted Pine	161.8	0.1398	116.1	1477	578	265
Upland HW (Priv.)	229.7	0.1533	112.2	3934	1399	204
Upland HW (Publ.)	285.9	0.0977	140.7	481	1094	252
Nonstocked	56.5	0.0000	0.0	19	2679	8
		SE				
Bottomland HW (Priv.)	963.2	0.0261	800.4	2516	2176	453
Bottomland HW (Publ.)	429.2	0.0573	291.6	334	2268	427
Natural Pine (Priv.)	356.4	0.0429	340.9	2892	541	382
Natural Pine (Publ.)	1213.0	0.0140	1610.1	662	689	357
Oak-Pine	420.1	0.0353	309.8	2307	660	347

Continued

Table 3.—continued.

Forest type	F	G	H	n	mse	Volume limit
Other Conifer	324.8	0.0233	201.1	145	1000	397
Planted Pine	226.4	0.0670	183.7	3865	413	267
Upland HW (Priv.)	417.4	0.0618	283.8	5071	1156	334
Upland HW (Publ.)	405.2	0.0915	260.0	779	1890	336
Nonstocked	56.5	0.0000	0.0	74	4515	214
		PSW				
Douglas-fir	2094.3	0.0164	2177.5	93	3605	1090
Fir-Spruce	897.3	0.0108	773.5	51	1445	1020
Hardwoods	1463.7	0.0000	1119.4	695	6812	639
Other Conifer	1323.8	0.0372	1480.6	795	2864	687
Pinyon-Juniper	58.0	0.0000	0.0	6335	2165	48
Redwood	4409.2	0.0124	6562.8	108	3639	1691
Nonstocked	35.7	0.0000	0.0	18	601	119
		PWE				
Douglas-fir (Priv.)	653.6	0.0168	572.1	226	719	488
Douglas-fir (Publ.)	3234.5	0.0000	3884.9	972	1564	636
Fir-Spruce (Priv.)	615.3	0.0129	561.6	95	870	496
Fir-Spruce (Publ.)	4480.5	0.0000	5880.2	1213	2512	761
Hardwoods	614.0	0.0534	660.4	46	2856	292
Lodgepole Pine (Priv.)	368.2	0.0195	390.1	65	289	325
Lodgepole Pine (Publ.)	692.3	0.0111	975.0	835	699	389
Ponderosa Pine (Priv.)	378.5	0.0178	330.0	262	425	336
Ponderosa Pine (Publ.)	1504.1	0.0058	2042.9	1939	331	402
Pinyon-Juniper	58.0	0.0000	0.0	6335	2165	48
Nonstocked	13.6	0.0000	0.0	49	357	293
		PWW				
Douglas-fir (Priv.)	1191.2	0.0187	1251.2	1032	1781	913
Douglas-fir (Publ.)	5062.8	0.0052	6830.2	2106	3510	1626
Fir-Spruce (Priv.)	793.9	0.0165	754.4	123	1305	835
Fir-Spruce (Publ.)	1837.9	0.0122	2418.7	776	3399	1517
Other Conifer	6695.1	0.0043	10108.6	158	748	616
Other Hardwoods	16854.7	0.0021	20533.0	512	2867	858
Red Alder	3100.3	0.0101	4587.8	557	1208	719
Western Hemlock	2017.5	0.0196	2967.6	963	3894	1556
Nonstocked	27.1	0.0000	0.0	49	2025	304
		RMN				
Douglas-fir	592.8	0.0415	503.8	3122	2389	526
Fir-Spruce	913.3	0.0225	960.9	1820	1684	578
Hardwoods	427.8	0.0526	374.6	243	642	243
Lodgepole Pine	422.1	0.0488	519.3	1381	967	491
Other Conifer	671.2	0.0314	544.4	273	1166	360
Ponderosa Pine	481.7	0.0263	484.2	889	483	401
Pinyon-Juniper	58.0	0.0000	0.0	6335	2165	48
Nonstocked	41.0	0.0000	0.0	78	1381	79
		RMS				
Douglas-fir	835.8	0.0461	703.2	833	1658	491
Fir-Spruce	764.4	0.0342	658.6	1371	1656	574

Continued

Table 3.—continued.

Forest type	F	G	H	n	mse	Volume limit
Hardwoods	669.7	0.0538	621.4	1712	1127	337
Lodgepole Pine	452.7	0.0581	567.6	533	907	422
Other Conifer	378.1	0.0326	234.1	263	1409	500
Ponderosa Pine (Priv.)	436.7	0.0556	399.8	585	658	289
Ponderosa Pine (Publ.)	353.0	0.0673	350.5	1192	624	321
Pinyon-Juniper	58.0	0.0000	0.0	6335	2165	48
Nonstocked	26.2	0.0000	0.0	620	1929	39

[a]Prediction of mass density of live trees based on the following equation: Live mass density (Mg/ha) = F*(G+(1-exp(-volume/H))). If coefficient H equals 0, then F is the predicted value, which is the mean for that forest type (units for F are then Mg/ha).

Table 4.—Coefficients for estimating mass density of standing dead trees (above- and belowground, Mg/ha) by type, region, and owner (as appropriate); *A*, *B*, and *C* are coefficients; *n* = number of FIA plots; *mse* = mean squared error of the prediction relative to individual plots; *volume limit* (m^3/ha) = 99th percentile of growing-stock volumes within each set of FIA plots (upper limit of independent variables in the regressions)[a]

Forest type	A	B	C	n	mse	Volume limit
		NE				
Aspen-Birch [b]	0.0436	704.78	3.506	264	12	250
MBB/Other HW (Priv.) [c]	0.1189	240.36	2.391	2302	143	273
MBB/Other HW (Publ.) [c]	0.1189	240.36	2.391	362	151	342
Oak-Hickory	0.0610	459.83	1.617	3314	137	306
Oak-Pine	0.0605	342.95	2.044	304	83	268
Other Pine [d]	0.1334	228.25	1.368	295	73	304
Spruce-Fir [d]	0.1334	228.25	1.368	236	47	237
WRJ-Pine [d]	0.1334	228.25	1.368	398	94	354
Nonstocked	9.9137	0.00	0.000	14	98	10
		NLS				
Aspen-Birch	0.4176	127.05	0.426	8072	342	239
Lowland HW (Priv.)	0.5147	97.24	0.642	1322	1894	223
Lowland HW (Publ.)	1.8111	1.00	0.149	662	3291	281
MBB[c]	0.1189	240.36	2.391	5871	524	259
Oak-Hickory	0.1888	329.05	0.432	2049	269	238
Pine	0.3818	7.48	0.156	2056	132	280
Spruce-Fir	0.1517	415.08	1.088	4926	221	217
Nonstocked	9.9137	0.00	0.000	83	418	119
		NPS				
Conifer	0.0396	287.04	11.740	256	79	236
Lowland HW	0.1178	220.67	1.409	1030	276	303
MBB	0.1006	164.17	1.145	1682	151	252
Oak-Hickory	0.0589	339.57	1.892	2516	151	243

Continued

Table 4.—continued.

Forest type	A	B	C	n	mse	Volume limit
Oak-Pine	0.0594	127.97	1.382	172	83	200
Nonstocked	14.7956	0.00	0.000	41	464	71
		SC				
Bottomland HW (Priv.)	0.1493	145.42	0.484	2092	147	309
Bottomland HW (Publ.)	0.3291	30.12	0.305	295	242	329
Natural Pine (Priv.)	0.0550	424.29	1.901	1620	55	321
Natural Pine (Publ.)	0.0467	974.52	1.355	448	61	373
Oak-Pine	0.0622	835.98	0.892	2000	67	265
Other Conifer	0.0457	116.64	4.311	72	30	208
Planted Pine	0.0631	5137.75	0.136	1477	29	265
Upland HW (Priv.)	0.0666	315.70	1.314	3934	82	204
Upland HW (Publ.)	0.0616	313.09	2.438	481	91	252
Nonstocked	3.6926	0.00	0.000	19	29	8
		SE				
Bottomland HW (Priv.) [e]	0.0774	347.43	1.104	2516	112	453
Bottomland HW (Publ.) [e]	0.0774	347.43	1.104	334	204	427
Natural Pine (Priv.) [e]	0.0510	826.84	1.353	2892	42	382
Natural Pine (Publ.) [e]	0.0510	826.84	1.353	662	31	357
Oak-Pine [e]	0.0510	826.84	1.353	2307	42	347
Other Conifer [e]	0.0510	826.84	1.353	145	44	397
Planted Pine [e]	0.0510	826.84	1.353	3865	18	267
Upland HW (Priv.) [e]	0.0774	347.43	1.104	5071	80	334
Upland HW (Publ.) [e]	0.0774	347.43	1.104	779	128	336
Nonstocked	3.6926	0.00	0.000	74	136	214
		PSW				
Douglas-fir [f]	0.2840	848.73	0.379	93	1737	1090
Fir-Spruce [f]	0.2840	848.73	0.379	51	1106	1020
Hardwoods [f]	1.0478	2.67	0.230	695	287	639
Other Conifer [f]	0.2840	848.73	0.379	795	937	687
Pinyon-Juniper	5.1131	0.00	0.000	6335	134	48
Redwood [f]	0.2840	848.73	0.379	108	2273	1691
Nonstocked	2.4773	0.00	0.000	18	99	119
		PWE				
Douglas-fir (Priv.)	0.1005	401.57	1.175	226	491	488
Douglas-fir (Publ.)	8.4407	1.00	0.313	972	1074	636
Fir-Spruce (Priv.) [g]	4.7263	1.00	0.205	95	3905	496
Fir-Spruce (Publ.)[g]	4.7263	1.00	0.205	1213	1904	761
Hardwoods	0.9233	1.00	0.585	46	362	292
Lodgepole Pine (Priv.) [g]	0.3081	422.52	0.868	65	912	325
Lodgepole Pine (Publ.) [g]	0.3081	422.52	0.868	835	655	389
Ponderosa Pine (Priv.) [g]	0.8898	3.11	0.178	262	2050	336
Ponderosa Pine (Publ.) [g]	0.8898	3.11	0.178	1939	365	402
Pinyon-Juniper	5.1131	0.00	0.000	6335	134	48
Nonstocked	27.1975	0.00	0.000	49	2162	293
		PWW				
Douglas-fir (Priv.) [f]	0.2840	848.73	0.379	1032	1440	913
Douglas-fir (Publ.) [f]	0.2840	848.73	0.379	2106	4218	1626

Continued

Table 4.—continued.

Forest type	A	B	C	n	mse	Volume limit
Fir-Spruce (Priv.) [f]	0.2840	848.73	0.379	123	1825	835
Fir-Spruce (Publ.) [f]	0.2840	848.73	0.379	776	3413	1517
Other Conifer	0.6505	1.76	0.132	158	244	616
Other Hardwoods [f]	1.0478	2.67	0.230	512	1078	858
Red Alder	0.3107	1.00	0.128	557	1485	719
Western Hemlock [f]	0.2840	848.73	0.379	963	5392	1556
Nonstocked	2.4773	0.00	0.000	49	1768	304
		RMN				
Douglas-fir [h]	1.9177	1.00	0.197	3122	1054	526
Fir-Spruce	2.1076	1.00	0.155	1820	2118	578
Hardwoods	0.1906	284.53	1.030	243	250	243
Lodgepole Pine	3.6764	1.00	0.235	1381	946	491
Other Conifer	0.7495	111.08	0.927	273	1742	360
Ponderosa Pine [h]	1.9177	1.00	0.197	889	388	401
Pinyon-Juniper	5.1131	0.00	0.000	6335	134	48
Nonstocked	15.8190	0.00	0.000	78	1622	79
		RMS				
Douglas-fir	0.6134	1.00	0.100	833	813	491
Fir-Spruce	1.7428	2.70	0.166	1371	2464	574
Hardwoods	0.1441	811.36	1.448	1712	316	337
Lodgepole Pine [h]	1.9177	1.00	0.197	533	1004	422
Other Conifer	0.4705	128.54	0.324	263	1183	500
Ponderosa Pine (Priv.)	0.5260	1.00	0.186	585	144	289
Ponderosa Pine (Publ.)	0.1986	238.44	0.415	1192	328	321
Pinyon-Juniper	5.1131	0.00	0.000	6335	134	48
Nonstocked	10.0360	0.00	0.000	620	1327	39

[a]Prediction of mass density of standing dead trees based on the following equation: Standing dead mass density (Mg/ha) = (predicted live-tree mass density)*A*exp(-((volume/B)^{C})). If coefficient C equals 0, then A is the predicted value, which is the mean for that forest type (units for A are then Mg/ha).
[b]From pooled hardwood forests in NE.
[c]From pooled MBB/Other HW forests in NE and MBB forests in NLS.
[d]From pooled softwood forests in North (NE, NLS, and NPS).
[e]From pooled softwood or hardwood forests in South (SC and SE).
[f]From pooled softwood or hardwood forests in Pacific Northwest (PWW and PWE).
[g]From pooled private and public ownerships.
[h]From pooled softwood forests in Rocky Mountains (RMN and RMS).

Table 5.—Coefficients for estimating mass density of live trees (aboveground only, Mg/ha) by type, region, and owner (as appropriate); *F*, *G*, and *H* are coefficients; *n* = number of FIA plots; *mse* = mean squared error of the prediction relative to individual plots; *volume limit* (m^3/ha) = 99th percentile of growing-stock volumes within each set of FIA plots (upper limit of independent variables in the regressions)[a]

Forest type	F	G	H	n	mse	Volume limit
		NE				
Aspen-Birch	438.5	0.0347	410.7	264	351	250
MBB/Other HW (Priv.)	357.4	0.0470	255.1	2302	658	273
MBB/Other HW (Publ.)	473.3	0.0272	379.5	362	806	342
Oak-Hickory	412.5	0.0502	314.8	3314	890	306
Oak-Pine	310.1	0.0482	247.8	304	457	268
Other Pine	594.5	0.0342	699.3	295	408	304
Spruce-Fir	252.5	0.0413	155.6	236	354	237
WRJ-Pine	344.1	0.0345	274.9	398	736	354
Nonstocked	4.8	0.0000	0.0	14	13	10
		NLS				
Aspen-Birch	304.5	0.0516	270.8	8072	397	239
Lowland HW (Priv.)	430.9	0.0411	366.8	1322	603	223
Lowland HW (Publ.)	645.4	0.0220	577.2	662	399	281
MBB	293.8	0.0491	187.2	5871	759	259
Oak-Hickory	307.5	0.0748	186.9	2049	806	238
Pine	358.7	0.0343	375.4	2056	381	280
Spruce-Fir	325.8	0.0569	280.8	4926	435	217
Nonstocked	7.1	0.0000	0.0	83	329	119
		NPS				
Conifer	501.1	0.0463	601.4	256	395	236
Lowland HW	1016.1	0.0279	1002.5	1030	973	303
MBB	394.7	0.0715	324.5	1682	862	252
Oak-Hickory	864.5	0.0384	740.0	2516	1014	243
Oak-Pine	213.3	0.1234	157.6	172	707	200
Nonstocked	19.1	0.0000	0.0	41	635	71
		SC				
Bottomland HW (Priv.)	263.0	0.1085	173.3	2092	1083	309
Bottomland HW (Publ.)	263.8	0.1011	147.9	295	977	329
Natural Pine (Priv.)	297.4	0.0926	422.4	1620	561	321
Natural Pine (Publ.)	301.3	0.1121	479.3	448	586	373
Oak-Pine	236.8	0.0893	198.8	2000	646	265
Other Conifer	136.8	0.1843	87.5	72	545	208
Planted Pine	134.4	0.1380	117.5	1477	393	265
Upland HW (Priv.)	193.5	0.1521	112.8	3934	988	204
Upland HW (Publ.)	241.0	0.0968	141.4	481	773	252
Nonstocked	47.4	0.0000	0.0	19	1887	8
		SE				
Bottomland HW (Priv.)	808.6	0.0258	801.6	2516	1553	453
Bottomland HW (Publ.)	359.9	0.0567	291.6	334	1618	427
Natural Pine (Priv.)	296.9	0.0423	344.1	2892	374	382
Natural Pine (Publ.)	1044.8	0.0133	1680.6	662	480	357
Oak-Pine	352.9	0.0347	312.4	2307	462	347

Continued

Table 5.—continued.

Forest type	F	G	H	n	mse	Volume limit
Other Conifer	268.5	0.0223	199.6	145	699	397
Planted Pine	187.3	0.0662	184.9	3865	281	267
Upland HW (Priv.)	352.6	0.0609	285.8	5071	816	334
Upland HW (Publ.)	342.3	0.0904	261.8	779	1337	336
Nonstocked	47.4	0.0000	0.0	74	3195	214
		PSW				
Douglas-fir	1719.4	0.0164	2155.5	93	5861	1090
Fir-Spruce	741.8	0.0107	776.3	51	4177	1020
Hardwoods	1244.6	0.0000	1142.2	695	4813	639
Other Conifer	1127.0	0.0368	1536.5	795	3054	687
Pinyon-Juniper	47.9	0.0000	0.0	6335	1470	48
Redwood	3738.2	0.0122	6752.8	108	8123	1691
Nonstocked	34.7	0.0000	0.0	18	557	119
		PWE				
Douglas-fir (Priv.)	540.6	0.0167	575.1	226	1603	488
Douglas-fir (Publ.)	2757.3	0.0000	4024.8	972	2556	636
Fir-Spruce (Priv.)	507.7	0.0127	562.3	95	1731	496
Fir-Spruce (Publ.)	3839.5	0.0000	6123.8	1213	4281	761
Hardwoods	557.1	0.0497	729.3	46	2015	292
Lodgepole Pine (Priv.)	303.4	0.0192	390.5	65	561	325
Lodgepole Pine (Publ.)	577.3	0.0108	989.6	835	1009	389
Ponderosa Pine (Priv.)	312.8	0.0176	331.2	262	727	336
Ponderosa Pine (Publ.)	1256.7	0.0057	2072.9	1939	729	402
Pinyon-Juniper	47.9	0.0000	0.0	6335	1470	48
Nonstocked	13.3	0.0000	0.0	49	332	293
		PWW				
Douglas-fir (Priv.)	984.2	0.0185	1251.5	1032	3659	913
Douglas-fir (Publ.)	4190.5	0.0052	6848.0	2106	9529	1626
Fir-Spruce (Priv.)	658.8	0.0162	757.6	123	2811	835
Fir-Spruce (Publ.)	1523.8	0.0121	2432.5	776	8683	1517
Other Conifer	6139.8	0.0039	11258.9	158	1375	616
Other Hardwoods	10429.2	0.0028	15217.0	512	3891	858
Red Alder	2318.0	0.0111	4085.2	557	1643	719
Western Hemlock	1670.1	0.0194	2977.1	963	8663	1556
Nonstocked	26.3	0.0000	0.0	49	1895	304
		RMN				
Douglas-fir	489.6	0.0413	505.6	3122	1622	526
Fir-Spruce	756.9	0.0223	967.6	1820	1142	578
Hardwoods	351.8	0.0530	366.2	243	450	243
Lodgepole Pine	348.2	0.0483	521.1	1381	649	491
Other Conifer	553.3	0.0313	545.5	273	789	360
Ponderosa Pine	398.4	0.0260	486.1	889	326	401
Pinyon-Juniper	47.9	0.0000	0.0	6335	1470	48
Nonstocked	34.2	0.0000	0.0	78	965	79
		RMS				
Douglas-fir	694.2	0.0457	709.7	833	1128	491
Fir-Spruce	630.6	0.0341	659.0	1371	1125	574

Continued

Table 5.—continued.

Forest type	F	G	H	n	mse	Volume limit
Hardwoods	556.1	0.0539	616.3	1712	783	337
Lodgepole Pine	373.1	0.0577	568.1	533	610	422
Other Conifer	311.6	0.0325	234.3	263	958	500
Ponderosa Pine (Priv.)	363.6	0.0552	405.0	585	450	289
Ponderosa Pine (Publ.)	291.4	0.0671	351.4	1192	424	321
Pinyon-Juniper	47.9	0.0000	0.0	6335	1470	48
Nonstocked	21.9	0.0000	0.0	620	1356	39

[a]Prediction of mass density of live trees based on the following equation: Live mass density (Mg/ha) = F*(G+(1-exp(-volume/H))). If coefficient H equals 0, then F is the predicted value, which is the mean for that forest type (units for F are then Mg/ha).

