Technical Support Document: -
Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis -
Under Executive Order 12866 -

Interagency Working Group on Social Cost of Greenhouse Gases, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of the Interior
Department of Transportation
Department of the Treasury
Environmental Protection Agency
National Economic Council
Office of Management and Budget
Office of Science and Technology Policy

August 2016

See Appendix B for Details on Revisions since May 2013

Preface

The Interagency Working Group on the Social Cost of Greenhouse Gases (formerly the Interagency Working Group on the Social Cost of Carbon) has a longstanding commitment to ensure that the social cost of carbon estimates continue to reflect the best available science and methodologies. Given this commitment and public comments on issues of a deeply technical nature received by the Office of Management and Budget and federal agencies, the Interagency Working Group is seeking independent expert advice on technical opportunities to update the social cost of carbon estimates. The Interagency Working Group asked the National Academies of Sciences, Engineering, and Medicine in 2015 to review the latest research on modeling the economic aspects of climate change to inform future revisions to the social cost of carbon estimates presented in this technical support document. In January 2016, the Academies' Committee on the Social Cost of Carbon issued an interim report that recommended against a near-term update to the social cost of carbon estimates, but included recommendations for enhancing the presentation and discussion of uncertainty around the current estimates. This revision to the TSD responds to these recommendations in the presentation of the current estimates. It does not revisit the interagency group's 2010 methodological decisions or update the schedule of social cost of carbon estimates presented in the July 2015 revision. The Academies' final report (expected in early 2017) will provide longer term recommendations for a more comprehensive update.

Executive Summary

Executive Order 12866 requires agencies, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the social cost of carbon (SC-CO_2)[1] estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions. The SC-CO_2 is the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

The interagency process that developed the original U.S. government SC-CO_2 estimates is described in the 2010 Technical Support Document on the Social Cost of Carbon (TSD) (Interagency Working Group on Social Cost of Carbon 2010). Through that process the Interagency Working Group (IWG) selected SC-CO_2 values for use in regulatory analyses. For each emissions year, four values are recommended. Three of these values are based on the average SC-CO_2 from three integrated assessment models (IAMs), at discount rates of 2.5, 3, and 5 percent. In addition, as discussed in the 2010 TSD, there is extensive evidence in the scientific and economic literature on the potential for lower-probability, but higher-impact outcomes from climate change, which would be particularly harmful to society and thus relevant to the public and policymakers. The fourth value is thus included to represent the marginal damages associated with these lower-probability, higher-impact outcomes. Accordingly, this fourth value is selected from further out in the tail of the distribution of SC-CO_2 estimates; specifically, the fourth value corresponds to the 95th percentile of the frequency distribution of SC-CO_2 estimates based on a 3 percent discount rate. Because the present value of economic damages associated with CO_2 emissions change over time, a separate set of estimates is presented for each emissions year through 2050, which is sufficient to cover the time frame addressed in most current regulatory impact analyses.

In May of 2013, the IWG provided an update of the SC-CO_2 estimates based on new versions of each IAM (DICE, PAGE, and FUND). The 2013 update did not revisit other IWG modeling decisions (e.g., the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity). Improvements in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The IWG subsequently provided additional minor technical revisions in November of 2013 and July of 2015, as described in Appendix B.

The purpose of this 2016 revision to the TSD is to enhance the presentation and discussion of quantified uncertainty around the current SC-CO_2 estimates, as a response to recommendations in the interim report by the National Academies of Sciences, Engineering, and Medicine. Included herein are an expanded

[1] Throughout this Technical Support Document (TSD) we refer to the estimates as "SC-CO_2 estimates" rather than the more simplified "SCC" abbreviation used in previous versions of the TSD.

graphical presentation of the SC-CO_2 estimates highlighting a symmetric range of uncertainty around estimates for each discount rate, new sections that provide a unified discussion of the methodology used to incorporate sources of uncertainty, and a detailed explanation of the uncertain parameters in both the FUND and PAGE models.

The distributions of SC-CO_2 estimates reflect uncertainty in key model parameters chosen by the IWG such as the sensitivity of the climate to increases in carbon dioxide concentrations, as well as uncertainty in default parameters set by the original model developers. This TSD maintains the same approach to estimating the SC-CO_2 and selecting four values for each emissions year that was used in earlier versions of the TSD. Table ES-1 summarizes the SC-CO_2 estimates for the years 2010 through 2050. These estimates are identical to those reported in the previous version of the TSD, released in July 2015. As explained in previous TSDs, the central value is the average of SC-CO_2 estimates based on the 3 percent discount rate. For purposes of capturing uncertainty around the SC-CO_2 estimates in regulatory impact analysis, the IWG emphasizes the importance of considering all four SC-CO_2 values.

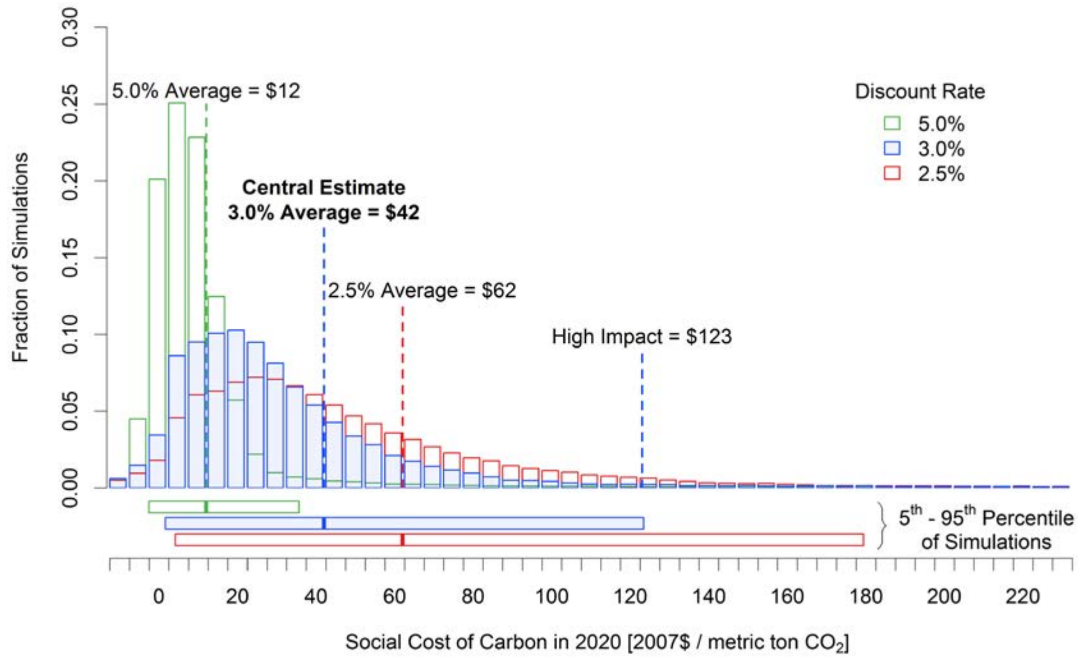
Table ES-1: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2015	11	**36**	56	105
2020	12	**42**	62	123
2025	14	**46**	68	138
2030	16	**50**	73	152
2035	18	**55**	78	168
2040	21	**60**	84	183
2045	23	**64**	89	197
2050	26	**69**	95	212

While point estimates are important for providing analysts with a tractable approach for regulatory analysis, they do not fully quantify uncertainty associated with the SC-CO_2 estimates. Figure ES-1 presents the quantified sources of uncertainty in the form of frequency distributions for the SC-CO_2 estimates for emissions in 2020. To highlight the difference between the impact of the discount rate on the SC-CO_2 and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-CO_2 estimates for each discount rate. When an agency determines that it is appropriate to conduct additional quantitative uncertainty analysis, it should follow best practices for probabilistic analysis.[2] The full set of information that underlies the frequency distributions in Figure ES-1, which have previously been available upon request, are now available on Office of Management and Budget's (OMB) website for easy public access.