Table 6.—Coefficients for estimating mass density of standing dead trees (aboveground only, Mg/ha) by type, region, and owner (as appropriate); *A*, *B*, and *C* are coefficients; *n* = number of FIA plots; *mse* = mean squared error of the prediction relative to individual plots; *volume limit* (m^3/ha) = 99th percentile of growing-stock volumes within each set of FIA plots (upper limit of independent variables in the regressions)[a]

Forest type	A	B	C	n	mse	Volume limit
		NE				
Aspen-Birch[b]	0.0439	697.18	3.478	264	9	250
MBB/Other HW (Priv.) [c]	0.1194	240.22	2.383	2302	101	273
MBB/Other HW (Publ.) [c]	0.1194	240.22	2.383	362	106	342
Oak-Hickory	0.0615	459.11	1.609	3314	98	306
Oak-Pine	0.0610	340.62	2.023	304	59	268
Other Pine [d]	0.1340	228.56	1.348	295	50	304
Spruce-Fir [d]	0.1340	228.56	1.348	236	32	237
WRJ-Pine [d]	0.1340	228.56	1.348	398	65	354
Nonstocked	8.2496	0.00	0.000	14	68	10
		NLS				
Aspen-Birch	0.4211	124.38	0.424	8072	240	239
Lowland HW (Priv.)	0.5168	97.30	0.641	1322	1362	223
Lowland HW (Publ.)	1.8157	1.00	0.149	662	2373	281
MBB [c]	0.1194	240.22	2.383	5871	373	259
Oak-Hickory	0.1879	329.99	0.441	2049	191	238
Pine	0.3847	7.12	0.155	2056	90	280
Spruce-Fir	0.1524	416.99	1.069	4926	151	217
Nonstocked	8.2496	0.00	0.000	83	291	119
		NPS				
Conifer	0.0400	286.14	11.668	256	56	236
Lowland HW	0.1189	220.02	1.401	1030	198	303
MBB	0.1015	163.51	1.144	1682	109	252
Oak-Hickory	0.0593	338.68	1.887	2516	109	243
Oak-Pine	0.0605	125.62	1.387	172	60	200

Continued

Table 6.—continued.

Forest type	A	B	C	n	mse	Volume limit
Nonstocked	12.4386	0.00	0.000	41	328	71
		SC				
Bottomland HW (Priv.)	0.1501	144.76	0.483	2092	105	309
Bottomland HW (Publ.)	0.3253	31.65	0.309	295	172	329
Natural Pine (Priv.)	0.0549	425.16	1.880	1620	38	321
Natural Pine (Publ.)	0.0465	1003.34	1.337	448	42	373
Oak-Pine	0.0623	845.84	0.874	2000	46	265
Other Conifer	0.0460	114.35	4.398	72	21	208
Planted Pine	0.0632	3207.56	0.150	1477	19	265
Upland HW (Priv.)	0.0666	315.78	1.313	3934	58	204
Upland HW (Publ.)	0.0615	313.20	2.451	481	65	252
Nonstocked	3.1095	0.00	0.000	19	21	8
		SE				
Bottomland HW (Priv.) [e]	0.0775	348.79	1.102	2516	80	453
Bottomland HW (Publ.) [e]	0.0775	348.79	1.102	334	146	427
Natural Pine (Priv.) [e]	0.0512	868.32	1.265	2892	29	382
Natural Pine (Publ.) [e]	0.0512	868.32	1.265	662	21	357
Oak-Pine [e]	0.0512	868.32	1.265	2307	30	347
Other Conifer [e]	0.0512	868.32	1.265	145	30	397
Planted Pine [e]	0.0512	868.32	1.265	3865	12	267
Upland HW (Priv.) [e]	0.0775	348.79	1.102	5071	57	334
Upland HW (Publ.) [e]	0.0775	348.79	1.102	779	91	336
Nonstocked	3.1095	0.00	0.000	74	97	214
		PSW				
Douglas-fir [f]	0.2794	448.29	0.344	93	1040	1090
Fir-Spruce [f]	0.2794	448.29	0.344	51	792	1020
Hardwoods [f]	1.0857	1.90	0.224	695	172	639
Other Conifer [f]	0.2794	448.29	0.344	795	608	687
Pinyon-Juniper	4.2241	0.00	0.000	6335	92	48
Redwood [f]	0.2794	448.29	0.344	108	1264	1691
Nonstocked	2.0326	0.00	0.000	18	4	119
		PWE				
Douglas-fir (Priv.)	0.0815	402.37	1.171	226	285	488
Douglas-fir (Publ.)	6.8161	1.00	0.312	972	719	636
Fir-Spruce (Priv.) [g]	3.8137	1.00	0.204	95	2585	496
Fir-Spruce (Publ.) [g]	3.8137	1.00	0.204	1213	1276	761
Hardwoods	0.9233	1.00	0.670	46	240	292
Lodgepole Pine (Priv.) [g]	0.2500	430.81	0.872	65	596	325
Lodgepole Pine (Publ.) [g]	0.2500	430.81	0.872	835	440	389
Ponderosa Pine (Priv.) [g]	0.6972	3.79	0.182	262	1340	336
Ponderosa Pine (Publ.) [g]	0.6972	3.79	0.182	1939	246	402
Pinyon-Juniper	4.2241	0.00	0.000	6335	92	48
Nonstocked	22.3113	0.00	0.000	49	1494	293
		PWW				
Douglas-fir (Priv.) [f]	0.2794	448.29	0.344	1032	749	913
Douglas-fir (Publ.) [f]	0.2794	448.29	0.344	2106	2907	1626
Fir-Spruce (Priv.) [f]	0.2794	448.29	0.344	123	683	835

Continued

Table 6.—continued.

Forest type	A	B	C	n	mse	Volume limit
Fir-Spruce (Publ.) [f]	0.2794	448.29	0.344	776	2428	1517
Other Conifer	0.5689	1.15	0.127	158	164	616
Other Hardwoods [f]	1.0857	1.90	0.224	512	697	858
Red Alder	0.1675	1.00	0.059	557	911	719
Western Hemlock [f]	0.2794	448.29	0.344	963	3703	1556
Nonstocked	2.0326	0.00	0.000	49	75	304
		RMN				
Douglas-fir [h]	1.9239	1.00	0.197	3122	719	526
Fir-Spruce	2.1217	1.00	0.155	1820	1447	578
Hardwoods	0.1911	284.22	1.025	243	173	243
Lodgepole Pine	3.7059	1.00	0.235	1381	643	491
Other Conifer	0.7522	110.91	0.929	273	1186	360
Ponderosa Pine [h]	1.9239	1.00	0.197	889	265	401
Pinyon-Juniper	4.2241	0.00	0.000	6335	92	48
Nonstocked	13.0819	0.00	0.000	78	1106	79
		RMS				
Douglas-fir	0.6141	1.00	0.100	833	554	491
Fir-Spruce	1.7483	2.68	0.166	1371	1682	574
Hardwoods	0.1439	817.86	1.456	1712	219	337
Lodgepole Pine [h]	1.9239	1.00	0.197	533	681	422
Other Conifer	0.4729	126.66	0.325	263	807	500
Ponderosa Pine (Priv.)	0.5251	1.00	0.186	585	99	289
Ponderosa Pine (Publ.)	0.1996	235.82	0.414	1192	225	321
Pinyon-Juniper	4.2241	0.00	0.000	6335	92	48
Nonstocked	8.3065	0.00	0.000	620	904	39

[a]Prediction of mass density of standing dead trees based on the following equation: Standing dead mass density (Mg/ha) = (predicted live-tree mass density)*A*exp(-((volume/B)^C)). If coefficient C equals 0, then A is the predicted value, which is the mean for that forest type (units for A are then Mg/ha).
[b]From pooled hardwood forests in NE.
[c]From pooled MBB/Other HW forests in NE and MBB forests in NLS.
[d]From pooled softwood forests in North (NE, NLS, and NPS).
[e]From pooled softwood or hardwood forests in South (SC and SE).
[f]From pooled softwood or hardwood forests in Pacific Northwest (PWW and PWE).
[g]From pooled private and public ownerships.
[h]From pooled softwood forests in Rocky Mountains (RMN and RMS).

Table 7.—Coefficients for estimating mass density of live softwood tree species (above- and belowground, Mg/ha) by type, region, and owner (as appropriate); *F*, *G*, and *H* are coefficients; *n* = number of FIA plots; *mse* = mean squared error of the prediction relative to individual plots; *volume limit* (m^3/ha) = 99th percentile of growing-stock volumes within each set of FIA plots (upper limit of independent variables in the regressions)[a]

Forest type	F	G	H	n	mse	Volume limit
		NE				
Aspen-Birch	73.3	0.0183	38.3	264	58	41
MBB/Other HW (Priv.)	471.3	0.0020	386.6	2302	29	74
MBB/Other HW (Publ.)	175.9	0.0020	135.4	362	49	111
Oak-Hickory	405.3	0.0008	372.8	3314	13	47
Oak-Pine	460.0	0.0149	538.3	304	92	132
Other Pine	1209.8	0.0170	1517.9	295	344	256
Spruce-Fir	334.7	0.0351	220.6	236	356	227
WRJ-Pine	322.1	0.0259	261.2	398	476	279
Nonstocked	0.8	0.0000	0.0	14	7	2
		NLS				
Aspen-Birch	181.8	0.0047	141.4	8072	44	84
Lowland HW (Priv.)	241.7	0.0018	169.8	1322	43	83
Lowland HW (Publ.)	193.5	0.0072	148.0	662	65	85
MBB	318.4	0.0009	230.8	5871	80	121
Oak-Hickory	118.8	0.0034	91.6	2049	18	60
Pine	428.7	0.0281	429.4	2056	341	268
Spruce-Fir	405.6	0.0517	320.0	4926	600	188
Nonstocked	2.5	0.0000	0.0	83	17	18
		NPS				
Conifer	291.9	0.0674	313.1	256	276	182
Lowland HW	109.8	0.0011	96.7	1030	2	12
MBB	36.9	0.0047	22.5	1682	2	15
Oak-Hickory [b]	1438.0	0.0002	1420.2	2516	5	26
Oak-Pine	382.2	0.0321	459.7	172	92	145
Nonstocked	3.0	0.0000	0.0	41	84	56
		SC				
Bottomland HW (Priv.)	342.8	0.0007	383.6	2092	75	184
Bottomland HW (Publ.) [b]	612.6	0.0012	793.0	295	56	85
Natural Pine (Priv.)	403.8	0.0561	655.7	1620	346	302
Natural Pine (Publ.)	396.0	0.0714	746.2	448	250	340
Oak-Pine	127.4	0.0748	177.4	2000	92	168
Other Conifer	105.4	0.1621	74.5	72	298	123
Planted Pine	132.6	0.1393	107.6	1477	404	253
Upland HW (Priv.)	84.4	0.0114	104.6	3934	13	59
Upland HW (Publ.)	57.7	0.0055	65.4	481	14	69
Nonstocked	5.0	0.0000	0.0	19	25	8
		SE				
Bottomland HW (Priv.)	813.1	0.0006	973.8	2516	100	276
Bottomland HW (Publ.)	477.5	0.0036	556.1	334	276	268
Natural Pine (Priv.)	289.6	0.0397	354.2	2892	268	337
Natural Pine (Publ.)	617.7	0.0207	947.1	662	219	303
Oak-Pine	337.1	0.0146	456.4	2307	77	167

Continued

Table 7.—continued.

Forest type	F	G	H	n	mse	Volume limit
Other Conifer	403.5	0.0254	423.4	145	487	386
Planted Pine	213.8	0.0621	200.2	3865	279	261
Upland HW (Priv.)	132.2	0.0042	160.9	5071	10	59
Upland HW (Publ.)	191.7	0.0035	224.6	779	16	71
Nonstocked	5.0	0.0000	0.0	74	121	79
		PSW				
Douglas-fir	3537.8	0.0081	4159.6	93	2610	1008
Fir-Spruce	903.2	0.0110	784.0	51	1480	1020
Hardwoods	726.9	0.0075	735.0	695	356	383
Other Conifer	791.4	0.0115	736.1	795	1063	617
Pinyon-Juniper	56.6	0.0000	0.0	6335	2135	47
Redwood	1974.9	0.0115	2634.0	108	3183	1691
Nonstocked	29.4	0.0000	0.0	18	482	96
		PWE				
Douglas-fir (Priv.)	645.3	0.0156	560.7	226	714	479
Douglas-fir (Publ.)	3364.5	0.0000	4050.1	972	1547	636
Fir-Spruce (Priv.)	709.1	0.0137	686.7	95	867	496
Fir-Spruce (Publ.)	4600.0	0.0000	6045.5	1213	2502	758
Hardwoods	237.4	0.0013	229.2	46	120	194
Lodgepole Pine (Priv.)	373.3	0.0199	405.4	65	318	305
Lodgepole Pine (Publ.)	689.2	0.0111	970.6	835	697	389
Ponderosa Pine (Priv.)	366.7	0.0194	325.7	262	330	327
Ponderosa Pine (Publ.)	1501.5	0.0057	2038.9	1939	312	402
Pinyon-Juniper	56.6	0.0000	0.0	6335	2135	47
Nonstocked	11.6	0.0000	0.0	49	262	291
		PWW				
Douglas-fir (Priv.)	1244.6	0.0155	1319.9	1032	1434	913
Douglas-fir (Publ.)	5215.8	0.0046	7046.3	2106	3251	1626
Fir-Spruce (Priv.)	686.1	0.0164	657.5	123	1200	768
Fir-Spruce (Publ.)	1846.0	0.0120	2424.4	776	3312	1517
Other Conifer	5934.2	0.0045	9074.3	158	586	616
Other Hardwoods	7750.0	0.0000	8874.0	512	918	754
Red Alder	2253.7	0.0035	2922.4	557	414	475
Western Hemlock	2084.8	0.0176	3074.5	963	3835	1549
Nonstocked	22.4	0.0000	0.0	49	1324	191
		RMN				
Douglas-fir	599.8	0.0397	510.9	3122	2374	526
Fir-Spruce	908.7	0.0221	954.4	1820	1681	578
Hardwoods	227.9	0.0045	169.1	243	65	118
Lodgepole Pine	422.1	0.0471	517.1	1381	966	491
Other Conifer	676.5	0.0306	549.0	273	1157	360
Ponderosa Pine	480.8	0.0261	483.5	889	463	401
Pinyon-Juniper	56.6	0.0000	0.0	6335	2135	47
Nonstocked	6.5	0.0000	0.0	78	189	79
		RMS				
Douglas-fir	723.0	0.0441	581.5	833	1517	468
Fir-Spruce	810.5	0.0265	707.0	1371	1519	574

Continued

Table 7.—continued.

Forest type	F	G	H	n	mse	Volume limit
Hardwoods	932.5	0.0038	844.5	1712	169	156
Lodgepole Pine	498.3	0.0476	640.5	533	874	422
Other Conifer	383.5	0.0295	240.1	263	1409	500
Ponderosa Pine (Priv.)	310.6	0.0453	251.7	585	431	280
Ponderosa Pine (Publ.)	350.8	0.0643	359.3	1192	538	312
Pinyon-Juniper	56.6	0.0000	0.0	6335	2135	47
Nonstocked	5.4	0.0000	0.0	620	206	39

[a]Prediction of mass density of live trees based on the following equation: Live mass density (Mg/ha) = F*(G+(1-exp(-volume/H))). Note that for this table, volume is growing-stock volume of softwood species only. If coefficient H equals 0, then F is the predicted value, which is the mean for that forest type (units for F are then Mg/ha).
[b]Coefficients from softwood tree mass in all hardwood forests across the region.

Table 8.—Coefficients for estimating mass density of live hardwood tree species (above- and belowground, Mg/ha) by type, region, and owner (as appropriate); *F*, *G*, and *H* are coefficients; *n* = number of FIA plots; *mse* = mean squared error of the prediction relative to individual plots; *volume limit* (m^3/ha) = 99th percentile of growing-stock volumes within each set of FIA plots (upper limit of independent variables in the regressions)[a]

Forest type	F	G	H	n	mse	Volume limit
		NE				
Aspen-Birch	683.6	0.0245	566.9	264	395	250
MBB/Other HW (Priv.)	426.4	0.0479	261.0	2302	889	259
MBB/Other HW (Publ.)	737.5	0.0240	534.2	362	993	335
Oak-Hickory	456.3	0.0527	285.2	3314	1230	299
Oak-Pine	243.6	0.0695	139.3	304	511	166
Other Pine	160.5	0.0356	78.4	295	184	92
Spruce-Fir	261.1	0.0138	117.1	236	123	59
WRJ-Pine	235.4	0.0317	127.6	398	286	140
Nonstocked	4.9	0.0000	0.0	14	19	9
		NLS				
Aspen-Birch	341.9	0.0534	258.2	8072	542	216
Lowland HW (Priv.)	504.1	0.0397	358.5	1322	795	213
Lowland HW (Publ.)	760.0	0.0204	561.8	662	479	257
MBB	328.1	0.0532	173.1	5871	990	244
Oak-Hickory	356.5	0.0760	176.8	2049	1088	236
Pine	5558.9	0.0000	3378.2	2056	177	87
Spruce-Fir	304.3	0.0084	182.0	4926	103	77
Nonstocked	6.0	0.0000	0.0	83	458	119
		NPS				
Conifer	495.4	0.0156	321.2	256	186	159
Lowland HW	1170.7	0.0285	962.3	1030	1370	303
MBB	469.3	0.0711	323.5	1682	1213	252
Oak-Hickory	1038.5	0.0381	747.0	2516	1420	240

Continued

Table 8.—continued.

Forest type	F	G	H	n	mse	Volume limit
Oak-Pine	289.3	0.0954	188.1	172	808	150
Nonstocked	19.8	0.0000	0.0	41	857	71
		SC				
Bottomland HW (Priv.)	312.9	0.1041	166.5	2092	1387	256
Bottomland HW (Publ.)	302.3	0.1038	136.2	295	1271	329
Natural Pine (Priv.)	129.1	0.0908	54.0	1620	287	70
Natural Pine (Publ.)	149.2	0.0985	70.4	448	343	112
Oak-Pine	185.1	0.1132	82.0	2000	599	124
Other Conifer	177.2	0.0991	84.8	72	386	140
Planted Pine	98.6	0.0667	36.6	1477	133	40
Upland HW (Priv.)	218.9	0.1519	97.0	3934	1311	190
Upland HW (Publ.)	290.5	0.1068	145.3	481	1031	230
Nonstocked	51.4	0.0000	0.0	19	2264	5
		SE				
Bottomland HW (Priv.)	1138.6	0.0204	893.0	2516	1776	370
Bottomland HW (Publ.)	470.7	0.0485	312.9	334	1910	359
Natural Pine (Priv.)	184.8	0.0430	97.0	2892	213	115
Natural Pine (Publ.)	238.0	0.0296	124.1	662	223	104
Oak-Pine	269.0	0.0582	154.5	2307	534	210
Other Conifer	306.0	0.0190	173.2	145	317	127
Planted Pine	156.2	0.0276	68.5	3865	116	40
Upland HW (Priv.)	413.4	0.0649	280.7	5071	1135	326
Upland HW (Publ.)	420.0	0.0926	277.3	779	1835	331
Nonstocked	51.4	0.0000	0.0	74	4420	214
		PSW				
Douglas-fir	257.6	0.0224	166.1	93	849	247
Fir-Spruce	26.0	0.0134	6.9	51	6	28
Hardwoods	2851.0	0.0000	2199.2	695	5801	421
Other Conifer	1064.4	0.0126	681.3	795	1653	194
Pinyon-Juniper	1.4	0.0000	0.0	6335	35	0
Redwood [b]	1173.8	0.0102	832.7	108	832	141
Nonstocked	6.3	0.0000	0.0	18	190	41
		PWE				
Douglas-fir (Priv.)	91.4	0.0023	66.8	226	9	36
Douglas-fir (Publ.)	134.7	0.0007	136.9	972	4	28
Fir-Spruce (Priv.)	153.0	0.0055	132.8	95	18	97
Fir-Spruce (Publ.)	555.4	0.0001	633.9	1213	3	14
Hardwoods	1883.5	0.0148	2026.8	46	2484	288
Lodgepole Pine (Priv.)	27.0	0.0088	1.4	65	3	57
Lodgepole Pine (Publ.) [b]	100.3	0.0006	67.3	835	1	3
Ponderosa Pine (Priv.)	81.3	0.0033	16.8	262	18	28
Ponderosa Pine (Publ.) [b]	100.3	0.0006	67.3	1939	9	3
Pinyon-Juniper	1.4	0.0000	0.0	6335	35	0
Nonstocked	2.0	0.0000	0.0	49	74	21
		PWW				
Douglas-fir (Priv.)	174.9	0.0114	179.0	1032	131	178
Douglas-fir (Publ.)	253.1	0.0055	299.9	2106	81	134

Continued

Table 8.—continued.