[2] See e.g. OMB Circular A-4, section on *Treatment of Uncertainty*. Available at: https://www.whitehouse.gov/omb/circulars_a004_a-4/#e.

Figure ES-1: Frequency Distribution of SC-CO_2 Estimates for 2020[3]



[3] Although the distributions in Figure ES-1 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.1 to 0.6 percent of the estimates lying below the lowest bin displayed and 0.2 to 3.7 percent of the estimates lying above the highest bin displayed, depending on the discount rate.

I. Purpose

The purpose of this document is to present the current schedule of social cost of carbon (SC-CO_2) estimates, along with an enhanced presentation and discussion of quantified sources of uncertainty around the estimates to respond to recommendations in the interim report of the National Academies of Sciences, Engineering, and Medicine (National Academies 2016).[4] Because the last substantive update to the SC-CO_2 estimates occurred in May 2013, this document maintains much of the earlier technical discussion from the May 2013 TSD. The SC-CO_2 estimates themselves remain unchanged since the July 2015 revision.

E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[5] Additionally, the IWG recommended in 2010 that the SC-CO_2 estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[6] By early 2013, new versions of the three integrated assessment models (IAMs) used by the U.S. government to estimate the SC-CO_2 (DICE, FUND, and PAGE) were available and had been published in the peer-reviewed literature. While acknowledging the continued limitations of the approach taken by the IWG in 2010 (documented in the original 2010 TSD), the May 2013 TSD provided an update of the SC-CO_2 estimates based on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years earlier in a rapidly evolving field. It did not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The agencies participating in the IWG continue to investigate potential improvements to the way in which economic damages associated with changes in CO_2 emissions are quantified.

Section II summarizes the major features of the IAMs used in this TSD that were updated in 2013 relative to the versions of the models used in the 2010 TSD. Section III presents the SC-CO_2 estimates for 2010 – 2050 based on these versions of the models. Section IV discusses the treatment of uncertainty in the analysis. Section V provides a discussion of other model limitations and research gaps.

II. Summary of Model Updates

This section briefly reviews the features of the three IAMs used in this TSD (DICE 2010, FUND 3.8, and PAGE 2009) that were updated by the model developers relative to the versions of the models used by the IWG in 2010 (DICE 2007, FUND 3.5, and PAGE 2002). The focus here is on describing those model updates that are relevant to estimating the social cost of carbon, as summarized in Table 1. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other

[4] In this document, we present all social cost estimates per metric ton of CO_2 emissions. Alternatively, one could report the social cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).
[5] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf
[6] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).

revisions to PAGE include: updated adaptation assumptions, revisions to ensure damages are constrained by GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages. The DICE model's simple carbon cycle has been updated to be more consistent with a more complex climate model. The FUND model includes updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the transient response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions. Changes made to parts of the models that are superseded by the IWG's modeling assumptions—regarding equilibrium climate sensitivity, discounting, and socioeconomic variables—are not discussed here but can be found in the references provided in each section below.

Table 1: Summary of Key Model Revisions Relevant to the IWG SC-CO_2 Estimates

IAM	Version used in 2010 IWG Analysis	Version Used since May 2013	Key changes relevant to IWG SC-CO_2
DICE	2007	2010	Updated calibration of the carbon cycle model and explicit representation of sea level rise (SLR) and associated damages.
FUND	3.5 (2009)	3.8 (2012)	Updated damage functions for space heating, SLR, agricultural impacts, changes to transient response of temperature to buildup of GHG concentrations, and inclusion of indirect climate effects of methane.
PAGE	2002	2009	Explicit representation of SLR damages, revisions to damage function to ensure damages do not exceed 100% of GDP, change in regional scaling of damages, revised treatment of potential abrupt damages, and updated adaptation assumptions.

A. DICE

DICE 2010 includes a number of changes over the previous 2007 version used in the 2010 TSD. The model changes that are relevant for the SC-CO_2 estimates developed by the IWG include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—but these components of DICE are superseded by the IWG's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008) and on DICE2010 in Nordhaus (2010). The DICE2010 model and documentation is also available for download from the homepage of William Nordhaus.

Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are “calibrated to match the carbon cycle in the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)” (Nordhaus 2008, p. 44).[7] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer 2009 version of MAGICC (Nordhaus 2010, p. 2). For example, in DICE2010, in each decade 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each decade, 9.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 85.3 percent remains in the shallow ocean, and 5 percent is transferred to the deep ocean.

The implication of these changes for DICE2010 is in general a weakening of the ocean as a carbon sink and therefore a higher concentration of carbon in the atmosphere than in DICE2007 for a given path of emissions. All else equal, these changes will generally increase the level of warming and therefore the SC-CO_2 estimates in DICE2010 relative to those from DICE2007.

Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer’s website.[8] The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC’s Fourth Assessment Report (AR4).[9] The rise in sea level from thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 ^{o}C and increases linearly from 0 meters to a maximum of 7.3 meters for temperature anomalies between 1 ^{o}C and 3.5 °C. The contribution to SLR in each period is proportional to the difference between the previous period’s sea

[7] MAGICC is a simple climate model initially developed by the U.S. National Center for Atmospheric Research that has been used heavily by the Intergovernmental Panel on Climate Change (IPCC) to emulate projections from more sophisticated state of the art earth system simulation models (Randall et al. 2007).
[8] Documentation on the new sea level rise module of DICE is available on William Nordhaus’ website at: http://nordhaus.econ.yale.edu/documents/SLR_021910.pdf.
[9] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011) and NAS (2011).

level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly between 3 °C and 6 °C to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future economic production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as a sigmoid, or "S"-shaped, function of the temperature anomaly in the period.[10] The loss function in DICE2010 has been expanded by including a quadratic sub-function of SLR. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010, p. 3), who notes that "…damages in the uncontrolled (baseline) [i.e., reference] case … in 2095 are $12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 ^{o}C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 ^{o}C in DICE2007. However, in DICE2010, annual damages are lower in most of the early periods of the modeling horizon but higher in later periods than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the IWG analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the IWG SC-CO_2 estimates slightly given that relative increases in damages in later periods are discounted more heavily, all else equal.

B. FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 (Narita et al. 2010) used in the 2010 TSD. Documentation supporting FUND and the model's source code for all versions of the model

[10] The model and documentation, including formulas, are available on the author's webpage at http://www.econ.yale.edu/~nordhaus/homepage/RICEmodels.htm.

is available from the model authors.[11] Notable changes, due to their impact on the SC-CO_2 estimates, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.[12] Each of these is discussed in turn.

Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave and that there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit of large temperature anomalies, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SC-CO_2. This update accounts for a significant portion of the difference in the expected SC-CO_2 estimates reported by the two versions of the model when run probabilistically.

Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region depends on the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving inland. In FUND 3.8 the function defining the potential land lost has been changed to be a convex function of sea level rise, thereby assuming that the slope of the shore line

[11] http://www.fund-model.org/. This report uses version 3.8 of the FUND model, which represents a modest update to the most recent version of the model to appear in the literature (version 3.7) (Anthoff and Tol, 2013a, 2013b). For the purpose of computing the SC-CO_2, the relevant changes (between 3.7 to 3.8) are associated with improving consistency with IPCC AR4 by adjusting the atmospheric lifetimes of CH_4 and N_2O and incorporating the indirect forcing effects of CH_4, along with making minor stability improvements in the sea wall construction algorithm.

[12] The other damage sectors (water resources, space cooling, land loss, migration, ecosystems, human health, and extreme weather) were not significantly updated.

increases moving inland. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, thereby lowering the expected SC-CO_2 estimate. [13]

[13] For stability purposes this report also uses an update to the model which assumes that regional coastal protection measures will be built to protect the most valuable land first, such that the marginal benefits of coastal protection is decreasing in the level of protection following Fankhauser (1995).

Agriculture

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is bounded from above by one and is made up of three additive components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the coefficients of this loss function are modeled as the ratio of two random normal variables. This specification had the potential for unintended extreme behavior as draws from the parameter in the denominator approached zero or went negative. In FUND 3.8, the coefficients are drawn directly from truncated normal distributions so that they remain in the range $[0,\infty)$ and $(-\infty,0]$, respectively, ensuring the correct sign and eliminating the potential for divide-by-zero errors. The means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to decrease the range of the distribution while spreading out the distributions' mass over the remaining range relative to the previous version. The net effect of this change on the SC-CO_2 estimates is difficult to predict.

Transient Temperature Response

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year's increase in the temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year's level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity, a relationship first noted by Hansen et al. (1985) based on the heat uptake of the deep ocean. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SC-CO_2 as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

Methane

The IPCC AR4 notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007). FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of methane emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increased by 40% to account for its net impact on ozone production and stratospheric water vapor. This update to the model is relevant for the SC-CO_2 because most of the damage functions are non-linear functions of the temperature anomaly, which represents the fact that as the climate system becomes more stressed an additional unit of warming will have a greater impact on damages. Accounting for the indirect effects of CH_4 emissions on temperature will therefore move the model further up the damage curves in the baseline, making a marginal change in emissions of CO_2 more impactful. All else equal, the effect of this increased radiative forcing will be to increase the estimated SC-CO_2 values, due to greater projected temperature anomaly.

C. PAGE

PAGE09 (Hope 2013) includes a number of changes from PAGE2002, the version used in the 2010 TSD. The changes that most directly affect the SC-CO_2 estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures.[14] More details on PAGE09 can be found in Hope (2011a, 2011b, 2011c). A description of PAGE2002 can be found in Hope (2006).

Sea Level Rise

While PAGE2002 aggregates all damages into two categories—economic and non-economic impacts—PAGE09 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. In PAGE09 sea level damages increase less than linearly with sea level under the assumption that land, people, and GDP are more concentrated in low-lying shoreline areas. Damages from the economic and non-economic sectors were adjusted to account for the introduction of this new category.

Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

[14] Because several changes in the PAGE model are structural (e.g., the addition of sea level rise and treatment of discontinuity), it is not possible to assess the direct impact of each change on the SC-CO_2 in isolation as done for the other two models above.

Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factors in PAGE09 are based on the length of each region's coastline relative to the EU (Hope 2011b). Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC's third assessment report, and allowed for benefits from temperature increases in Eastern Europe, smaller impacts in developed countries, and higher damages in developing countries.

Probability of a Discontinuity

In PAGE2002, the damages associated with a "discontinuity" (nonlinear extreme event) were modeled as an expected value. Specifically, a stochastic probability of a discontinuity was multiplied by the damages associated with a discontinuity to obtain an expected value, and this was added to the economic and non-economic impacts. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of discontinuity is treated as a discrete event for each year in the model. The damages for each model run are estimated either with or without a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by their regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

Adaptation

As in PAGE2002, adaptation is available to help mitigate any climate change impacts that occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 2°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 2°C by 50-90 percent after 20 years. Beyond 2°C, no adaptation is assumed to be available to mitigate the impacts of climate change. For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c) estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SC-CO_2 by approximately 30 percent.

Other Noteworthy Changes

Two other changes in the model are worth noting. There is a change in the way the model accounts for decreased CO_2 absorption on land and in the ocean as temperature rises. PAGE09 introduces a linear feedback from global mean temperature to the percentage gain in the excess concentration of CO_2, capped at a maximum level. In PAGE2002, an additional amount was added to the CO_2 emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In PAGE2002, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass, to capture relatively greater changes in temperature forecast to be experienced at higher latitudes.

III. SC-CO_2 Estimates

The three IAMs were run using the same methodology detailed in the 2010 TSD (Interagency Working Group on Social Cost of Carbon 2010). The approach, along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the IPCC AR4, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, use of three models, three discount rates, and five scenarios produces 45 separate frequency distributions of SC-CO_2 estimates in a given year. The approach laid out in the 2010 TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions, one for each of the three discount rates. The IWG selected four values from these distributions for use in regulatory analysis. Three values are based on the average SC-CO_2 across models and socioeconomic and emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value is included to provide information on the marginal damages associated with lower-probability, higher-impact outcomes that would be particularly harmful to society. As discussed in the 2010 TSD, there is extensive evidence in the scientific and economic literature of the potential for lower-probability, higher-impact outcomes from climate change, which would be particularly harmful to society and thus relevant to the public and policymakers. This points to the relevance of values above the mean in right skewed distributions. Accordingly, this fourth value is selected from further out in the tails of the frequency distribution of SC-CO_2 estimates, and, in particular, is set to the 95th percentile of the frequency distribution of SC-CO_2 estimates based on a 3 percent discount rate. (A detailed set of percentiles by model and scenario combination and additional summary statistics for the 2020 values is available in Appendix A.) As noted in the 2010 TSD, "the 3 percent discount rate is the central value, and so the central value that emerges is the average SC-CO_2 across models at the 3 percent discount rate" (Interagency Working Group on Social Cost of Carbon 2010, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the IWG emphasizes the importance and value of including all four SC-CO_2 values.

Table 2 shows the four selected SC-CO_2 estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using linear interpolation. The full set of revised annual SC-CO_2 estimates between 2010 and 2050 is reported in the Appendix and the full set of model results are available on the OMB website.[15]

Table 2: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2015	11	**36**	56	105
2020	12	**42**	62	123
2025	14	**46**	68	138
2030	16	**50**	73	152
2035	18	**55**	78	168
2040	21	**60**	84	183
2045	23	**64**	89	197
2050	26	**69**	95	212

As was the case in the 2010 TSD, the SC-CO_2 increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modeled as proportional to gross GDP. The approach taken by the IWG is to compute the cost of a marginal ton emitted in the future by running the models for a set of perturbation years out to 2050. Table 3 illustrates how the growth rate for these four SC-CO_2 estimates varies over time.

[15] https://www.whitehouse.gov/omb/oira/social-cost-of-carbon.

Table 3: Average Annual Growth Rates of SC-CO_2 Estimates between 2010 and 2050

Average Annual Growth Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.2%	2.4%	4.4%
2020-2030	3.4%	2.1%	1.7%	2.3%
2030-2040	3.0%	1.9%	1.5%	2.0%
2040-2050	2.6%	1.6%	1.3%	1.6%

The future monetized value of emission reductions in each year (the SC-CO_2 in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. As previously discussed in the 2010 TSD, damages from future emissions should be discounted at the same rate as that used to calculate the SC-CO_2 estimates themselves to ensure internal consistency—i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted to the base year of the analysis using the same rate.