Forest type	F	G	H	n	mse	Volume limit
Fir-Spruce (Priv.)	825.2	0.0023	922.4	123	153	198
Fir-Spruce (Publ.) [b]	264.5	0.0039	309.2	776	39	73
Other Conifer	506.5	0.0052	573.2	158	113	90
Other Hardwoods	526.3	0.0506	548.3	512	1454	487
Red Alder	551.3	0.0306	755.8	557	594	488
Western Hemlock	362.8	0.0011	469.2	963	30	134
Nonstocked	4.7	0.0000	0.0	49	141	114
		RMN				
Douglas-fir	147.8	0.0032	125.3	3122	15	35
Fir-Spruce	283.4	0.0007	252.6	1820	5	16
Hardwoods	309.1	0.0578	254.3	243	594	201
Lodgepole Pine	107.8	0.0011	71.4	1381	3	13
Other Conifer [b]	165.3	0.0018	139.9	273	9	0
Ponderosa Pine	27.2	0.0003	6.4	889	2	6
Pinyon-Juniper	1.4	0.0000	0.0	6335	35	0
Nonstocked	34.5	0.0000	0.0	78	1441	4
		RMS				
Douglas-fir	238.8	0.0134	172.6	833	91	78
Fir-Spruce	273.6	0.0120	241.4	1371	121	106
Hardwoods	424.6	0.0737	379.2	1712	909	268
Lodgepole Pine	79.3	0.0253	42.5	533	41	23
Other Conifer	246.6	0.0047	154.8	263	26	28
Ponderosa Pine (Priv.)	132.3	0.0480	80.8	585	300	26
Ponderosa Pine (Publ.)	57.5	0.0409	23.9	1192	67	19
Pinyon-Juniper	1.4	0.0000	0.0	6335	35	0
Nonstocked	20.8	0.0000	0.0	620	1701	0

[a]Prediction of mass density of live trees based on the following equation: Live mass density (Mg/ha) = F*(G+(1-exp(-volume/H))). Note that for this table, volume is growing-stock volume of hardwood species only. If coefficient H equals 0, then F is the predicted value, which is the mean for that forest type (units for F are then Mg/ha).
[b]Coefficients from hardwood tree mass in all softwood forests across the region.

Table 9.—Coefficients for estimating mass density of live softwood tree species (aboveground only, Mg/ha) by type, region, and owner (as appropriate); *F*, *G*, and *H* are coefficients; *n* = number of FIA plots; *mse* = mean squared error of the prediction relative to individual plots; *volume limit* (m^3/ha) = 99^{th} percentile of growing-stock volumes within each set of FIA plots (upper limit of independent variables in the regressions)[a]

Forest type	F	G	H	n	mse	Volume limit
NE						
Aspen-Birch	60.3	0.0180	38.4	264	39	41
MBB/Other HW (Priv.)	387.3	0.0020	386.1	2302	20	74
MBB/Other HW (Publ.)	144.8	0.0020	135.5	362	33	111
Oak-Hickory	335.1	0.0008	374.6	3314	9	47
Oak-Pine	380.5	0.0147	540.6	304	62	132
Other Pine	1011.3	0.0167	1541.0	295	231	256
Spruce-Fir	276.7	0.0345	222.3	236	237	227
WRJ-Pine	265.1	0.0258	261.0	398	323	279
Nonstocked	0.7	0.0000	0.0	14	5	2
NLS						
Aspen-Birch	150.3	0.0046	142.5	8072	29	84
Lowland HW (Priv.)	199.6	0.0018	170.8	1322	29	83
Lowland HW (Publ.)	159.8	0.0071	148.8	662	44	85
MBB	262.7	0.0009	231.4	5871	54	121
Oak-Hickory	98.2	0.0033	92.2	2049	12	60
Pine	354.8	0.0278	432.4	2056	229	268
Spruce-Fir	336.0	0.0508	322.9	4926	400	188
Nonstocked	2.1	0.0000	0.0	83	12	18
NPS						
Conifer	238.8	0.0673	310.4	256	186	182
Lowland HW	90.8	0.0011	97.4	1030	1	12
MBB	30.4	0.0047	22.6	1682	2	15
Oak-Hickory [b]	1225.1	0.0002	1472.0	2516	3	26
Oak-Pine	317.6	0.0316	464.2	172	62	145
Nonstocked	2.5	0.0000	0.0	41	57	56
SC						
Bottomland HW (Priv.)	282.5	0.0007	383.7	2092	51	184
Bottomland HW (Publ.) [b]	505.0	0.0012	793.6	295	38	85
Natural Pine (Priv.)	333.0	0.0555	655.2	1620	232	302
Natural Pine (Publ.)	325.0	0.0709	740.6	448	168	340
Oak-Pine	105.6	0.0736	178.6	2000	62	168
Other Conifer	87.4	0.1597	75.5	72	199	123
Planted Pine	109.6	0.1376	108.4	1477	271	253
Upland HW (Priv.)	70.1	0.0112	105.6	3934	9	59
Upland HW (Publ.)	47.8	0.0054	66.0	481	9	69
Nonstocked	4.2	0.0000	0.0	19	17	8
SE						
Bottomland HW (Priv.)	670.4	0.0006	976.0	2516	67	276
Bottomland HW (Publ.)	390.1	0.0036	551.5	334	185	268
Natural Pine (Priv.)	239.3	0.0392	355.9	2892	179	337
Natural Pine (Publ.)	510.2	0.0205	949.6	662	147	303
Oak-Pine	279.4	0.0143	459.3	2307	52	167

Continued

Table 9.—continued.

Forest type	F	G	H	n	mse	Volume limit
Other Conifer	332.8	0.0250	423.8	145	328	386
Planted Pine	176.6	0.0613	201.5	3865	186	261
Upland HW (Priv.)	109.6	0.0041	162.2	5071	6	59
Upland HW (Publ.)	160.1	0.0035	228.2	779	11	71
Nonstocked	4.2	0.0000	0.0	74	82	79
		PSW				
Douglas-fir	2949.5	0.0080	4203.5	93	5302	1008
Fir-Spruce	746.9	0.0109	787.2	51	4198	1020
Hardwoods	602.8	0.0074	739.9	695	547	383
Other Conifer	654.6	0.0114	739.4	795	2055	617
Pinyon-Juniper	46.7	0.0000	0.0	6335	1449	47
Redwood	1631.3	0.0114	2637.1	108	7886	1691
Nonstocked	29.4	0.0000	0.0	18	482	96
		PWE				
Douglas-fir (Priv.)	533.7	0.0155	563.8	226	1591	479
Douglas-fir (Publ.)	2860.8	0.0000	4185.0	972	2541	636
Fir-Spruce (Priv.)	586.7	0.0136	690.5	95	1723	496
Fir-Spruce (Publ.)	3939.7	0.0000	6292.4	1213	4274	758
Hardwoods	194.8	0.0013	228.1	46	183	194
Lodgepole Pine (Priv.)	307.0	0.0197	405.2	65	584	305
Lodgepole Pine (Publ.)	574.4	0.0109	984.8	835	1007	389
Ponderosa Pine (Priv.)	303.1	0.0192	327.2	262	662	327
Ponderosa Pine (Publ.)	1254.6	0.0056	2069.0	1939	716	402
Pinyon-Juniper	46.7	0.0000	0.0	6335	1449	47
Nonstocked	11.6	0.0000	0.0	49	262	291
		PWW				
Douglas-fir (Priv.)	1031.2	0.0153	1327.3	1032	3353	913
Douglas-fir (Publ.)	4350.7	0.0045	7126.1	2106	9334	1626
Fir-Spruce (Priv.)	567.4	0.0162	660.1	123	2746	768
Fir-Spruce (Publ.)	1531.1	0.0118	2439.7	776	8598	1517
Other Conifer	5423.1	0.0040	10083.7	158	1276	616
Other Hardwoods	6636.5	0.0000	9217.1	512	2232	754
Red Alder	1877.9	0.0035	2953.7	557	911	475
Western Hemlock	1733.6	0.0173	3101.5	963	8611	1549
Nonstocked	22.4	0.0000	0.0	49	1324	191
		RMN				
Douglas-fir	495.5	0.0395	512.9	3122	1612	526
Fir-Spruce	753.4	0.0219	961.4	1820	1141	578
Hardwoods	187.5	0.0045	169.0	243	44	118
Lodgepole Pine	348.3	0.0466	519.1	1381	649	491
Other Conifer	557.8	0.0305	550.1	273	783	360
Ponderosa Pine	397.6	0.0259	485.4	889	312	401
Pinyon-Juniper	46.7	0.0000	0.0	6335	1449	47
Nonstocked	5.3	0.0000	0.0	78	128	79
		RMS				
Douglas-fir	597.7	0.0438	584.2	833	1029	468
Fir-Spruce	669.9	0.0263	710.1	1371	1030	574

Continued

Table 9.—continued.

Forest type	F	G	H	n	mse	Volume limit
Hardwoods	778.3	0.0037	857.2	1712	114	156
Lodgepole Pine	411.2	0.0471	642.3	533	587	422
Other Conifer	316.2	0.0294	240.5	263	959	500
Ponderosa Pine (Priv.)	256.3	0.0451	252.4	585	291	280
Ponderosa Pine (Publ.)	289.5	0.0641	360.3	1192	364	312
Pinyon-Juniper	46.7	0.0000	0.0	6335	1449	47
Nonstocked	4.4	0.0000	0.0	620	140	39

[a]Prediction of mass density of live trees based on the following equation: Live mass density (Mg/ha) = F*(G+(1-exp(-volume/H))). Note that for this table, volume is growing-stock volume of softwood species only. If coefficient H equals 0, then F is the predicted value, which is the mean for that forest type (units for F are then Mg/ha).
[b]Coefficients from softwood tree mass in all hardwood forests across the region.

Table 10.—Coefficients for estimating mass density of live hardwood tree species (aboveground only, Mg/ha) by type, region, and owner (as appropriate); *F*, *G*, and *H* are coefficients; *n* = number of FIA plots; *mse* = mean squared error of the prediction relative to individual plots; *volume limit* (m^3/ha) = 99^{th} percentile of growing-stock volumes within each set of FIA plots (upper limit of independent variables in the regressions)[a]

Forest type	F	G	H	n	mse	Volume limit
		NE				
Aspen-Birch	581.3	0.0239	574.9	264	275	250
MBB/Other HW (Priv.)	360.4	0.0473	262.8	2302	626	259
MBB/Other HW (Publ.)	627.6	0.0236	541.8	362	702	335
Oak-Hickory	385.6	0.0519	286.9	3314	867	299
Oak-Pine	205.9	0.0685	140.5	304	359	166
Other Pine	135.3	0.0351	78.9	295	128	92
Spruce-Fir	221.1	0.0135	118.6	236	86	59
WRJ-Pine	198.9	0.0312	128.6	398	201	140
Nonstocked	4.1	0.0000	0.0	14	14	9
		NLS				
Aspen-Birch	287.7	0.0525	258.3	8072	379	216
Lowland HW (Priv.)	428.2	0.0391	363.1	1322	562	213
Lowland HW (Publ.)	646.4	0.0199	569.3	662	338	257
MBB	276.4	0.0526	173.7	5871	699	244
Oak-Hickory	300.0	0.0756	177.2	2049	770	236
Pine	5420.6	0.0000	3931.4	2056	124	87
Spruce-Fir	258.4	0.0083	184.6	4926	72	77
Nonstocked	5.0	0.0000	0.0	83	324	119
		NPS				
Conifer	427.2	0.0152	331.2	256	130	159
Lowland HW	996.9	0.0279	974.7	1030	967	303
MBB	397.4	0.0702	326.3	1682	855	252
Oak-Hickory	885.2	0.0374	757.8	2516	1002	240

Continued

Table 10.—continued.

Forest type	F	G	H	n	mse	Volume limit
Oak-Pine	244.7	0.0943	189.7	172	568	150
Nonstocked	16.6	0.0000	0.0	41	604	71
		SC				
Bottomland HW (Priv.)	263.9	0.1033	167.1	2092	980	256
Bottomland HW (Publ.)	254.7	0.1031	136.3	295	899	329
Natural Pine (Priv.)	108.8	0.0897	54.3	1620	201	70
Natural Pine (Publ.)	125.7	0.0975	70.7	448	241	112
Oak-Pine	156.1	0.1119	82.4	2000	421	124
Other Conifer	150.4	0.0979	86.0	72	272	140
Planted Pine	83.1	0.0655	36.9	1477	93	40
Upland HW (Priv.)	184.7	0.1508	97.6	3934	924	190
Upland HW (Publ.)	245.2	0.1058	146.2	481	727	230
Nonstocked	43.2	0.0000	0.0	19	1600	5
		SE				
Bottomland HW (Priv.)	968.3	0.0200	904.5	2516	1254	370
Bottomland HW (Publ.)	397.5	0.0480	314.8	334	1350	359
Natural Pine (Priv.)	156.1	0.0423	97.9	2892	149	115
Natural Pine (Publ.)	200.6	0.0292	124.9	662	156	104
Oak-Pine	227.2	0.0574	155.7	2307	375	210
Other Conifer	260.0	0.0187	175.7	145	223	127
Planted Pine	132.6	0.0269	69.9	3865	81	40
Upland HW (Priv.)	349.1	0.0641	282.2	5071	801	326
Upland HW (Publ.)	355.3	0.0915	279.5	779	1297	331
Nonstocked	43.2	0.0000	0.0	74	3131	214
		PSW				
Douglas-fir	217.2	0.0222	166.9	93	1006	247
Fir-Spruce	21.9	0.0134	7.0	51	7	28
Hardwoods	2431.0	0.0000	2232.3	695	6560	421
Other Conifer	897.1	0.0125	683.1	795	1811	194
Pinyon-Juniper	1.2	0.0000	0.0	6335	25	0
Redwood [b]	990.1	0.0101	835.7	108	624	141
Nonstocked	6.3	0.0000	0.0	18	190	41
		PWE				
Douglas-fir (Priv.)	77.1	0.0023	67.2	226	11	36
Douglas-fir (Publ.)	114.1	0.0007	138.5	972	5	28
Fir-Spruce (Priv.)	127.6	0.0055	131.3	95	23	97
Fir-Spruce (Publ.)	482.1	0.0001	655.1	1213	4	14
Hardwoods	1620.9	0.0144	2079.2	46	2719	288
Lodgepole Pine (Priv.)	22.7	0.0087	1.6	65	4	57
Lodgepole Pine (Publ.) [b]	84.6	0.0006	67.7	835	1	3
Ponderosa Pine (Priv.)	68.5	0.0033	17.0	262	21	28
Ponderosa Pine (Publ.) [b]	84.6	0.0006	67.7	1939	10	3
Pinyon-Juniper	1.2	0.0000	0.0	6335	25	0
Nonstocked	2.0	0.0000	0.0	49	74	21
		PWW				
Douglas-fir (Priv.)	147.4	0.0113	179.6	1032	159	178
Douglas-fir (Publ.)	214.5	0.0054	302.6	2106	96	134

Continued

Table 10.—continued.

Forest type	F	G	H	n	mse	Volume limit
Fir-Spruce (Priv.)	703.3	0.0022	935.2	123	213	198
Fir-Spruce (Publ.) [b]	223.7	0.0039	311.4	776	30	73
Other Conifer	431.9	0.0051	582.8	158	121	90
Other Hardwoods	444.4	0.0501	550.7	512	1901	487
Red Alder	463.4	0.0303	754.3	557	1069	488
Western Hemlock	308.2	0.0011	474.5	963	43	134
Nonstocked	4.7	0.0000	0.0	49	141	114
		RMN				
Douglas-fir	124.6	0.0032	125.9	3122	10	35
Fir-Spruce	241.9	0.0006	257.4	1820	3	16
Hardwoods	260.6	0.0571	255.1	243	418	201
Lodgepole Pine	90.9	0.0011	72.0	1381	2	13
Other Conifer [b]	139.7	0.0017	141.3	273	6	0
Ponderosa Pine	22.8	0.0003	6.4	889	1	6
Pinyon-Juniper	1.2	0.0000	0.0	6335	25	0
Nonstocked	28.8	0.0000	0.0	78	1007	4
		RMS				
Douglas-fir	201.6	0.0132	173.9	833	63	78
Fir-Spruce	231.2	0.0119	243.1	1371	85	106
Hardwoods	357.3	0.0731	379.8	1712	636	268
Lodgepole Pine	66.8	0.0250	42.9	533	29	23
Other Conifer	208.9	0.0046	156.4	263	18	28
Ponderosa Pine (Priv.)	111.3	0.0475	81.0	585	210	26
Ponderosa Pine (Publ.)	48.5	0.0404	24.1	1192	47	19
Pinyon-Juniper	1.2	0.0000	0.0	6335	25	0
Nonstocked	17.5	0.0000	0.0	620	1201	0

[a]Prediction of mass density of live trees based on the following equation: Live mass density (Mg/ha) = F*(G+(1-exp(-volume/H))). Note that for this table, volume is growing-stock volume of hardwood species only. If coefficient H equals 0, then F is the predicted value, which is the mean for that forest type (units for F are then Mg/ha).
[b]Coefficients from hardwood tree mass in all softwood forests across the region.

Table 11.—Estimated mass density of live trees (aboveground only, Mg/ha) by region and hardwood/softwood types; to ensure consistent comparisons among estimates, all were applied to the same set of plot and tree records from the FIADB (nonstocked and woodland forest types were excluded)

Region	Forest type	Estimates based on Table 3	FIADB (DRYBIOT)	Birdsey (1992)	Brown and others (1999)
			Mg/ha		
NE	Hardwood	116.7	110.6	102.4	128.2
	Softwood	84.0	79.3	60.2	82.8
NLS	Hardwood	103.7	94.0	89.8	121.4
	Softwood	81.1	67.0	58.3	87.8
NPS	Hardwood	100.7	80.8	91.1	102.1
	Softwood	69.1	51.5	54.0	62.8
SC	Hardwood	104.6	112.1	90.5	104.0
	Softwood	78.5	97.3	71.1	89.8
SE	Hardwood	120.8	105.7	114.2	144.8
	Softwood	67.0	66.0	59.8	89.8
PSW	Hardwood	140.7	159.1	101.0	
	Softwood	178.3	174.1	133.1	
PWE	Hardwood	84.3	67.4	56.2	
	Softwood	108.3	98.4	96.4	
PWW	Hardwood	191.1	201.8	181.04	
	Softwood	264.0	264.5	268.5	
RMN	Hardwood	71.6	49.7	47.2	
	Softwood	122.3	111.7	119.8	
RMS	Hardwood	72.0	53.2	39.4	
	Softwood	113.0	92.7	91.0	

Table 12.—Estimated total mass (Mt) of live and standing dead trees larger than 1 inch d.b.h. (aboveground and coarse roots) and area, by region and forest classification; values obtained by applying biomass estimates from Tables 3 and 4 to data from 1997 RPA database (Smith and others 2001)

	Timberland[a]			Reserved			Other		
Region	Live	Dead	Area	Live	Dead	Area	Live	Dead	Area
			Thousand ha			*Thousand ha*			*Thousand ha*
NE	4846	349	31940	315	20	2009	79	6	647
NLS	2470	311	19906	19	6	775	11	3	402
NPS	1735	100	13937	27	2	408	17	3	340
North	9051	760	65783	362	28	3191	108	11	1388
SC	5722	311	47024	58	3	486	183	11	3254
SE	4230	206	34320	87	5	1092	22	1	469
South	9953	517	81344	146	8	1579	205	13	3723
PSW	1664	223	7265	714	82	2415	464	57	5920
PWE	1097	125	7989	185	28	1151	100	14	1559
PWW	2251	257	8671	275	33	1268	18	2	249
RMN	2104	201	14685	280	87	2893	57	11	701
RMS	1625	228	12796	232	126	4440	1335	140	21025
West	8740	1033	51407	1686	355	12167	1974	223	29454
All regions	27744	2311	198534	2193	391	16937	2286	248	34565

[a]Timberland is forest land classified as having a growth capacity of at least 20 cubic feet industrial wood per acre per year. Reserved forests are withdrawn by law from the production of wood products.

Literature Cited

Birdsey, R.A. 1992. **Carbon storage and accumulation in United States forest ecosystems.** Gen. Tech. Rep. WO-59. Washington, DC: U.S. Department of Agriculture, Forest Service. 51 p.

Birdsey, R.A.; Heath, L.S. 1995. **Carbon changes in U.S. forests.** In: Joyce, L.A., ed. Productivity of America's forests and climate change. Gen. Tech. Rep. RM-271. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 56-70.

Brown, S.; Schroeder, P.; Birdsey, R. 1997. **Aboveground biomass distribution of US eastern hardwood forests and the use of large trees as an indicator of forest development.** Forest Ecology and Management. 96: 37-47.

Brown, S.L.; Schroeder, P.; Kern, J.S. 1999. **Spatial distribution of biomass in forests of the eastern USA.** Forest Ecology and Management. 123: 81-90.