Current guidance contained in OMB Circular A-4 indicates that analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the IWG (including OMB) determined that a modified approach is more appropriate in this case because the climate change problem is highly unusual in a number of respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States—and conversely, greenhouse gases emitted elsewhere contribute to damages in the United States. Consequently, to address the global nature of the problem, the SC-CO_2 must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Other countries will also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions. For example, the United States joined over 170 other nations and signed the Paris Agreement on April 22, 2016, signaling worldwide commitment to reduce GHG emissions. The United States has been active in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. Using a global estimate of damages in U.S. regulatory analyses sends a strong signal to other nations that they too should base their emissions reductions strategies on a global perspective, thus supporting a cooperative and mutually beneficial approach to achieving needed reduction. Thirteen prominent academics noted that these "are compelling reasons to focus on a global [SC-CO_2]" in a recent article on the SC-CO_2 (Pizer et al. 2014). In addition, adverse impacts on other countries can have spillover effects on the United States, particularly in the areas of national security, international trade, public health, and humanitarian concerns. When these considerations are taken as a whole, the IWG concluded that a global measure of the benefits from reducing U.S. emissions is appropriate. For additional discussion, see the 2010 TSD.

IV. Treatment of Uncertainty

Uncertainty about the value of the SC-CO_2 is in part inherent, as with any analysis that looks into the future, but it is also driven by current data gaps associated with the complex physical, economic, and behavioral processes that link GHG emissions to human health and well-being. Some sources of uncertainty pertain to aspects of the natural world, such as quantifying the physical effects of greenhouse gas emissions on Earth systems. Other sources of uncertainty are associated with current and future human behavior and well-being, such as population and economic growth, GHG emissions, the translation of Earth system changes to economic damages, and the role of adaptation. It is important to note that even in the presence of uncertainty, scientific and economic analysis can provide valuable information to the public and decision makers, though the uncertainty should be acknowledged and when possible taken into account in the analysis. This section summarizes the sources of uncertainty that the IWG was able to consider in a quantitative manner in estimating the SC-CO_2. Further discussion on sources of uncertainty that are active areas of research and have not yet been fully quantified in the SC-CO_2 estimates is provided in Section V and in the 2010 TSD.

In developing the SC-CO_2 estimates, the IWG considered various sources of uncertainty through a combination of a multi-model ensemble, probabilistic analysis, and scenario analysis. For example, the three IAMs used collectively span a wide range of Earth system and economic outcomes to help reflect the uncertainty in the literature and in the underlying dynamics being modeled. The use of an ensemble of three different models is also intended to, at least partially, address the fact that no single model includes all of the quantified economic damages. It also helps to reflect structural uncertainty across the models, which is uncertainty in the underlying relationships between GHG emissions, Earth systems, and economic damages that are included in the models. Bearing in mind the different limitations of each model (discussed in the 2010 TSD) and lacking an objective basis upon which to differentially weight the models, the three IAMs are given equal weight in the analysis.

The IWG used Monte Carlo techniques to run the IAMs a large number of times. In each simulation the uncertain parameters are represented by random draws from their defined probability distributions. In all three models the equilibrium climate sensitivity is treated probabilistically based on the probability distribution described in the 2010 TSD. The equilibrium climate sensitivity is a key parameter in this analysis because it helps define the strength of the climate response to increasing GHG concentrations in the atmosphere. In addition, the FUND and PAGE models define many of their parameters with probability distributions instead of point estimates. For these two models, the model developers' default probability distributions are maintained for all parameters other than those superseded by the IWG's harmonized inputs (i.e., equilibrium climate sensitivity, socioeconomic and emissions scenarios, and discount rates). More information on the uncertain parameters in PAGE and FUND is presented in Appendix C.

For the socioeconomic and emissions scenarios, uncertainty is included in the analysis by considering a range of scenarios, which are described in detail in the 2010 SC-CO_2 TSD. As noted in the 2010 TSD, while the IWG considered formally assigning probability weights to the different socioeconomic scenarios selected, it came to the conclusion that this could not be accomplished in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socioeconomic pathways. Thus, the IWG determined that, because no basis for assigning differential weights was available, the most transparent way to present a range of uncertainty was simply to weight each of the five scenarios equally for the consolidated estimates. To provide additional information as to how the results vary with the scenarios, summarized results for each scenario are presented separately in Appendix A. The results of each model run are available on the OMB website.

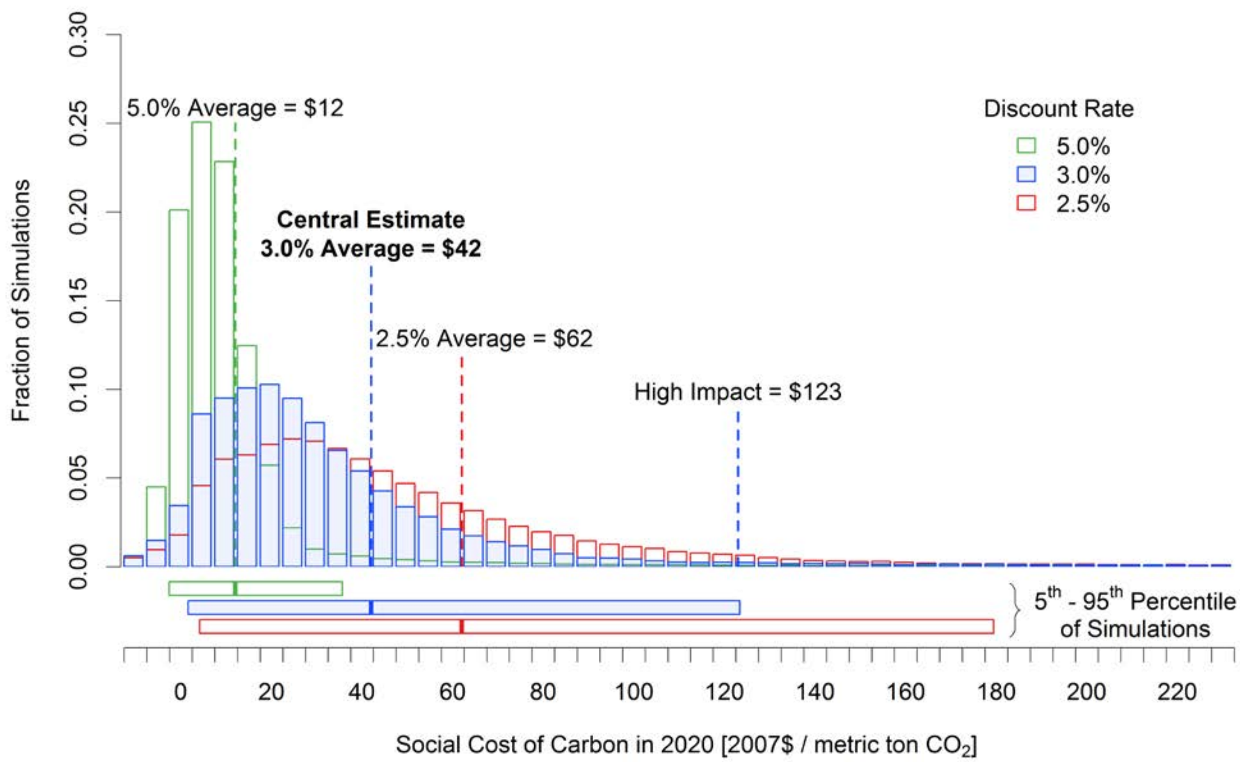
Finally, based on the review of the literature, the IWG chose discount rates that reflect reasonable judgements under both prescriptive and descriptive approaches to intergenerational discounting. As discussed in the 2010 TSD, in light of disagreement in the literature on the appropriate discount rate to use in this context and uncertainty about how rates may change over time, the IWG selected three certainty-equivalent constant discount rates to span a plausible range: 2.5, 3, and 5 percent per year. However, unlike the approach taken for consolidating results across models and socioeconomic and emissions scenarios, the SC-CO_2 estimates are not pooled across different discount rates because the range of discount rates reflects both uncertainty and, at least in part, different policy or value judgements.

The outcome of accounting for various sources of uncertainty using the approaches described above is a frequency distribution of the SC-CO_2 estimates for emissions occurring in a given year for each of the three discount rates. These frequency distributions reflect the uncertainty around the input parameters for which probability distributions were defined, as well as from the multi-model ensemble and socioeconomic and emissions scenarios where probabilities were implied by the equal weighting assumption. It is important to note that the set of SC-CO_2 estimates obtained from this analysis does not yield a probability distribution that fully characterizes uncertainty about the SC-CO_2 due to impact categories omitted from the models and sources of uncertainty that have not been fully characterized due to data limitations.

Figure 1 presents the frequency distribution of the SC-CO_2 estimates for emissions in 2020 for each of the three discount rates. Each of these distributions represents 150,000 estimates based on 10,000 simulations for each combination of the three models and five socioeconomic and emissions scenarios.[16] In general, the distributions are skewed to the right and have long right tails, which tend to be even longer for lower discount rates. To highlight the difference between the impact of the discount rate on the SC-CO_2 and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-CO_2 estimates conditioned on each discount rate. The full set of SC-CO_2 results through 2050 is available on OMB's website. This may be useful to analysts in situations that warrant additional quantitative uncertainty analysis (e.g., as recommended by OMB for rules that exceed $1 billion in annual benefits or costs). See OMB Circular A-4 for guidance and discussion of best practices in conducting uncertainty analysis in RIAs.

[16] Although the distributions in Figure 1 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.1 to 0.6 percent of the estimates lying below the lowest bin displayed and 0.2 to 3.7 percent of the estimates lying above the highest bin displayed, depending on the discount rate.

Figure 1: Frequency Distribution of $SC\text{-}CO_2$ Estimates for 2020 (in 2007$ per metric ton CO_2)



As previously described, the $SC\text{-}CO_2$ estimates produced by the IWG are based on a rigorous approach to accounting for quantifiable uncertainty using multiple analytical techniques. In addition, the scientific and economics literature has further explored known sources of uncertainty related to estimates of the $SC\text{-}CO_2$. For example, researchers have published papers that explore the sensitivity of IAMs and the resulting $SC\text{-}CO_2$ estimates to different assumptions embedded in the models (see, e.g., Hope (2013), Anthoff and Tol (2013a), and Nordhaus (2014)). However, there remain additional sources of uncertainty that have not been fully characterized and explored due to remaining data limitations. Additional research is needed in order to expand the quantification of various sources of uncertainty in estimates of the $SC\text{-}CO_2$ (e.g., developing explicit probability distributions for more inputs pertaining to climate impacts and their valuation). The IWG is actively following advances in the scientific and economic literature that could provide guidance on, or methodologies for, a more robust incorporation of uncertainty.

V. Other Model Limitations and Research Gaps

The 2010 $SC\text{-}CO_2$ TSD discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. While the more recent versions of the models discussed above offer some improvements in these areas, further research is still needed. Currently, IAMs do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature due to a lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research.[17] These individual limitations do not all work in the same direction in terms of their influence on the SC-CO_2 estimates; however, it is the IWG's judgment that, taken together, these limitations suggest that the SC-CO_2 estimates are likely conservative. In particular, the IPCC Fourth Assessment Report (Meehl et al. 2007), which was the most current IPCC assessment available at the time of the IWG's 2009-2010 review, concluded that SC-CO_2 estimates "very likely…underestimate the damage costs" due to omitted impacts. Since then, the peer-reviewed literature has continued to support this conclusion, as noted in the IPCC Fifth Assessment report (Oppenheimer et al. 2014).

Another area of active research relates to intergenerational discounting, including the application of discount rates to regulations in which some costs and benefits accrue intra-generationally while others accrue inter-generationally. Some experts have argued that a declining discount rate would be appropriate to analyze impacts that occur far into the future (Arrow et al. 2013). However, additional research and analysis is still needed to develop a methodology for implementing a declining discount rate and to understand the implications of applying these theoretical lessons in practice.

The 2010 TSD also discusses the need to more carefully assess the implications of risk aversion for SC-CO_2 estimation as well as the substitution possibilities between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in research on modeling and valuation of climate impacts that can potentially improve SC-CO_2 estimation in the future. See the 2010 SC-CO_2 TSD for the full discussion.

[17] See, for example, Howard (2014) and EPRI (2014) for recent discussions.

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Appendix A

Table A1: Annual SC-CO_2 Values: 2010-2050 (2007$/metric ton CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2011	11	**32**	51	90
2012	11	**33**	53	93
2013	11	**34**	54	97
2014	11	**35**	55	101
2015	11	**36**	56	105
2016	11	**38**	57	108
2017	11	**39**	59	112
2018	12	**40**	60	116
2019	12	**41**	61	120
2020	12	**42**	62	123
2021	12	**42**	63	126
2022	13	**43**	64	129
2023	13	**44**	65	132
2024	13	**45**	66	135
2025	14	**46**	68	138
2026	14	**47**	69	141
2027	15	**48**	70	143
2028	15	**49**	71	146
2029	15	**49**	72	149
2030	16	**50**	73	152
2031	16	**51**	74	155
2032	17	**52**	75	158
2033	17	**53**	76	161
2034	18	**54**	77	164
2035	18	**55**	78	168
2036	19	**56**	79	171
2037	19	**57**	81	174
2038	20	**58**	82	177
2039	20	**59**	83	180
2040	21	**60**	84	183
2041	21	**61**	85	186
2042	22	**61**	86	189
2043	22	**62**	87	192
2044	23	**63**	88	194
2045	23	**64**	89	197
2046	24	**65**	90	200
2047	24	**66**	92	203
2048	25	**67**	93	206
2049	25	**68**	94	209
2050	26	**69**	95	212

Table A2: 2020 Global SC-CO_2 Estimates at 2.5 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario[18]					PAGE					
IMAGE	6	10	15	26	55	123	133	313	493	949
MERGE Optimistic	4	6	8	15	32	75	79	188	304	621
MESSAGE	4	7	10	19	41	104	103	266	463	879
MiniCAM Base	5	8	12	21	45	102	108	255	412	835
5th Scenario	2	4	6	11	24	81	66	192	371	915
Scenario					DICE					
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE Optimistic	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126
Scenario					FUND					
IMAGE	-14	-2	4	15	31	39	55	86	107	157
MERGE Optimistic	-6	1	6	14	27	35	46	70	87	141
MESSAGE	-16	-5	1	11	24	31	43	67	83	126
MiniCAM Base	-7	2	7	16	32	39	55	83	103	158
5th Scenario	-29	-13	-6	4	16	21	32	53	69	103

Table A3: 2020 Global SC-CO_2 Estimates at 3 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	4	7	9	17	36	87	91	228	369	696
MERGE Optimistic	2	4	6	10	22	54	55	136	222	461
MESSAGE	3	5	7	13	28	72	71	188	316	614
MiniCAM Base	3	5	7	13	29	70	72	177	288	597
5th Scenario	1	3	4	7	16	55	46	130	252	632
Scenario					DICE					
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE Optimistic	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79
Scenario					FUND					
IMAGE	-13	-4	0	8	18	23	33	51	65	99
MERGE Optimistic	-7	-1	2	8	17	21	29	45	57	95
MESSAGE	-14	-6	-2	5	14	18	26	41	52	82
MiniCAM Base	-7	-1	3	9	19	23	33	50	63	101
5th Scenario	-22	-11	-6	1	8	11	18	31	40	62

[18] See 2010 TSD for a description of these scenarios.