Clutter, J.L.; Fortson, J.C.; Pienaar, L.V.; Brister, G.H.; Bailey, R.L. 1983. **Timber management: a quantitative approach.** New York: John Wiley & Sons. 333 p.

Cost, N.D.; Howard, J.O.; Mead, B.; McWilliams, W.H.; Smith, W.B.; Van Hooser, D.D.; Wharton, E.H. 1990. **The forest biomass resource of the United States.** Gen. Tech. Rep. WO-57. Washington, DC: U.S. Department of Agriculture, Forest Service. 21 p.

Hansen, M.H.; Frieswyk, T.; Glover, J.F.; Kelly, J.F. 1992. **The Eastwide forest inventory data base: users manual.** Gen. Tech. Rep. NC-151. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 48 p.

Haynes, R.W.; Adams, D.M.; Mills, J.R. 1995. **The 1993 RPA timber assessment update.** Gen. Tech. Rep. RM-259. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 66 p.

Heath, L.S.; Birdsey, R.A. 1993. **Carbon trends of productive temperate forests of the coterminous United States.** Water, Air, and Soil Pollution. 70: 279-293.

Heath, L.S.; Birdsey, R.A.; Row, C.; Plantinga, A.J. 1996. **Carbon pools and flux in U.S. forest products.** In: Apps, M.J.; Price, D.T., eds. Forest ecosystems, forest management, and the global carbon cycle. NATO ASI SER. Vol. I 40. Berlin: Springer-Verlag: 271-278.

Heath, L.S.; Chojnacky, D.C. 2001. **Down dead wood statistics for Maine timberlands, 1995.** Resour. Bull. NE-150. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 80 p.

Heath, L.S.; Smith, J.E. 2000. **An assessment of uncertainty in forest carbon budget projections.** Environmental Science and Policy. 3: 73-82.

Jenkins, J.; Chojnacky, D.; Heath, L.; Birdsey, R. **National-scale biomass estimators for United States tree species.** Forest Science. [in press].

Miles, P.D.; Brand, G.J.; Alerich, C.L.; Bednar, L.F.; Woudenberg, S.W.; Glover, J.F.; Ezell, E.N. 2001. **The forest inventory and analysis database description and users manual version 1.0.** Gen. Tech. Rep. NC-218. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 130 p.

Mills, J.R.; Kincaid, J.C. 1992. **The aggregate timberland assessment system—ATLAS: a comprehensive timber projection model.** Gen. Tech. Rep. PNW-GTR-281. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 16 p.

Parresol, B.R. 1999. **Assessing tree and stand biomass: a review with examples and critical comparisons.** Forest Science. 45: 573-593.

Plantinga, A.J.; Birdsey, R.A. 1993. **Carbon fluxes resulting from US private timberland management.** Climatic Change. 23: 37-53.

Powell, D.S.; Faulkner, J.L.; Darr, D.R.; Zhu, Z.; MacCleery, D.W. 1993. **Forest resources of the United States.** Gen. Tech. Rep. RM-234. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 132 p.

Rastetter, E.B.; King, A.W.; Cosby, B.J.; Hornberger, G.M.; O'Neill, R.V.; Hobbie, J.E. 1992. **Aggregating fine-scale ecological knowledge to model coarser-scale attributes of ecosystems.** Ecological Applications. 2: 55-70.

Schreuder, H.T.; Gregoire, T.G.; Wood, G.B. 1993. **Sampling methods for multiresource forest inventory.** New York: John Wiley & Sons. 446 p.

Schroeder, P.; Brown, S.; Mo, J.; Birdsey, R.; Cieszewski, C. 1997. **Biomass estimation for temperate broadleaf forests of the United States using inventory data.** Forest Science. 43: 424-434.

Skog, K.E.; Nicholson, G.A. 1998. **Carbon cycling through wood products: the role of wood and paper products in carbon sequestration.** Forest Products Journal. 48: 75-83.

Smith, J.E.; Heath, L.S. 2000. **Considerations for interpreting probabilistic estimates of uncertainty of forest carbon.** In: Joyce, L.; Birdsey, R., eds. The impact of climate change on America's forests. Gen. Tech. Rep. RMRS-GTR-59. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 102-111.

Smith, J.E.; Heath, L.S. 2001. **Identifying influences on model uncertainty: an application using a forest carbon budget model.** Environmental Management. 27: 253-267.

Smith, W.B.; Vissage, J.S.; Darr, D.R.; Sheffield, R.M. 2001. **Forest resources of the United States, 1997.** Gen. Tech. Rep. NC-219. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 190 p.

Turner, D.P.; Koerper, G.J.; Harmon, M.E.; Lee, J.J. 1995. **A carbon budget for forests of the conterminous United States.** Ecological Applications. 5: 421-436.

U.S. State Department. 2000. **U.S. submission to UNFCCC on land use, land-use change, and forestry.** <http://www.state.gov/www/global/global_issues/climate/climate_2000_submiss.html> (5 April 2002).

Waddell, K.L.; Oswald, D.D.; Powell, D.S. 1989. **Forest statistics of the United States, 1987.** Resour. Bull. PNW-RB-168. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 106 p.

Watson, R.T.; Noble, I.R.; Bolin, B.; Ravindranath, N.H.; Verardo, D.J.; Dokken, D.J., eds. 2000. **Land use, land-use change, and forestry. Special report of the Intergovernmental Panel for Climate Change.** Cambridge, UK: Cambridge University Press. 375 p.

Woudenberg, S.W.; Farrenkopf, T.O. 1995. **The Westwide forest inventory data base: user's manual.** Gen. Tech. Rep. INT-317. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 30 p.

Apendix

Index to Figures

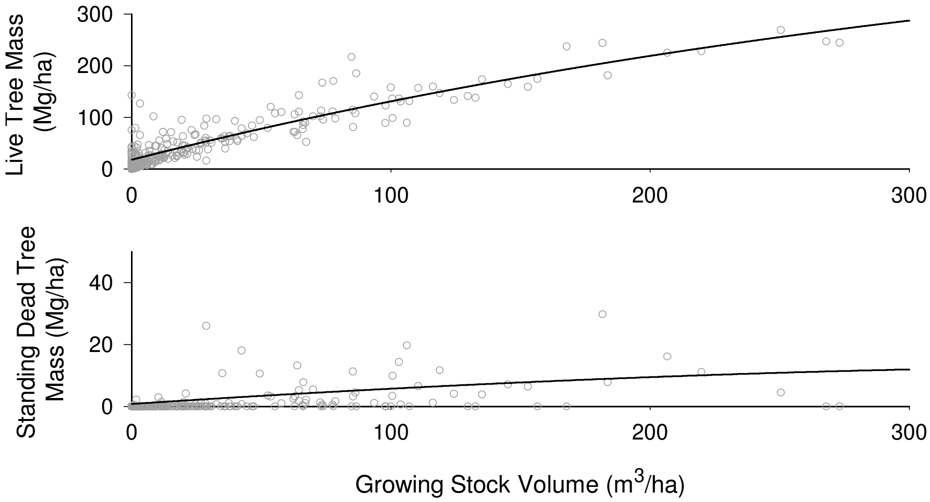


Figure 5.—Estimated mass density of live and standing dead trees in NE Aspen-Birch forests (individual points are plot-level density summaries).

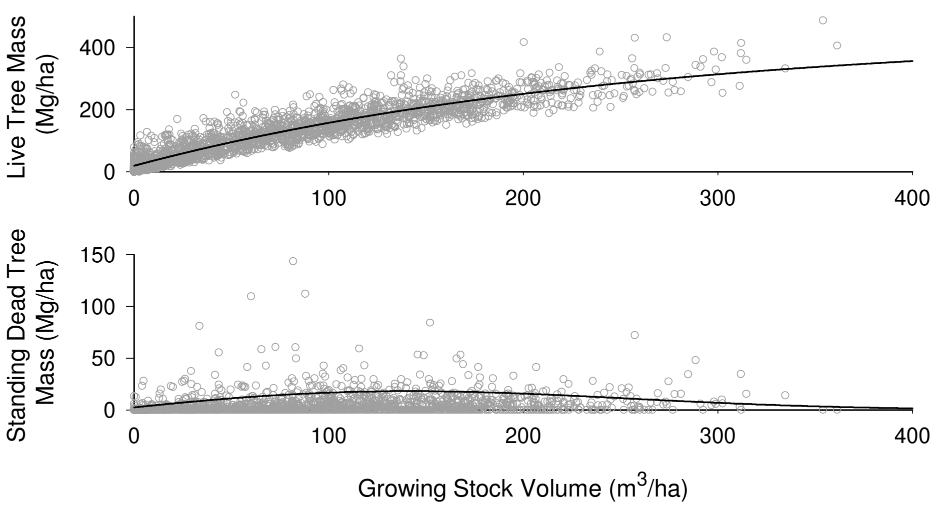


Figure 6.—Estimated mass density of live and standing dead trees in NE MBB/Other HW forests on privately owned land.

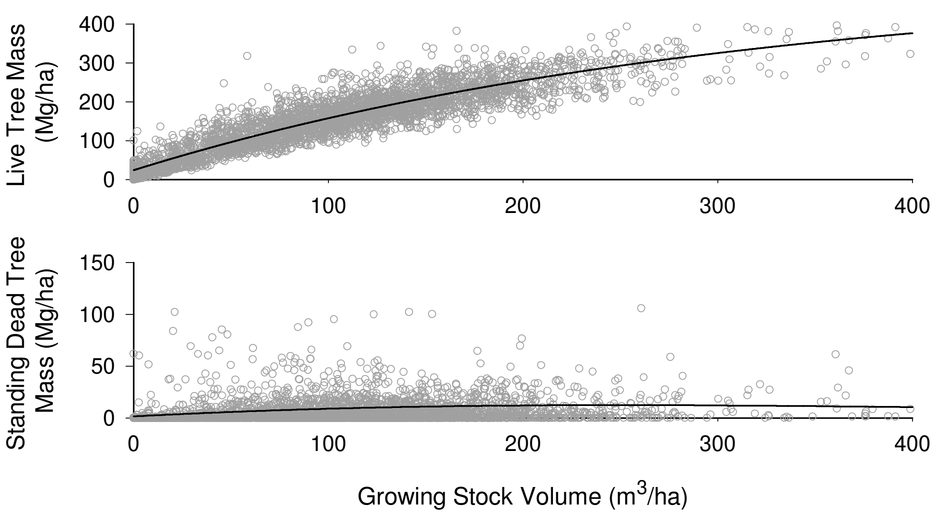


Figure 7.—Estimated mass density of live and standing dead trees in NE Oak-Hickory forests.

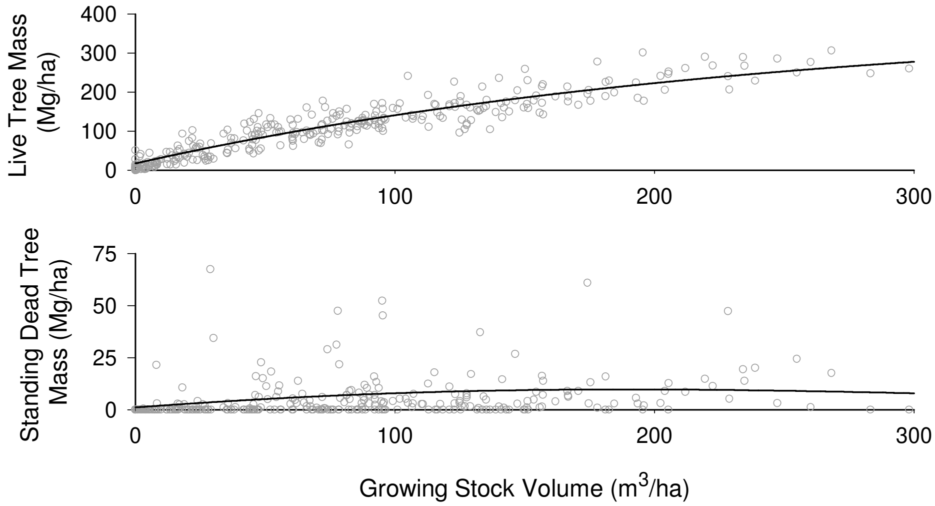


Figure 8.—Estimated mass density of live and standing dead trees in NE Oak-Pine forests.

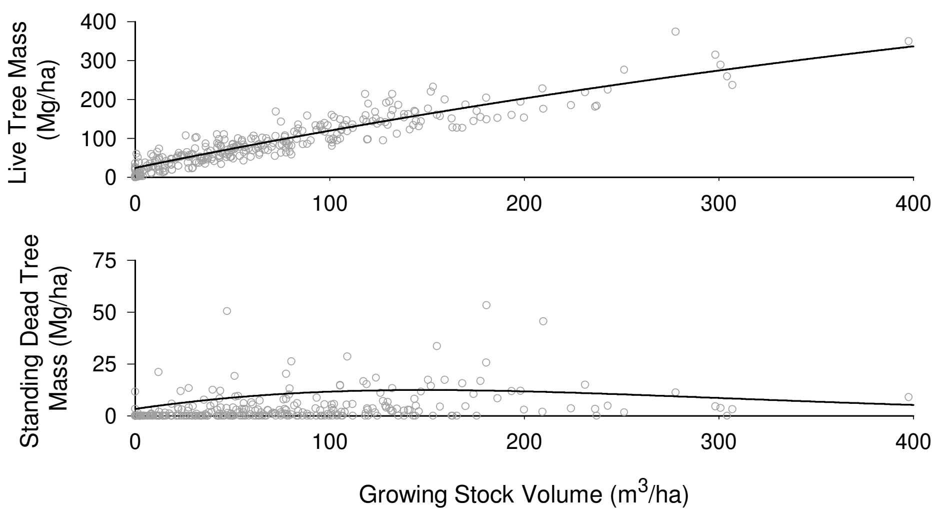


Figure 9.—Estimated mass density of live and standing dead trees in NE Other Pine forests.

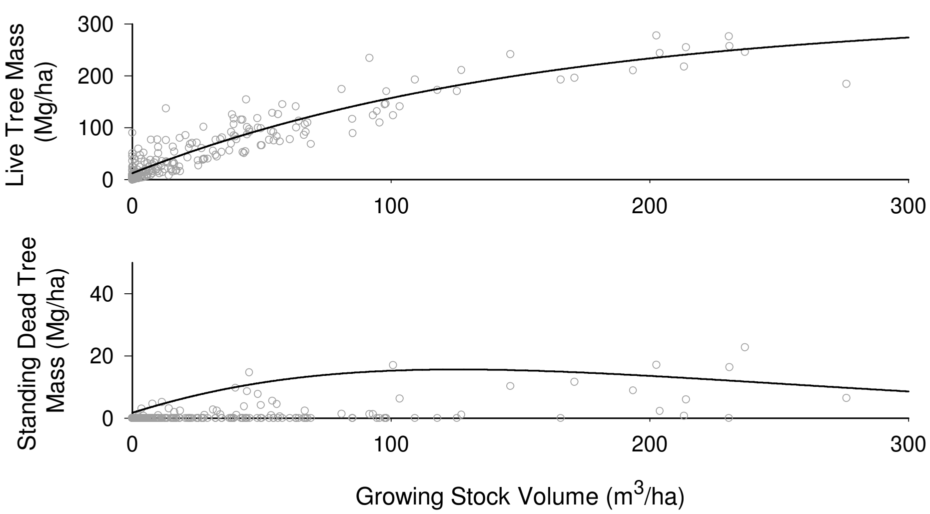


Figure 10.—Estimated mass density of live and standing dead trees in NE Spruce-Fir forests.

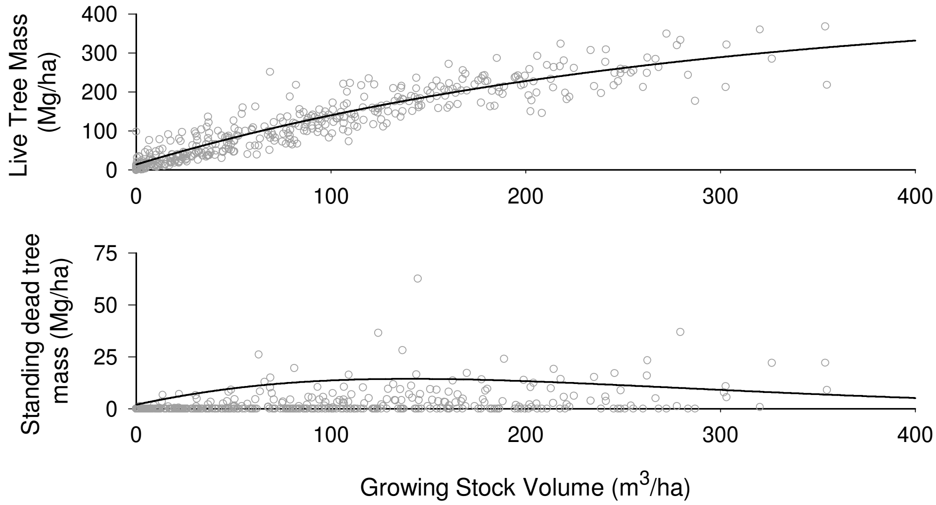


Figure 11.—Estimated mass density of live and standing dead trees in NE WRJ-Pine forests.

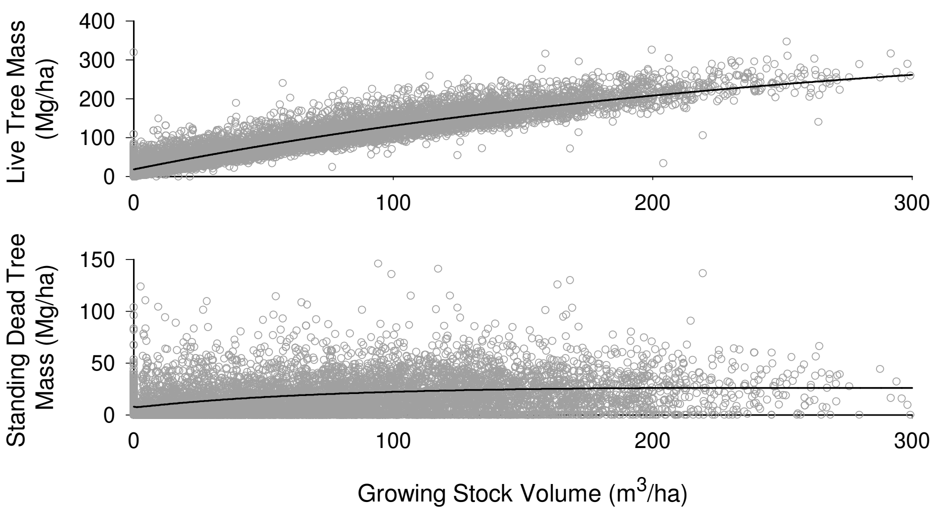


Figure 12.—Estimated mass density of live and standing dead trees in NLS Aspen-Birch forests.

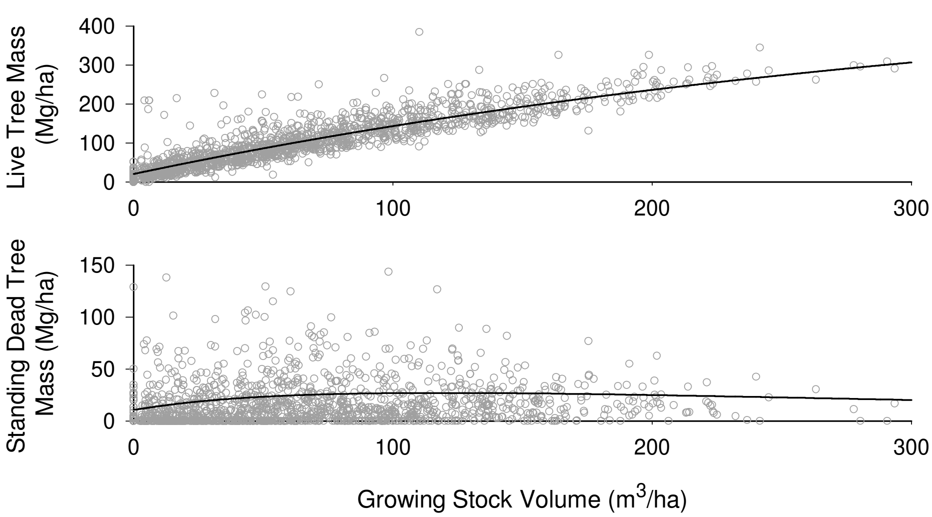


Figure 13.—Estimated mass density of live and standing dead trees in NLS Lowland HW forests on privately owned land.