Table A4: 2020 Global SC-CO_2 Estimates at 5 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	1	2	2	4	10	27	26	68	118	234
MERGE Optimistic	1	1	2	3	6	17	17	43	72	146
MESSAGE	1	1	2	4	8	23	22	58	102	207
MiniCAM Base	1	1	2	3	8	20	20	52	90	182
5th Scenario	0	1	1	2	5	17	14	39	75	199

Scenario	DICE									
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE Optimistic	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21

Scenario	FUND									
IMAGE	-9	-5	-4	-1	2	3	6	10	14	24
MERGE Optimistic	-6	-4	-2	0	3	4	6	11	15	26
MESSAGE	-10	-6	-4	-1	1	2	5	9	12	21
MiniCAM Base	-7	-4	-2	0	3	4	6	11	14	25
5th Scenario	-11	-7	-5	-3	0	0	3	5	7	13

Table A5: Additional Summary Statistics of 2020 Global SC-CO_2 Estimates

Discount rate:	5.0%				3.0%				2.5%			
Statistic:	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	12	26	2	15	38	409	3	24	57	1097	3	30
PAGE	21	1481	5	32	68	13712	4	22	97	26878	4	23
FUND	3	41	5	179	19	1452	-42	8727	33	6154	-73	14931

Appendix B

The November 2013 revision of this TSD is based on two corrections to the runs based on the FUND model. First, the potential dry land loss in the algorithm that estimates regional coastal protections was misspecified in the model's computer code. This correction is covered in an erratum to Anthoff and Tol (2013a) published in the same journal (*Climatic Change*) in October 2013 (Anthoff and Tol (2013b)). Second, the equilibrium climate sensitivity distribution was inadvertently specified as a truncated Gamma distribution (the default in FUND) as opposed to the truncated Roe and Baker distribution as was intended. The truncated Gamma distribution used in the FUND runs had approximately the same mean and upper truncation point, but lower variance and faster decay of the upper tail, as compared to the intended specification based on the Roe and Baker distribution. The difference between the original estimates reported in the May 2013 version of this TSD and this revision are generally one dollar or less.

The July 2015 revision of this TSD is based on two corrections. First, the DICE model had been run up to 2300 rather than through 2300, as was intended, thereby leaving out the marginal damages in the last year of the time horizon. Second, due to an indexing error, the results from the PAGE model were in 2008 U.S. dollars rather than 2007 U.S. dollars, as was intended. In the current revision, all models have been run through 2300, and all estimates are in 2007 U.S. dollars. On average the revised SC-CO_2 estimates are one dollar less than the mean SC-CO_2 estimates reported in the November 2013 version of this TSD. The difference between the 95th percentile estimates with a 3% discount rate is slightly larger, as those estimates are heavily influenced by results from the PAGE model.

The July 2016 revision provides additional discussion of uncertainty in response to recommendations from the National Academy of Sciences, Engineering, and Medicine. It does not revisit the IWG's 2010 methodological decisions or update the schedule of SC-CO_2 estimates presented in the July 2015 revision. The IWG is currently seeking external expert advice from the National Academies on the technical merits and challenges of potential approaches to future updates of the SC-CO_2 estimates presented in this TSD. To date, the Academies' committee has issued an interim report that recommended against a near-term update to the SC-CO_2 estimates, but included recommendations for enhancing the presentation and discussion of uncertainty around the current estimates. This revision includes additional information that the IWG determined was appropriate to respond to these recommendations. Specifically, the executive summary presents more information about the range of quantified uncertainty in the SC-CO_2 estimates (including a graphical representation of symmetric high and low values from the frequency distribution of SC-CO_2 estimates conditional on each discount rate), and a new section has also been added that provides a unified discussion of the various sources of uncertainty and how they were handled in estimating the SC-CO_2. Efforts to make the sources of uncertainty clear have also been enhanced with the addition of a new appendix that describes in more detail the uncertain parameters in both the FUND and PAGE models (Appendix C). Furthermore, the full set of SC-CO_2 modeling results, which have previously been available upon request, are now provided on the OMB website for easy access. The Academies' final report (expected in early 2017) will provide longer term recommendations for a more comprehensive update. For more information on the status of the Academies' process, see: http://sites.nationalacademies.org/DBASSE/BECS/CurrentProjects/DBASSE_167526.

Appendix C

This appendix provides a general overview of the parameters that are treated probabilistically in each of the three integrated assessment models the IWG used to estimate the SC-CO_2. In the DICE model the only uncertain parameter considered was the equilibrium climate sensitivity as defined by the probability distribution harmonized across the three models. By default, all of the other parameters in the model are defined by point estimates and these definitions were maintained by the IWG. In the FUND and PAGE models many of the parameters, beyond the equilibrium climate sensitivity, are defined by probability distributions in the default versions of the models. The IWG maintained these default assumptions and allowed these parameters to vary in the Monte Carlo simulations conducted with the FUND and PAGE models.

Default Uncertainty Assumptions in FUND

In the version of the FUND model used by the IWG (version 3.8.1) over 90 of the over 150 parameters in the model are defined by probability distributions instead of point estimates, and for 30 of those parameters the values vary across the model's 16 regions. This includes parameters related to the physical and economic components of the model. The default assumptions in the model include parameters whose probability distributions are based on the normal, Gamma, and triangular distributions. In most cases the distributions are truncated from above or below. The choice of distributions and parameterizations are based on the model developers' assessment of the scientific and economic literature. Complete information on the exact probability distributions specified for each uncertain parameter is provided through the model's documentation, input data, and source code, available at: http://www.fund-model.org/home.

The physical components of the model map emissions to atmospheric concentrations, then map those concentrations to radiative forcing, which is then mapped to changes in global mean temperature. Changes in temperature are then used to estimate sea level rise. The parameters treated probabilistically in these relationships may be grouped into three main categories: atmospheric lifetimes, speed of temperature response, and sea level rise. First, atmospheric concentrations are determined by one box models, that capture a single representative sink, for each of the three non-CO_2 GHGs and a five box model for CO_2, that represents the multiple sinks in the carbon cycle that operate on different time frames. In each of these boxes, the lifetime of additions to the atmospheric concentration in the box are treated as uncertain. Second, parameters associated with speed at which the climate responds to changes in radiative forcing are treated as uncertain. In the FUND model radiative forcing, R_t, is mapped to changes in global mean temperature, T_t, through

$$T_t = T_{t-1} + \frac{1}{\theta_1 + \theta_2 ECS + \theta_3 ECS^2}\left(\frac{\psi ECS}{\ln(2)} R_t - T_{1-t}\right),$$

where the probability distribution for the equilibrium climate sensitivity, ECS, was harmonized across the models as discussed in the 2010 TSD. The parameters θ_i define the speed at which the temperature anomaly responds to changes in radiative forcing and are treated as uncertain in the model. Third, sea level rise is treated as a mean reverting function, where the mean is determined as proportional to the current global mean temperature anomaly. Both this proportionality parameter and the rate of mean reversion in this relationship are treated as uncertain in the model.

The economic components of the model map changes in the physical components to monetized damages. To place the uncertain parameters of the model associated with mapping physical endpoints to damages in context, it is useful to consider the general form of the damage functions in the model. Many of the damage functions in the model have forms that are roughly comparable to

$$D_{r,t} = \alpha_r Y_{r,t} \beta_{r,t} \left(\frac{y_{r,t}}{y_{r,b}} \right)^{\gamma} \left(\frac{N_{r,t}}{N_{r,b}} \right)^{\phi} T_t^{\delta}, \quad (1)$$

where α_r is the damage at a 1 °C global mean temperature increase as a fraction of regional GDP, $Y_{r,t}$. The model considers numerous changes that may reduce a region's benchmark vulnerability to climate change. For example, γ represents the elasticity of damages with respect to changes in the region's GDP per capita, $y_{r,t}$, relative to a benchmark value, $y_{r,b}$; ϕ represents the elasticity of damages with respect to changes in the region's population, $N_{r,t}$, relative to a benchmark value, $N_{r,b}$; and the projection $\beta_{r,t}$ provides for an exogenous reduction in vulnerability (e.g., forecast energy efficiency improvements the affect space cooling costs). Once the benchmark damages have been scaled due to changes in vulnerability they are adjusted based on a non-linear scaling of the level of climate change forecast, using a power function with the exponent, δ.

Some damage categories have damage function specifications that differ from the example in (1). For example, agriculture and forestry damages take atmospheric concentrations of CO_2 and the rate of climate change into account in different forms, though the method by which they calculate the monetized impact in these cases is similar with respect to accounting for GDP growth and changes in vulnerability. In other cases the process by which damages are estimated is more complex. For example, in estimating damages from sea level rise the model considers explicit regional decision makers that choose levels of coastal protection in a given year based on a benefit-cost test. In estimating the damages from changes in cardiovascular mortality risk the model considers forecast changes in the proportion of the population over the age of 65 and deemed most vulnerable by the model developers. Other damage categories may also have functional forms that differ slightly from (1), but in general this form provides a useful framework for discussing the parameters for which the model developers have defined probability distributions as opposed to point estimates.

In many damage categories (e.g., sea level rise, water resources, biodiversity loss, agriculture and forestry, and space conditioning) the benchmark damages, α_r, are treated as uncertain parameters in the model and in most case they are assumed to vary by region. The elasticity of damages with respect to changes in regional GDP per capita, γ, and the elasticity with respect to changes in regional population, ϕ, are also treated as uncertain parameters in most damage functions in the model, though they are not assumed to vary across regions. In most cases the exponent, δ, on the power function that scales damages based on the forecast level of climate change are also treated as uncertain parameters, though they are not assumed to vary across regions in most cases.

Figure C1 presents results of an analysis from the developers of the FUND model that examines the uncertain parameters that have the greatest influence on estimates of the SC-CO_2 based on the default version of the model. While some of the modeling inputs are different for the SC-CO_2 estimates calculated by the IWG these parameters are likely to remain highly influential in the FUND modeling results.

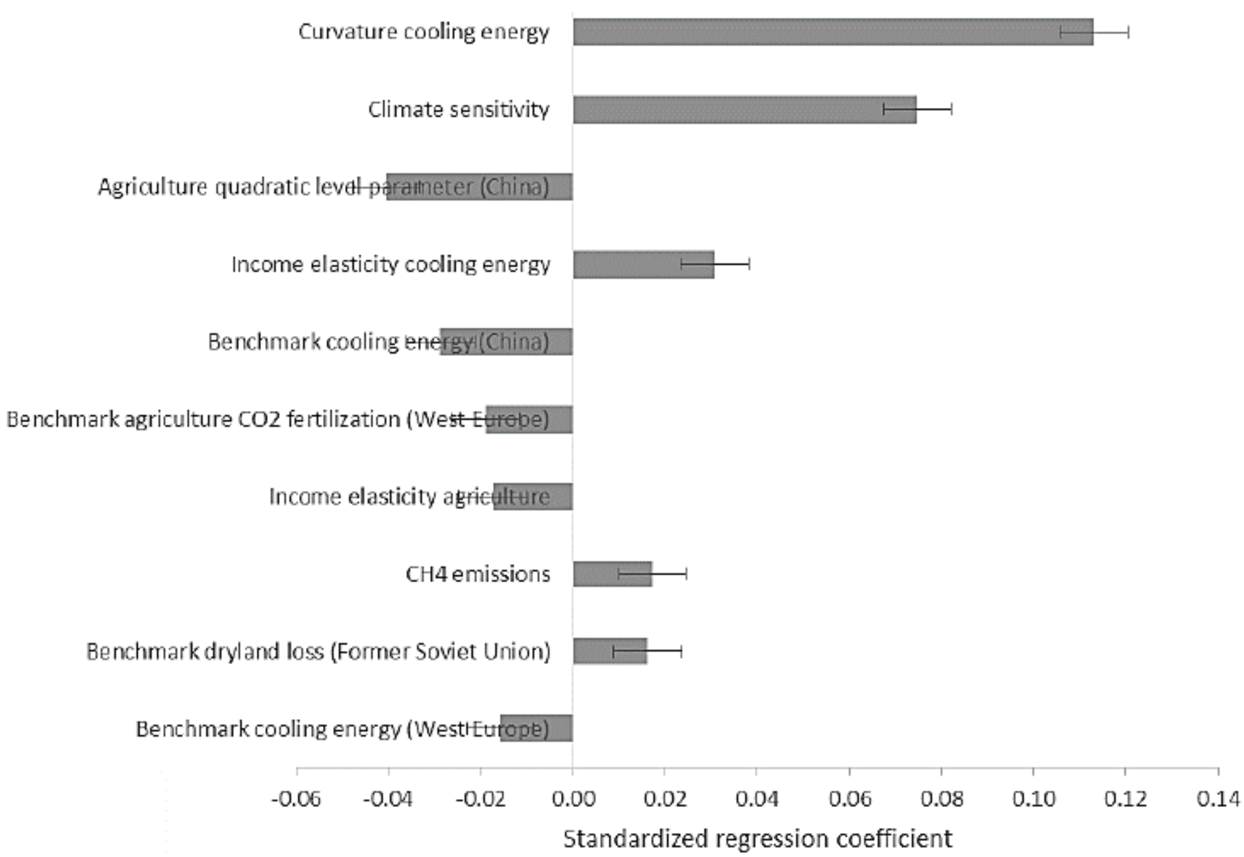

Figure C1: Influence of Key Uncertain Parameters in Default FUND Model (Anthoff and Tol 2013a)[19]

Default Uncertainty Assumptions in PAGE

In the version of the PAGE model used by the IWG (version PAGE09) there are over 40 parameters defined by probability distributions instead of point estimates.[20] The parameters can broadly be classified as related to climate science, damages, discontinuities, and adaptive and preventive costs. In the default version of the model, all of the parameters are modeled as triangular distributions except for the one variable related to the probability of a discontinuity occurring, with is represented by a uniform distribution. More detail on the model equations can be found in Hope (2006, 2011a) and the default minimum, mode, and maximum values for the parameters are provided in Appendix 2 of Hope (2011a). The calibration of these distributions is based on the developer's assessment of the IPCC's Fourth Assessment report and scientific articles referenced in Hope (2011a, 2011b, 2011c). The IWG added an uncertain parameter to the default model, specifically the equilibrium climate sensitivity parameter, which was harmonized across the models as discussed in the 2010 TSD.