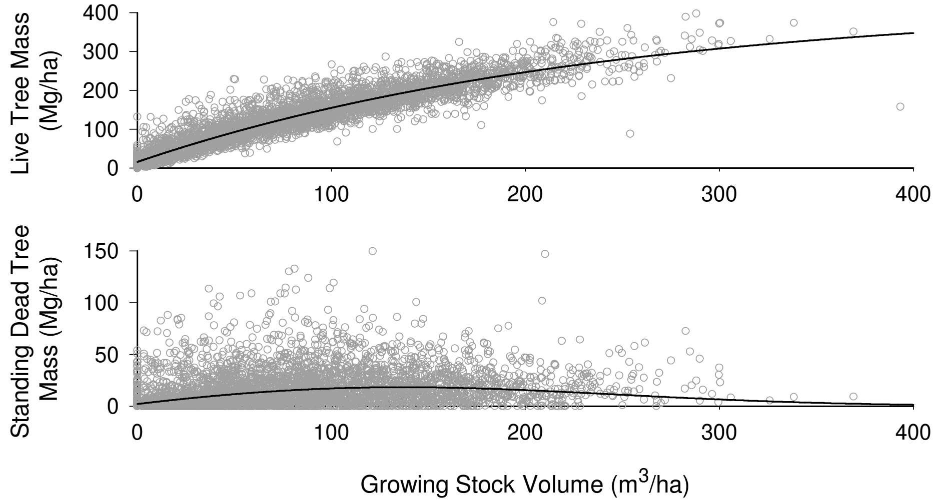


Figure 14.—Estimated mass density of live and standing dead trees in NLS MBB forests.

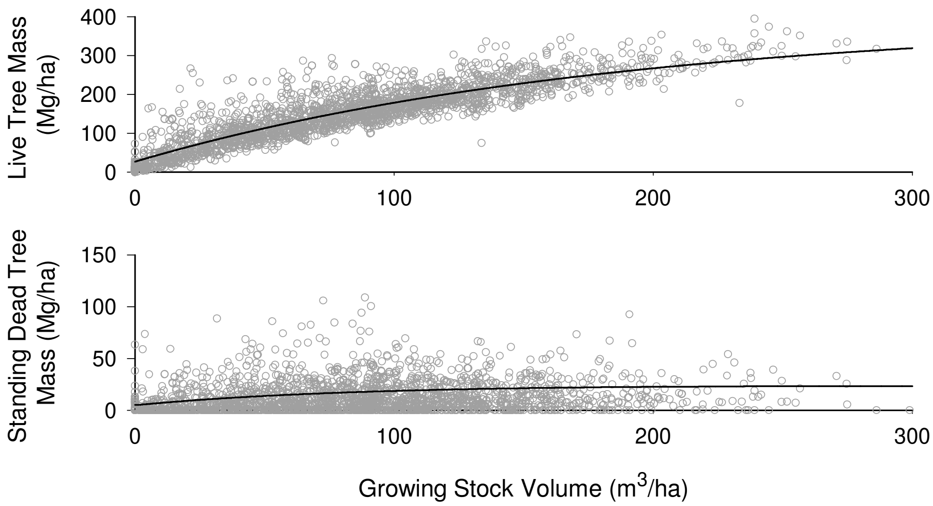


Figure 15.—Estimated mass density of live and standing dead trees in NLS Oak-Hickory forests.

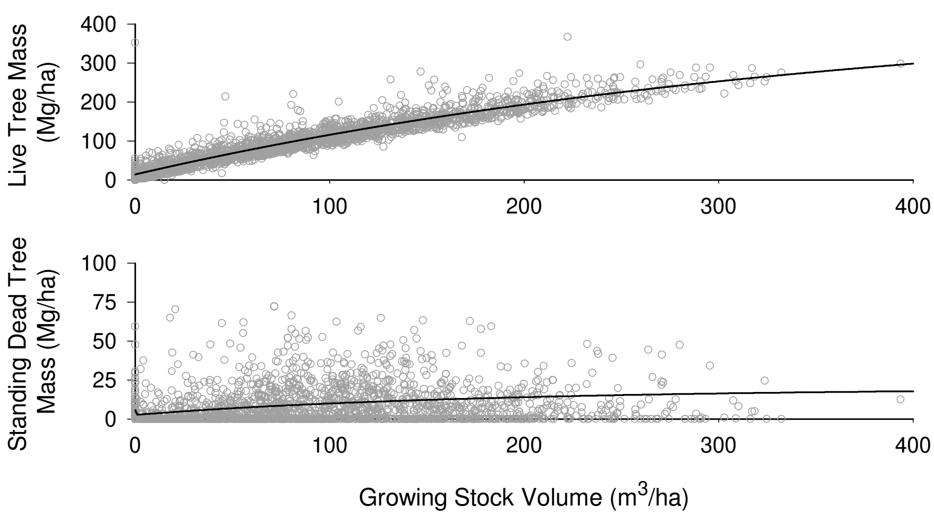


Figure 16.—Estimated mass density of live and standing dead trees in NLS Pine forests.

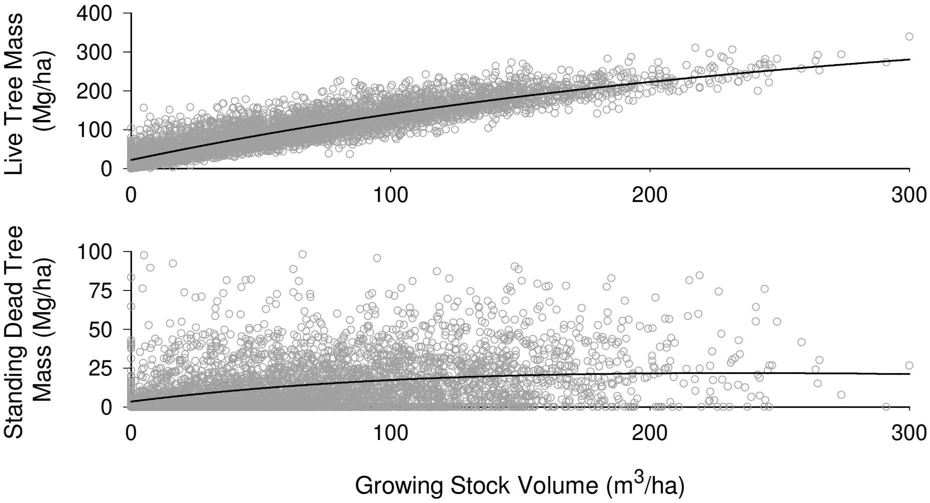


Figure 17.—Estimated mass density of live and standing dead trees in NLS Spruce-Fir forests.

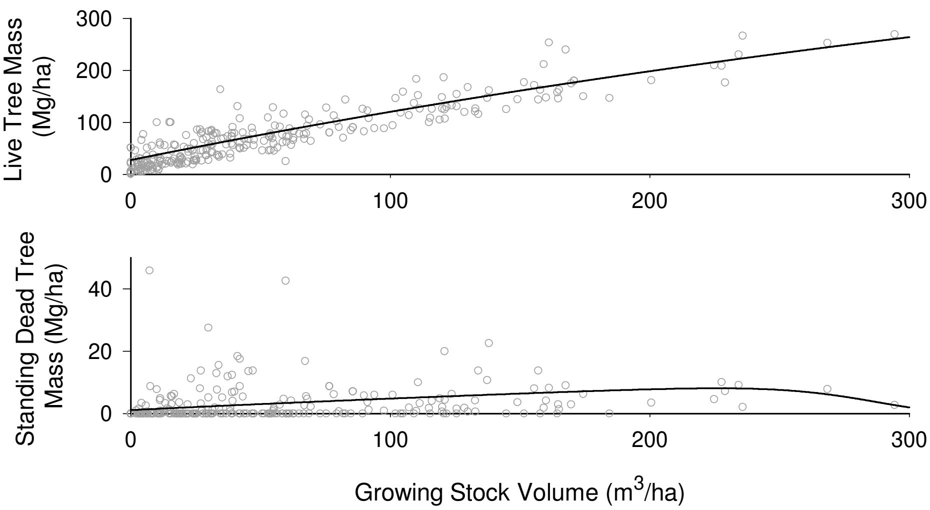


Figure 18.—Estimated mass density of live and standing dead trees in NPS Conifer forests.

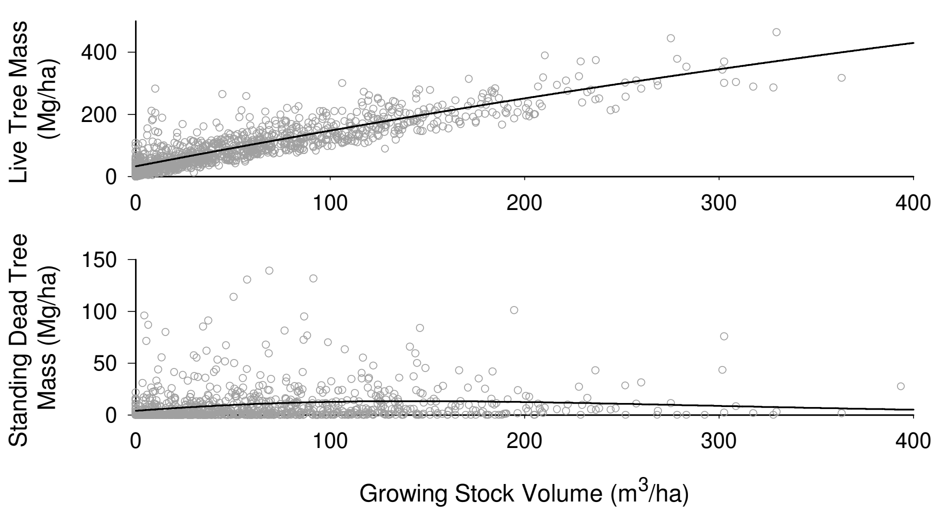


Figure 19.—Estimated mass density of live and standing dead trees in NPS Lowland HW forests.

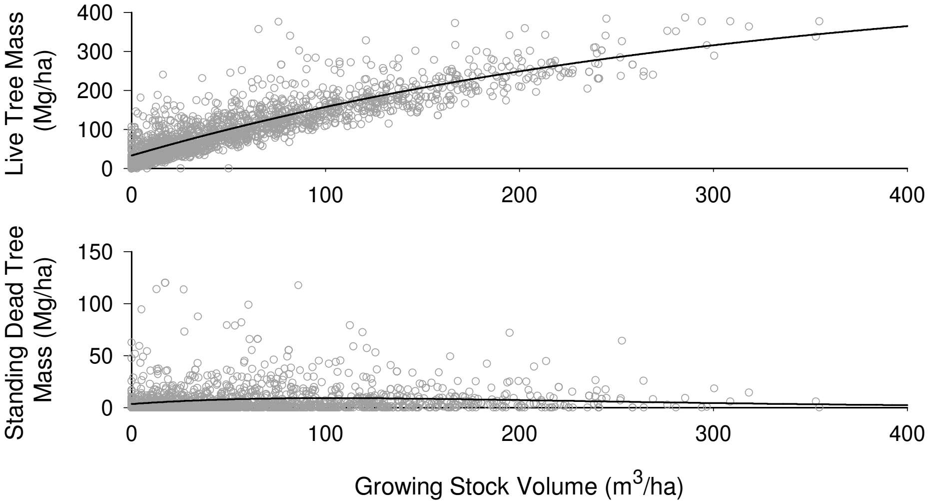


Figure 20.—Estimated mass density of live and standing dead trees in NPS MBB forests.

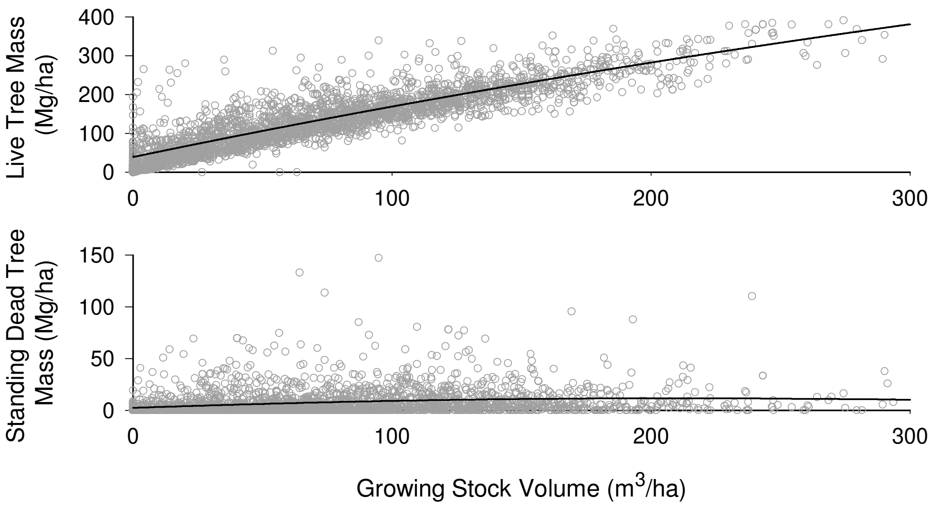


Figure 21.—Estimated mass density of live and standing dead trees in NPS Oak-Hickory forests.

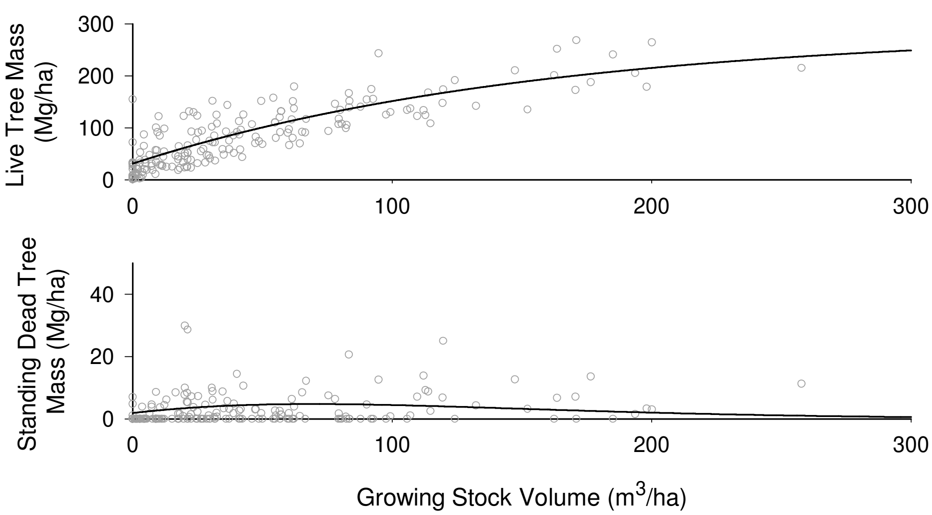


Figure 22.—Estimated mass density of live and standing dead trees in NPS Oak-Pine forests.

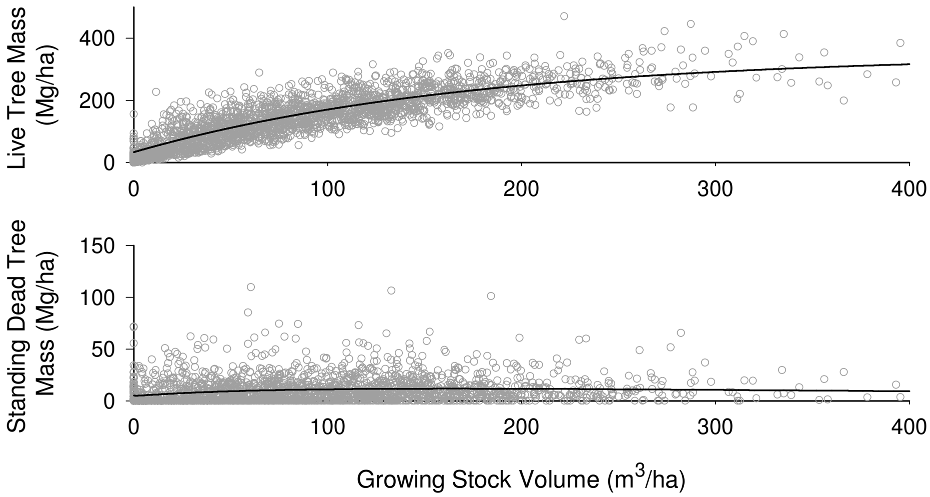


Figure 23.—Estimated mass density of live and standing dead trees in SC Bottomland HW forests on privately owned land.

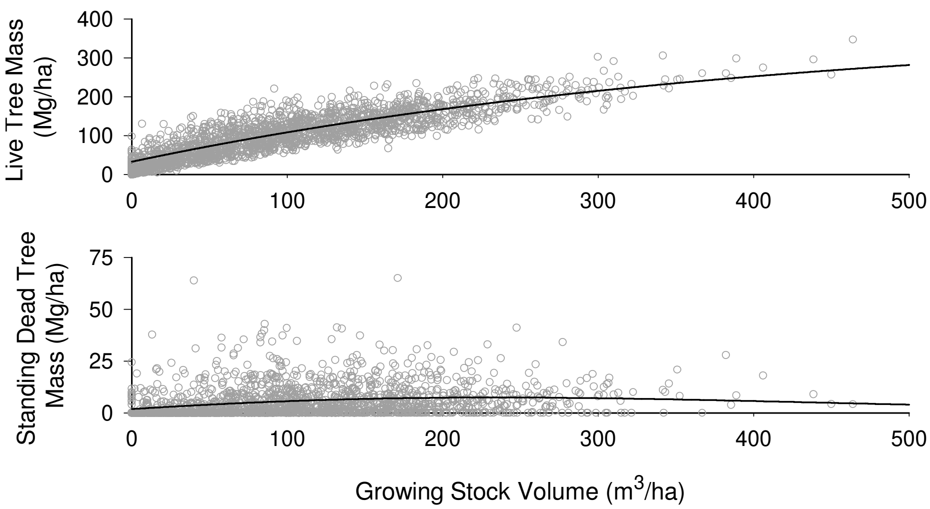


Figure 24.—Estimated mass density of live and standing dead trees in SC Natural Pine forests on privately owned land.

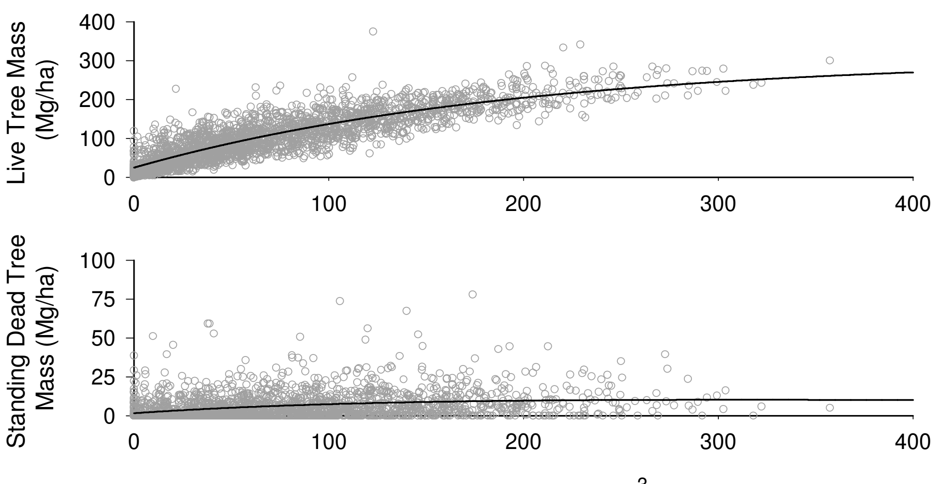


Figure 25.—Estimated mass density of live and standing dead trees in SC Oak-Pine forests.

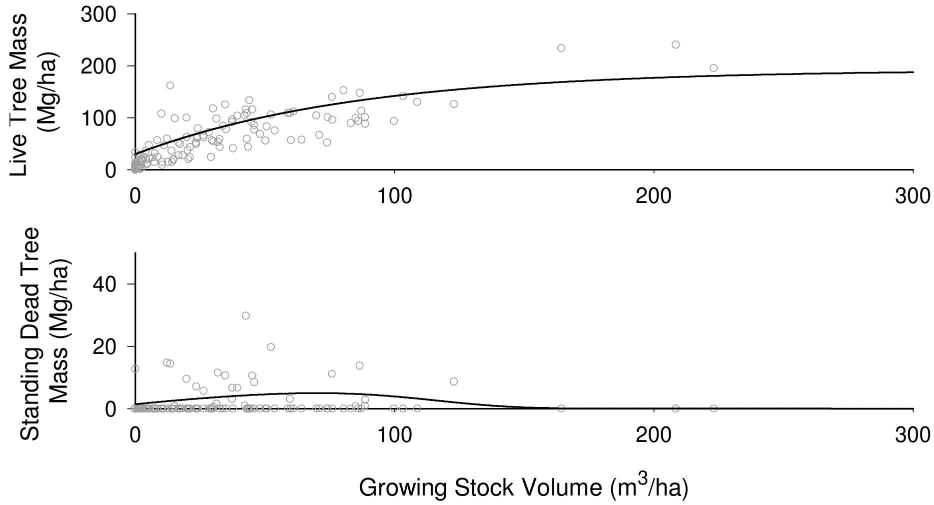


Figure 26.—Estimated mass density of live and standing dead trees in SC Other Conifer forests.

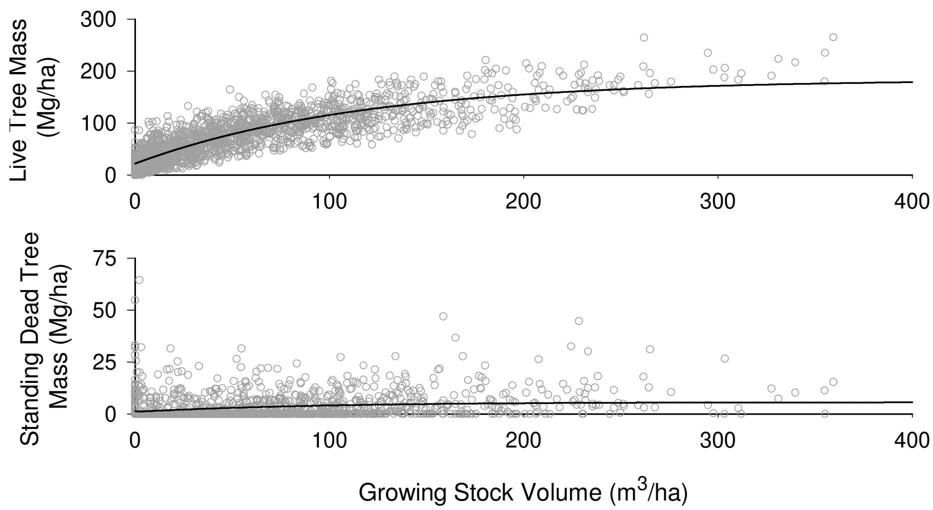


Figure 27.—Estimated mass density of live and standing dead trees in SC Planted Pine forests.

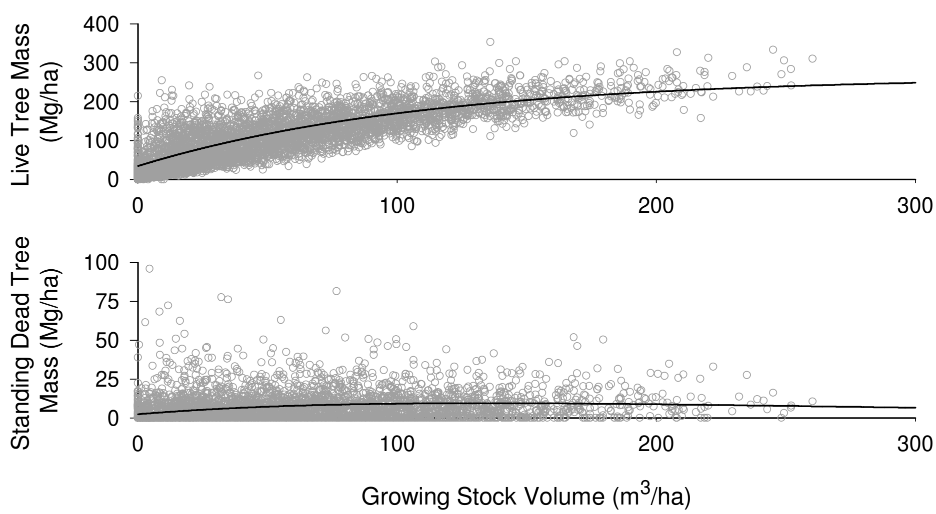


Figure 28.—Estimated mass density of live and standing dead trees in SC Upland HW forests on privately owned land.

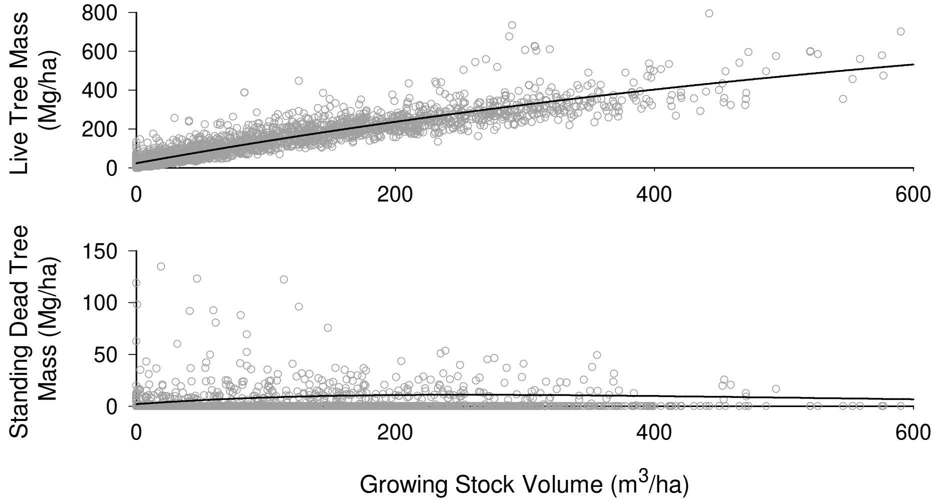


Figure 29.—Estimated mass density of live and standing dead trees in SE Bottomland HW forests on privately owned land.

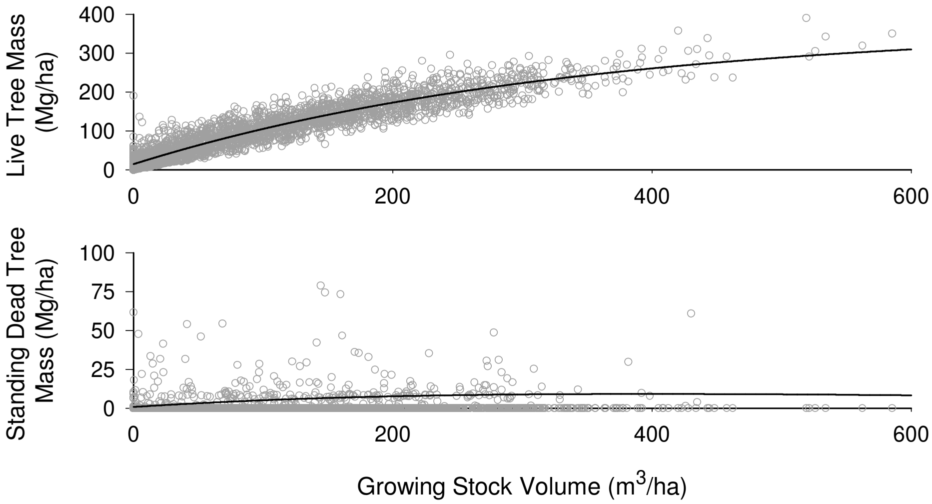


Figure 30.—Estimated mass density of live and standing dead trees in SE Natural Pine forests on privately owned land.

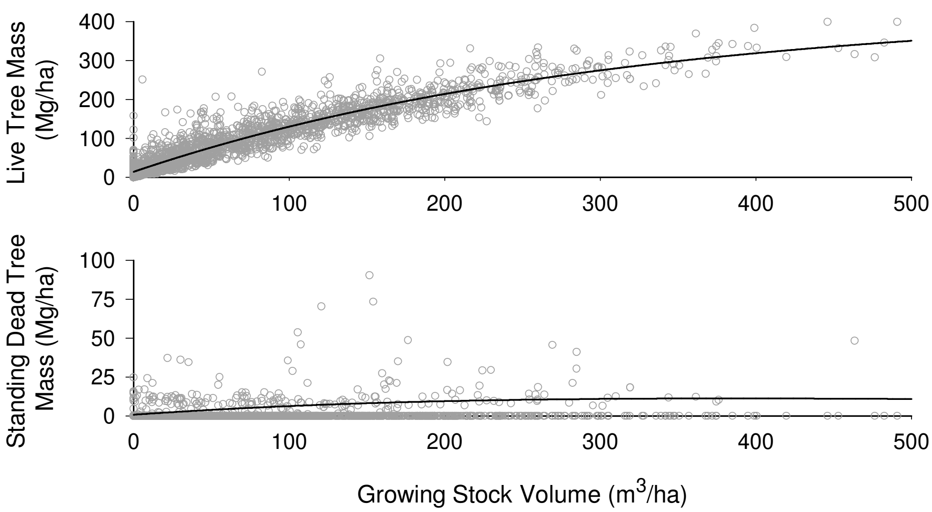


Figure 31.—Estimated mass density of live and standing dead trees in SE Oak-Pine forests.

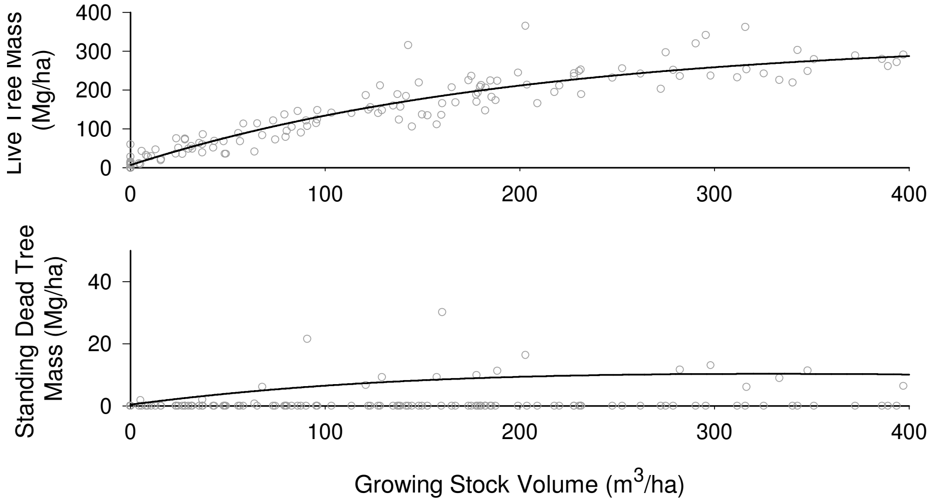


Figure 32.—Estimated mass density of live and standing dead trees in SE Other Conifer forests.

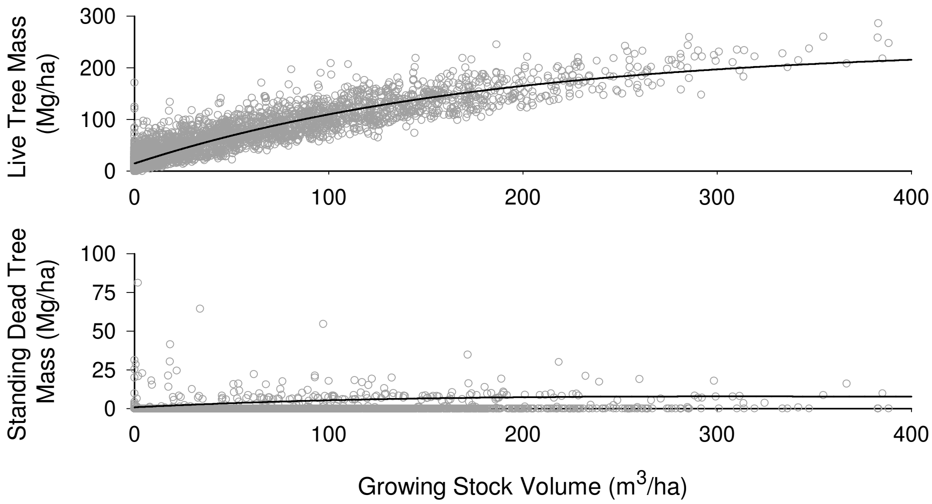


Figure 33.—Estimated mass density of live and standing dead trees in SE Planted Pine forests.

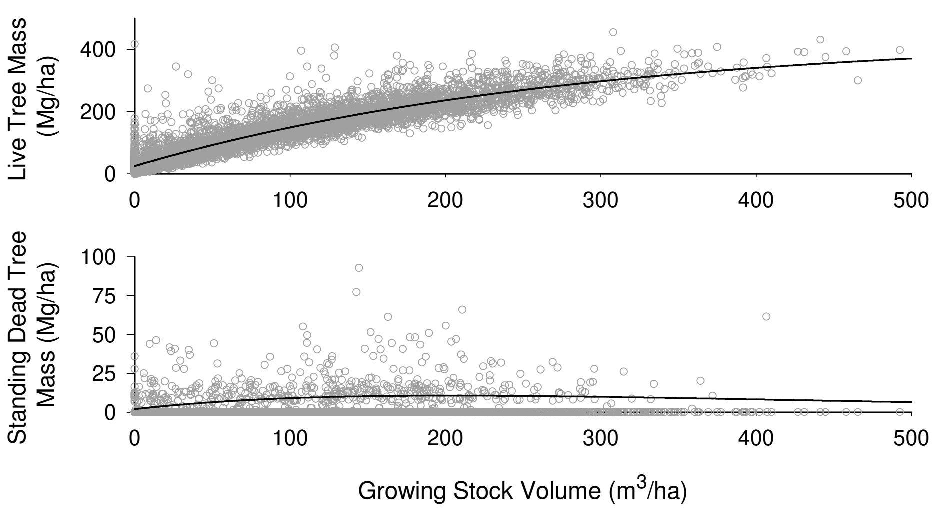


Figure 34.—Estimated mass density of live and standing dead trees in SE Upland HW forests on privately owned land.

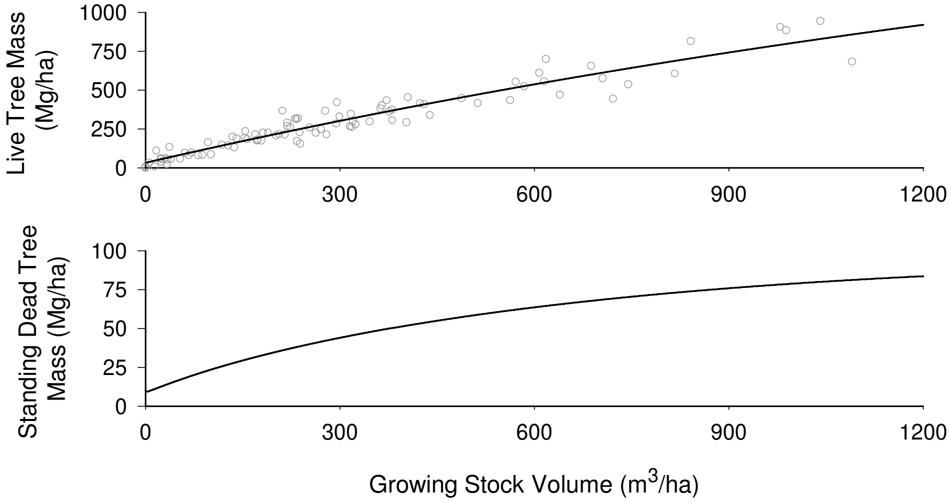


Figure 35.—Estimated mass density of live and standing dead trees in PSW Douglas-fir forests (estimates of standing dead tree mass for PSW were based on Pacific Northwest data, individual plot-level summaries are not available).

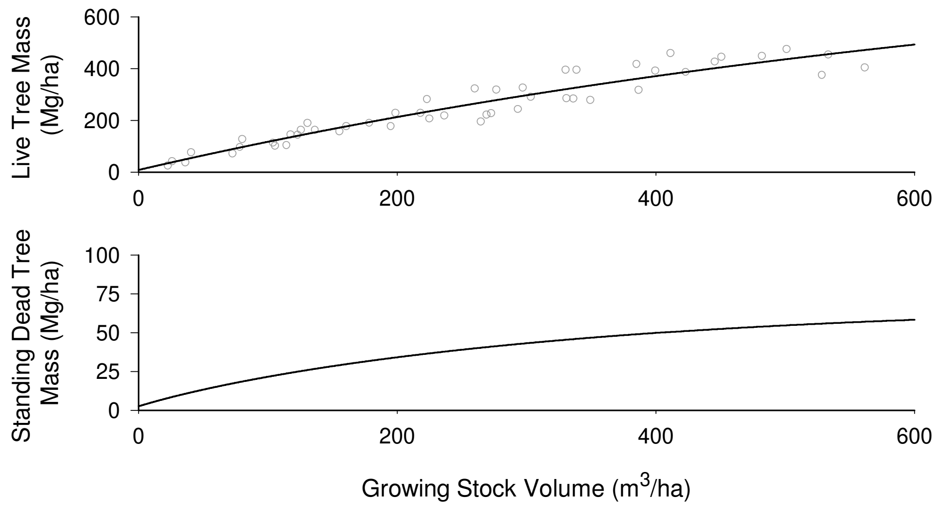


Figure 36.—Estimated mass density of live and standing dead trees in PSW Fir-Spruce forests.

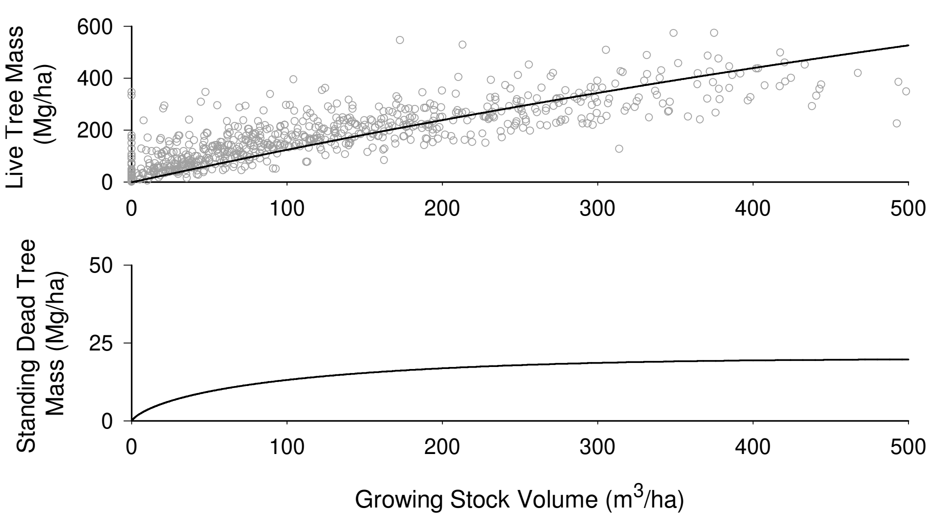


Figure 37.—Estimated mass density of live and standing dead trees in PSW Hardwoods forests.

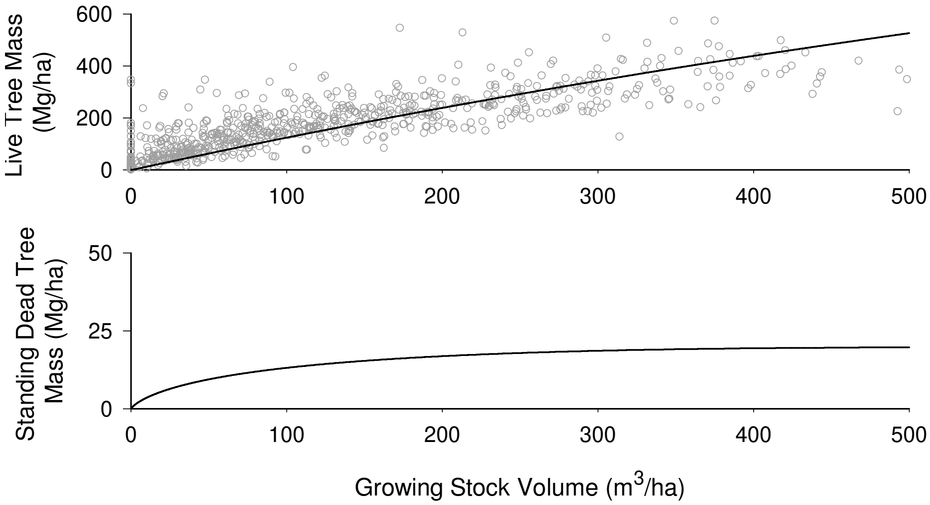


Figure 38.—Estimated mass density of live and standing dead trees in PSW Other Conifer forests.

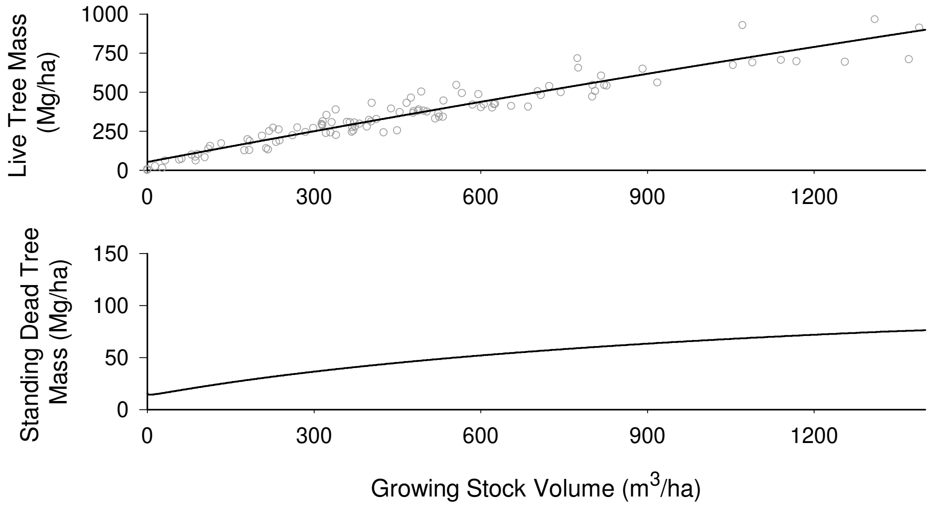


Figure 39.—Estimated mass density of live and standing dead trees in PSW Redwood forests.

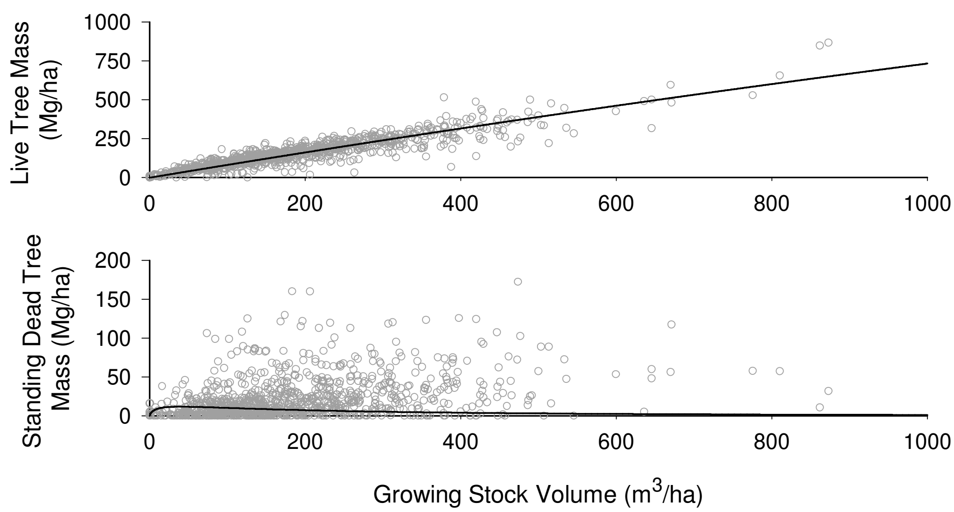


Figure 40.—Estimated mass density of live and standing dead trees in PWE Douglas-fir forests on publicly owned land.

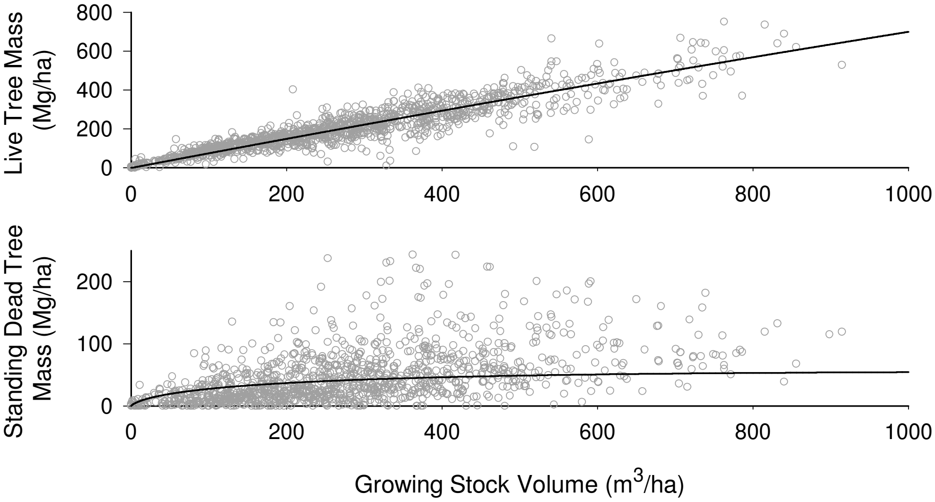


Figure 41.—Estimated mass density of live and standing dead trees in PWE Fir-Spruce forests on publicly owned land.

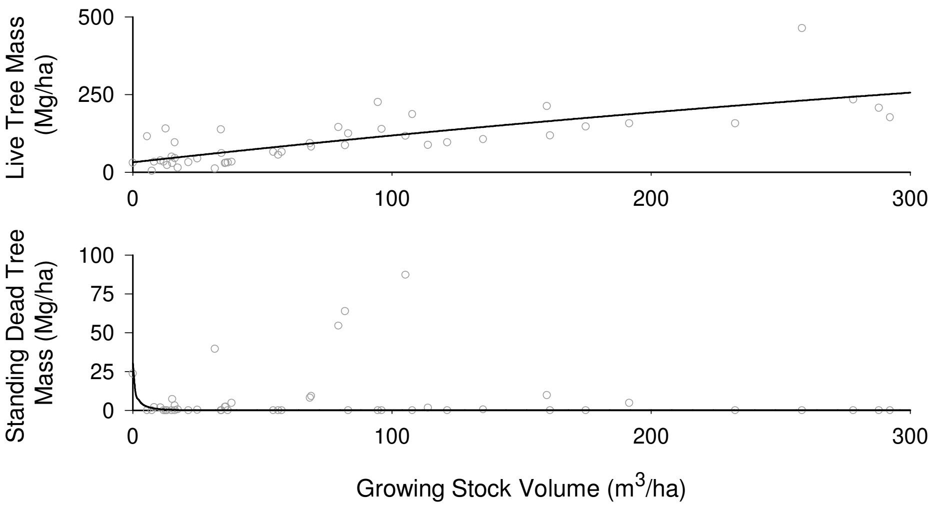


Figure 42.—Estimated mass density of live and standing dead trees in PWE Hardwoods forests.

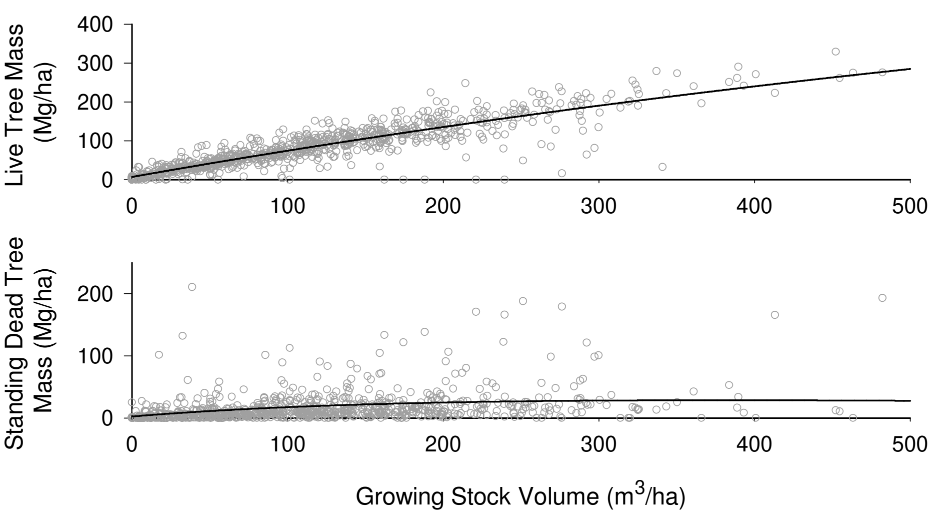


Figure 43.—Estimated mass density of live and standing dead trees in PWE Lodgepole Pine forests on publicly owned land.

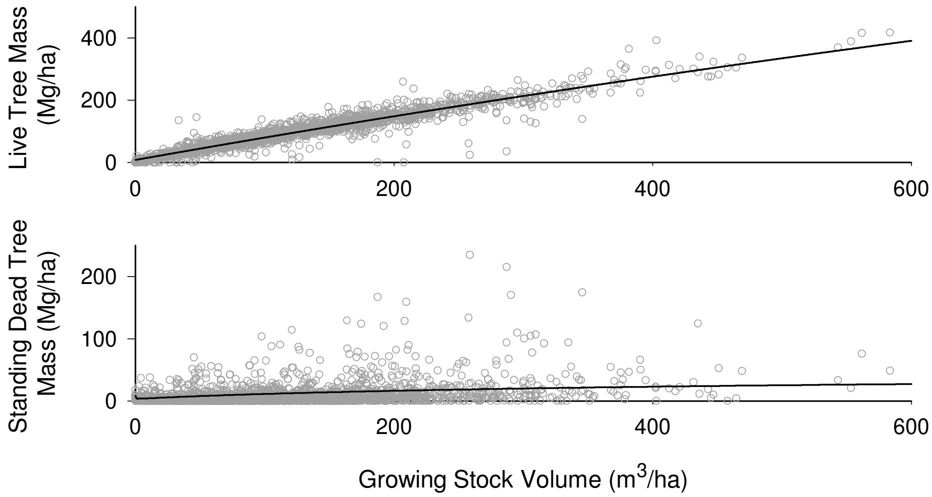


Figure 44.—Estimated mass density of live and standing dead trees in PWE Ponderosa Pine forests on publicly owned land.

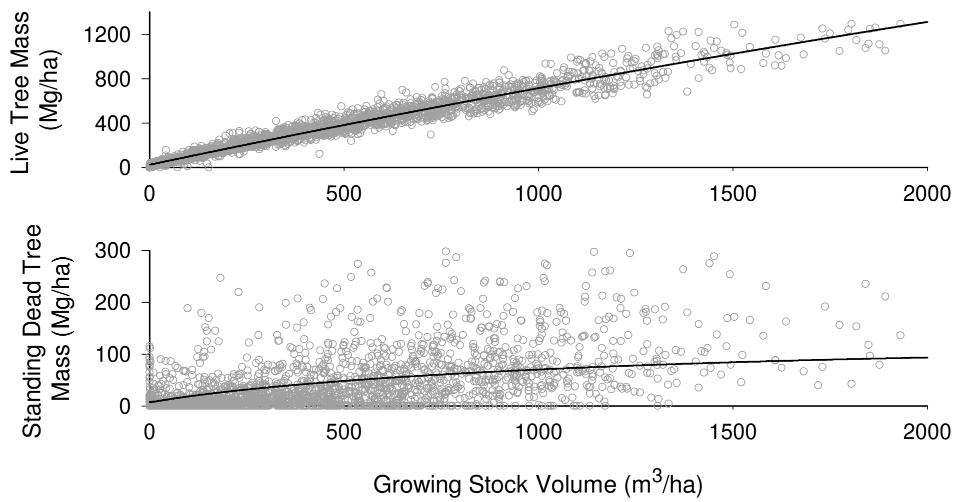


Figure 45.—Estimated mass density of live and standing dead trees in PWW Douglas-fir forests on publicly owned land.

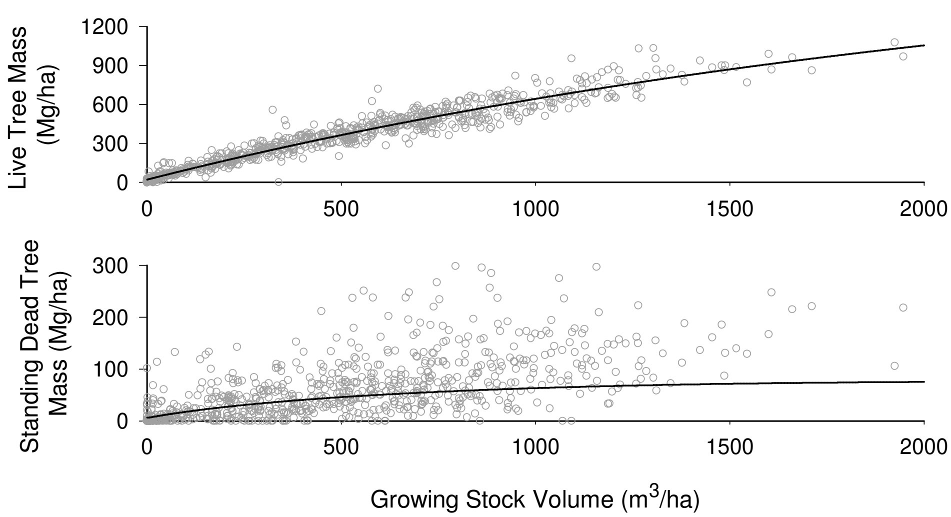


Figure 46.—Estimated mass density of live and standing dead trees in PWW Fir-Spruce forests on publicly owned land.

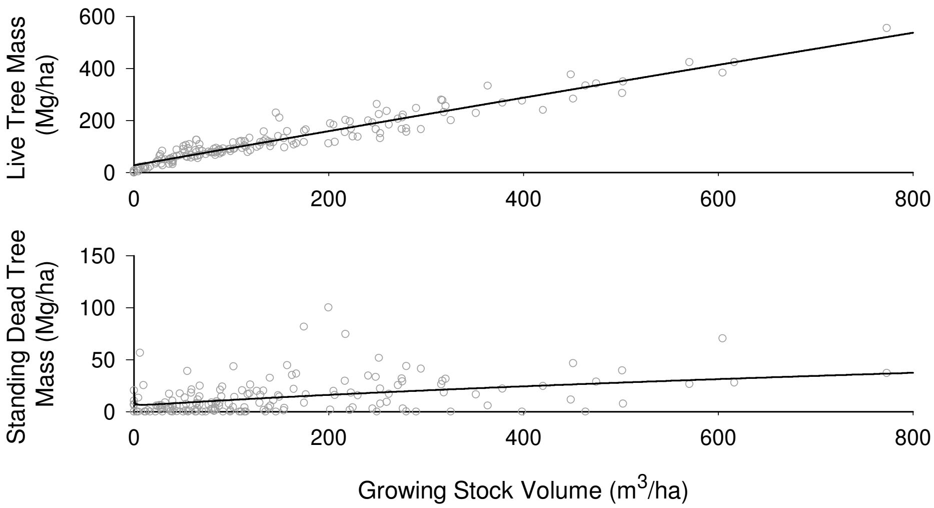


Figure 47.—Estimated mass density of live and standing dead trees in PWW Other Conifer forests.

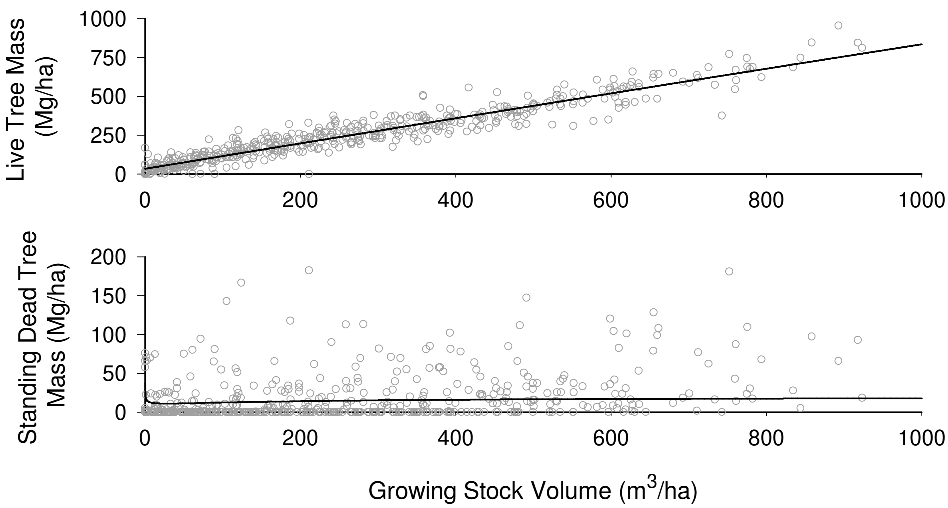


Figure 48.—Estimated mass density of live and standing dead trees in PWW Other Hardwoods forests.

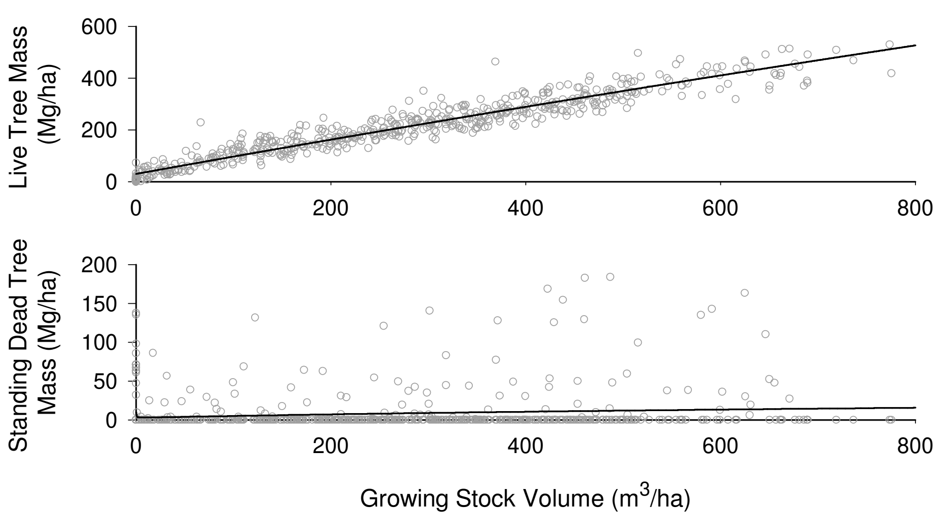


Figure 49.—Estimated mass density of live and standing dead trees in PWW Red Alder forests.

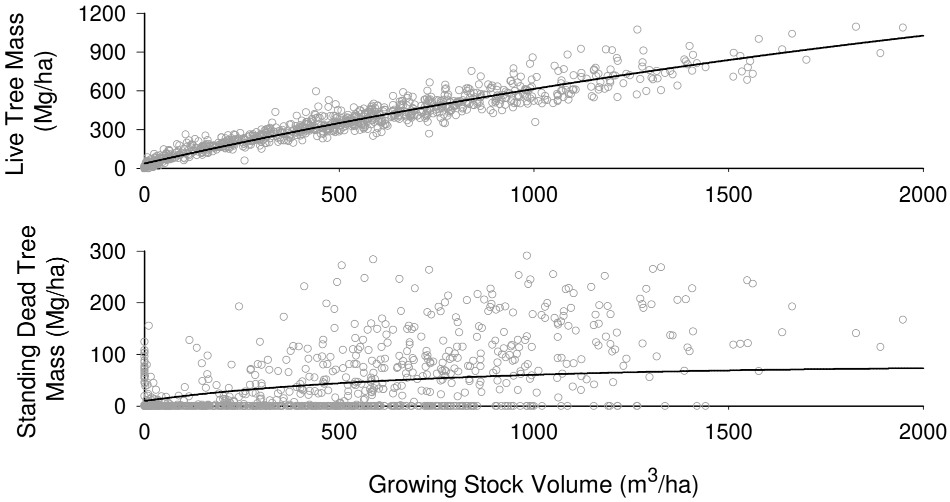


Figure 50.—Estimated mass density of live and standing dead trees in PWW Western Hemlock forests.

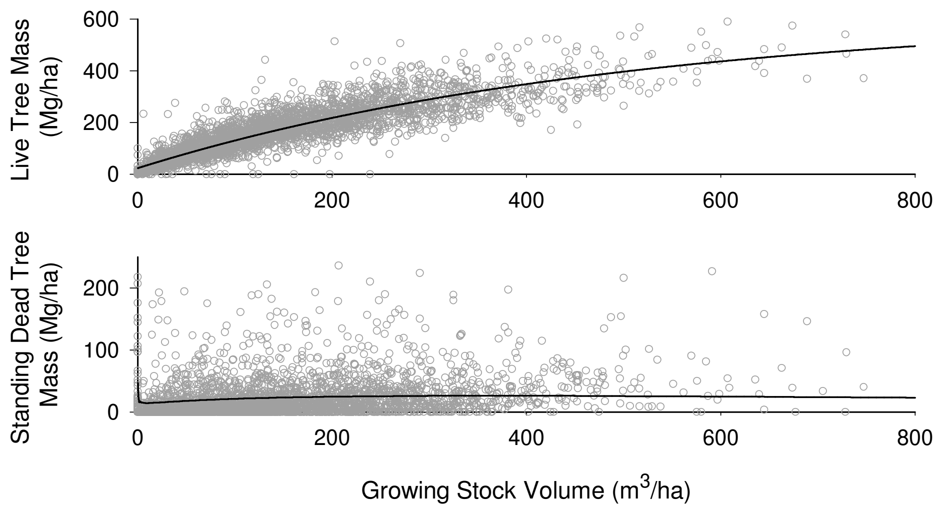


Figure 51.—Estimated mass density of live and standing dead trees in RMN Douglas-fir forests.

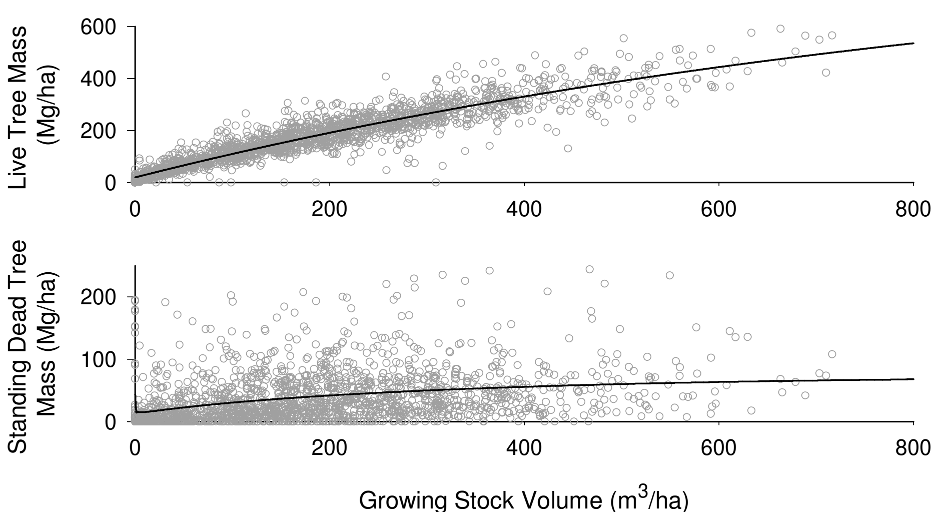


Figure 52.—Estimated mass density of live and standing dead trees in RMN Fir-Spruce forests.

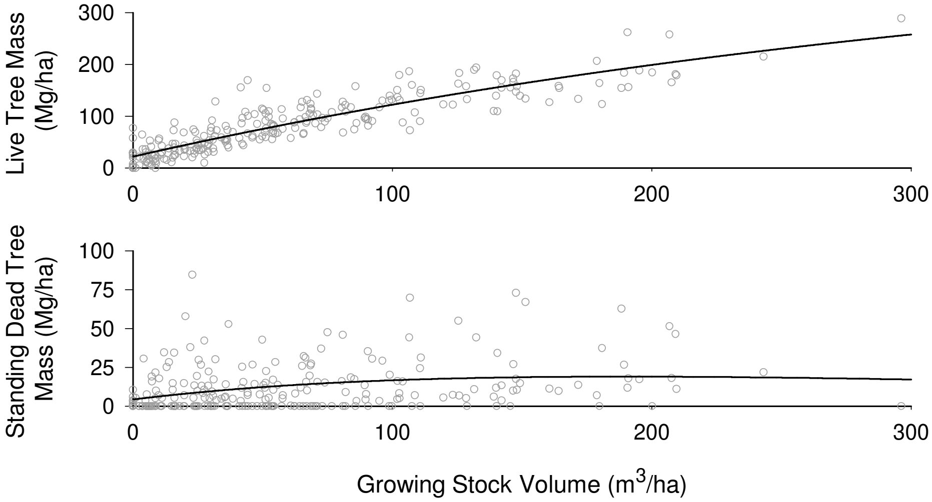


Figure 53.—Estimated mass density of live and standing dead trees in RMN Hardwoods forests.

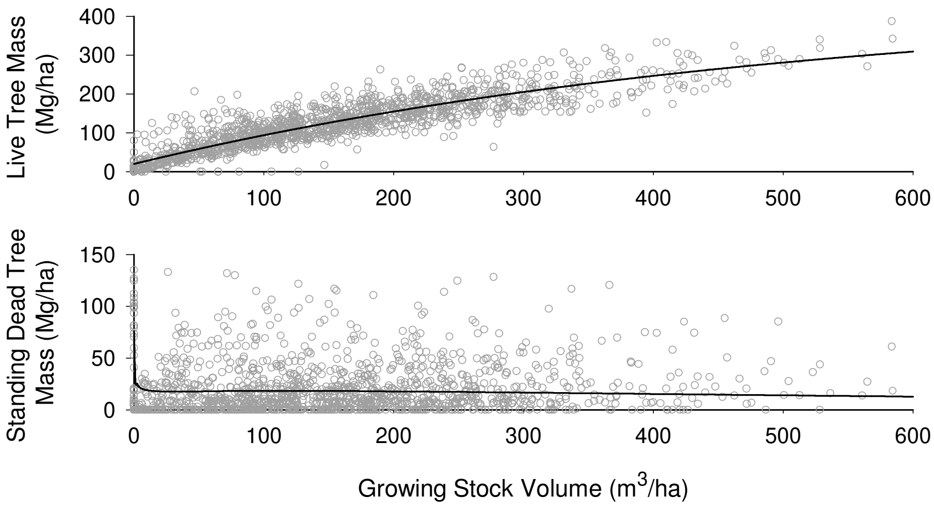


Figure 54.—Estimated mass density of live and standing dead trees in RMN Lodgepole Pine forests.

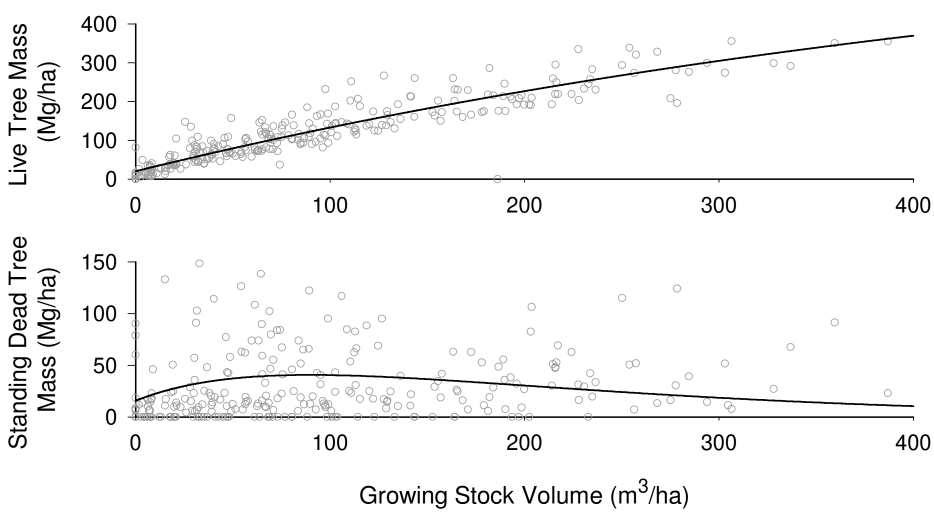


Figure 55.—Estimated mass density of live and standing dead trees in RMN Other Conifer forests.

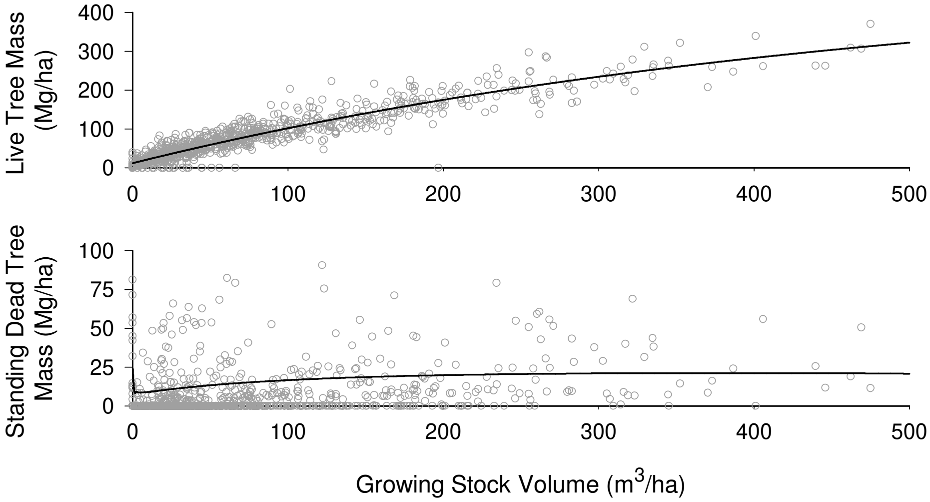


Figure 56.—Estimated mass density of live and standing dead trees in RMN Ponderosa Pine forests.

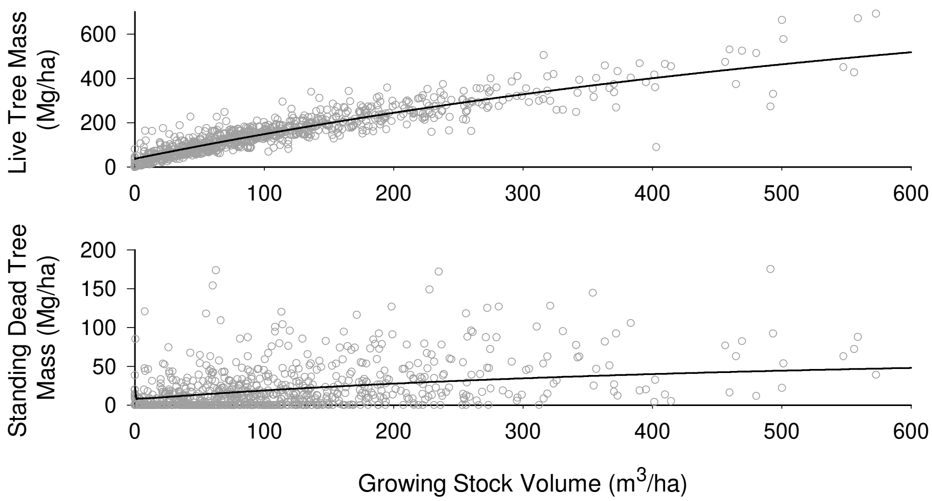


Figure 57.—Estimated mass density of live and standing dead trees in RMS Douglas-fir forests.

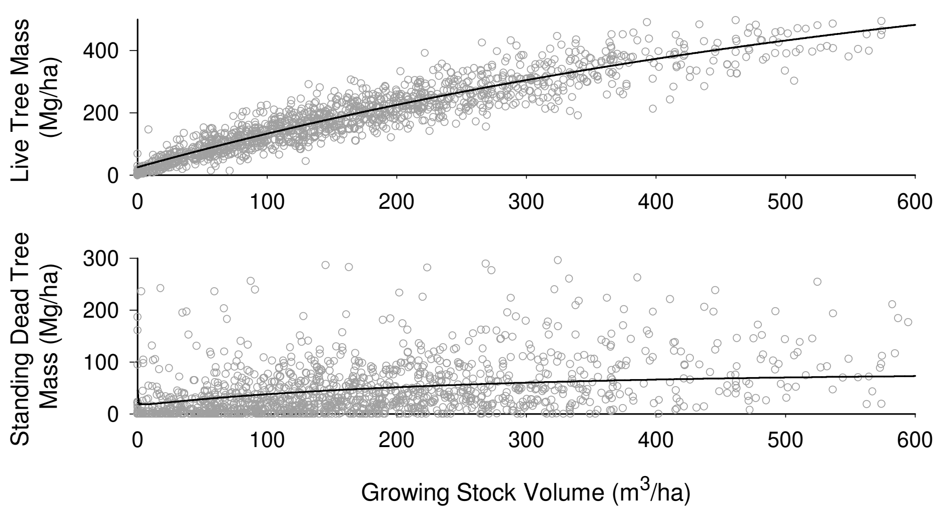


Figure 58.—Estimated mass density of live and standing dead trees in RMS Fir-Spruce forests.

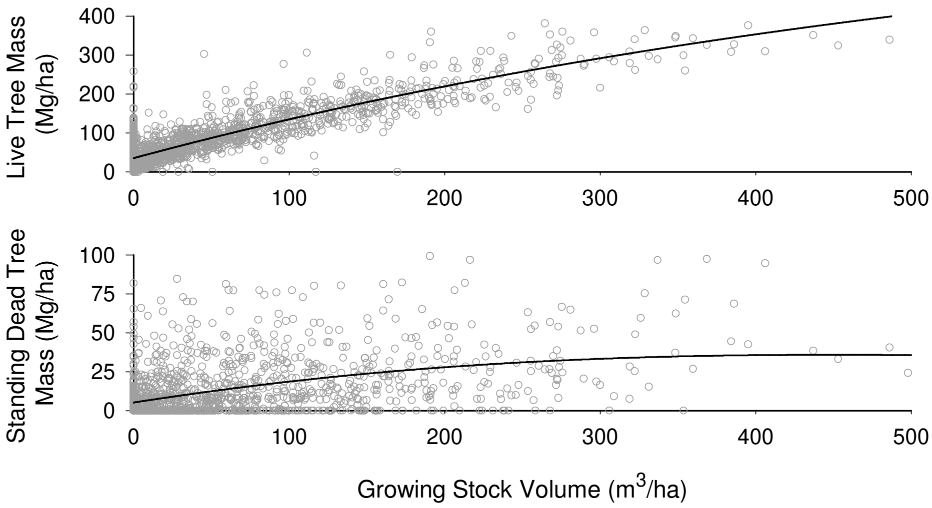


Figure 59.—Estimated mass density of live and standing dead trees in RMS Hardwoods forests.

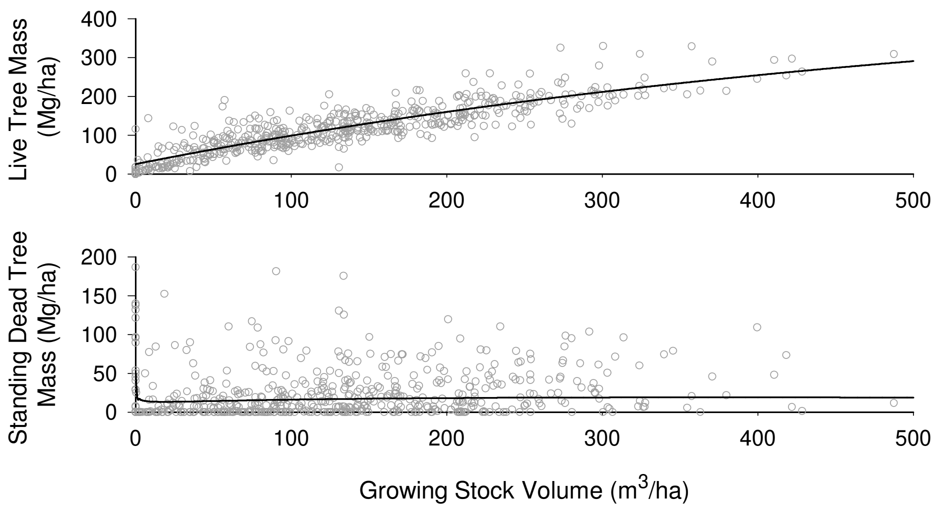


Figure 60.—Estimated mass density of live and standing dead trees in RMS Lodgepole Pine forests.

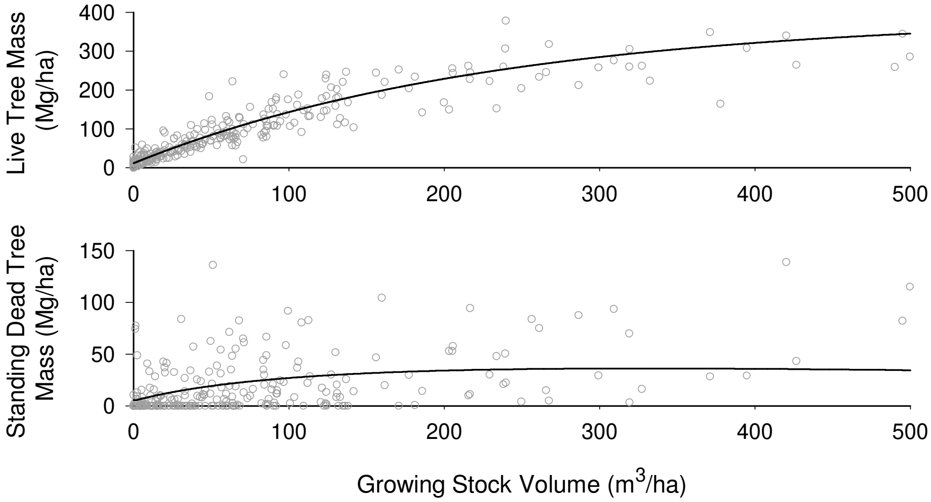


Figure 61.—Estimated mass density of live and standing dead trees in RMS Other Conifer forests.

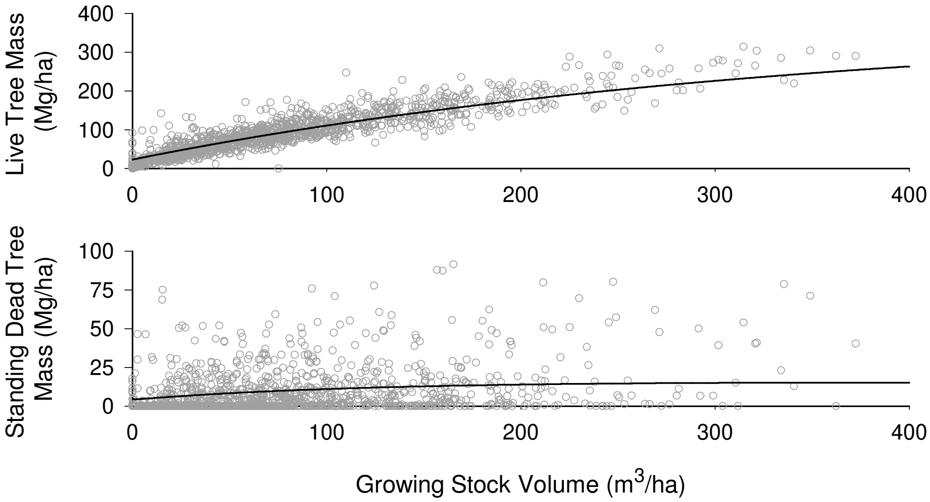


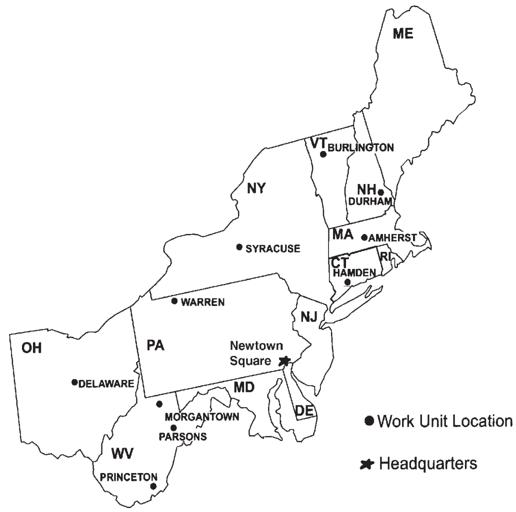
Figure 62.—Estimated mass density of live and standing dead trees in RMS Ponderosa Pine forests on publicly owned land.

Smith, James E.; Heath, Linda S.; Jenkins, Jennifer C. 2003. **Forest volume-to-biomass models and estimates of mass for live and standing dead trees of U.S. forests.** Gen. Tech. Rep. NE-298. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 57 p.

Includes methods and equations for nationally consistent estimates of tree-mass density at the stand level (Mg/ha) as predicted by growing-stock volumes reported by the USDA Forest Service for forests of the conterminous United States. Developed for use in FORCARB, a carbon budget model for U.S. forests, the equations also are useful for converting plot-, stand- and regional-level forest merchantable volumes to estimates of total mass. Also includes separate equations for live, standing dead, aboveground only and full trees (including coarse roots), and for hardwood and softwood species. Example estimates are provided for regional tree-mass totals using summary forest statistics for the United States.

Keywords: biomass, carbon, carbon sequestration, forest, live and standing dead trees

Printed on Recycled Paper



Headquarters of the Northeastern Research Station is in Newtown Square, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

Burlington, Vermont, in cooperation with the University of Vermont

Delaware, Ohio

Durham, New Hampshire, in cooperation with the University of New Hampshire

Hamden, Connecticut, in cooperation with Yale University

Morgantown, West Virginia, in cooperation with West Virginia University

Parsons, West Virginia

Princeton, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

Warren, Pennsylvania

"Caring for the Land and Serving People Through Research"