In the climate component of the PAGE model, atmospheric CO_2 concentration is assumed to follow an initial rapid decay followed by an exponential decline to an equilibrium level. The parameters treated probabilistically in this decay are the proportion of the anthropogenic CO_2 emissions that enter the atmosphere, the half-life of the CO_2's atmospheric residence, and the fraction of cumulative emissions that ultimately remains in the atmosphere. A carbon cycle feedback is included to represent the impact of increasing temperatures on the role of the terrestrial biosphere and oceans in the carbon cycle. This feedback is modeled with probabilistic parameters representing the percentage increase in the CO_2 concentration anomaly and with an uncertain upper bound on this percentage.

The negative radiative forcing effect from sulfates is modeled with probabilistic parameters for the direct linear effect due to backscattering and the indirect logarithmic effect assumed for cloud interactions. The radiative forcing from CO_2, all other greenhouse gases, and sulfates are combined in a one box model to estimate the global mean temperature. Uncertainty in the global mean temperature response to change in radiative forcing is based on the uncertain equilibrium climate sensitivity parameter and uncertainty in the half-life of the global response to an increase in radiative forcing, which defines the inertia of the climate system in the model. Temperature anomalies in the model vary geographically, with larger increases over land and the poles. Probabilistic parameters are used for the ratios of the temperature anomaly over land relative to the ocean and the ratio of the temperature anomaly over the poles relative to the equator. The PAGE model also includes an explicit sea level component, modelled as a lagged function of the global mean temperature anomaly. The elements of this component that are treated

[19] Based on a coefficients of standardized regression of parameter draws on the SC-CO_2 using FUND 3.8.1 under Ramsey discounting with a pure rate of time preference of one percent and rate of relative risk aversion of 1.5. The 90 percent confidence intervals around the regression coefficients are presented as error bars.

[20] This appendix focuses on the parameters in the PAGE model related to estimating the climate impacts and principle calculation of the monetized damages. There are over 60 additional parameters in the model related to abatement and adaptation, which may be highly relevant for purposes other than estimating the SC-CO_2, but are not discussed here.

probabilistically include: sea level rise from preindustrial levels to levels in the year 2000, the asymptotic sea level rise expected with no temperature change, the predicted sea level rise experience with a temperature change, and the half-life of the sea level rise.

In the economic impacts module, damages are estimated for four categories: sea level rise, economic damages, non-economic damages, and damages from a discontinuity. Each damage category is calculated as a loss proportional to GDP. The model first calculates damages for a “focus region” (set to the European Union) assuming the region’s base year GDP per capita. Damages for other regions are assumed to be proportional to the focus region’s damage, represented by a regional weighting factor.

Economic damages, non-economic damages, and damages from sea level rise are modeled as polynomial functions of the temperature or sea level impact, which are defined as the regional temperature or sea level rise above a regional tolerable level. These functions are calibrated to damages at some reference level (e.g., damages at 3°C or damages for a ½ meter sea level rise). The specification allows for the possibility of “initial benefits” from small increases in regional temperature. The variables represented by a probability distributions in this specification are: the regional weighting factors; the initial benefits; the calibration point; the damages at the calibration point; and the exponent on the damage functions.

The damages from a discontinuity are treated differently from other damages in PAGE because the event either occurs or it does not in a given model simulation. In the PAGE model, the probability of a discontinuity is treated as a discrete event, where if it occurs, additional damages would be borne and therefore added to the other estimates of climate damages. Uncertain parameters related to this discontinuity include the threshold global mean temperature beyond which a discontinuity becomes possible and the increase in the probability of a discontinuity as the temperature anomaly continues to increase beyond this threshold. If the global mean temperature has exceeded the threshold for any time period in a model run, then the probability of a discontinuity occurring is assigned, otherwise the probability is set to zero. For each time period a uniform random variable is drawn and compared to this probability to determine if a discontinuity event has occurred in that simulation. The additional loss if a discontinuity does occur in a simulation is represented by an uncertain parameter and is multiplied by the uncertain regional weighting factor to obtain the regional effects.

Damages for each category in each region are adjusted to account for the region’s forecast GDP in a given model year to reflect differences in vulnerability based on the relative level of economic development. Specifically, the damage estimates are multiplied by a factor equal to the ratio of a region’s actual GDP per capita to the base year GDP per capita, where the ratio exponentiated with a value less than or equal to zero. The exponents vary across damage categories and in each case are treated as uncertain parameters.

Finally, in each region damages for each category are calculated sequentially (sea level rise, economic, non-economic, and discontinuity, in that order) and are assessed to ensure that they do not create total damages that exceed 100 percent of GDP for that region. Damages transition from a polynomial function to a logistic path once they exceed a certain proportion of remaining GDP, and the proportion where this transition begins is treated as uncertain. An additional parameter labeled the “statistical value of civilization," also treated as uncertain, caps total damages (including abatement and adaptation costs described below) at some maximum level.

Figure C2 presents results of an analysis from the developers of the PAGE model that examines the uncertain parameters that have the greatest influence on estimates of the SC-CO_2 based on the default version of the model. Although some of the modeling inputs are different for the SC-CO_2 estimates calculated by the IWG, these parameters are likely to remain highly influential in the PAGE modeling results.

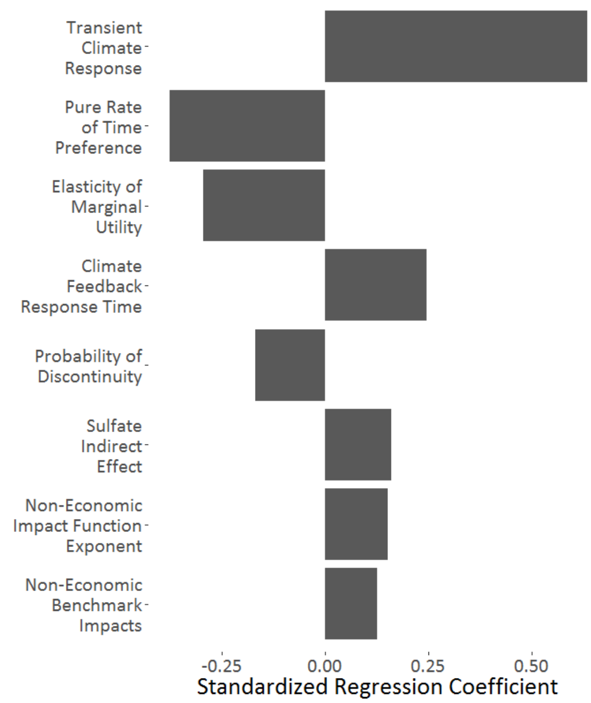

Figure C2: Influence of Key Uncertain Parameters in Default PAGE Model (Hope 2013)[21]

[21] Based on a standardized regression of the parameters. The values give the predicted increase in the SC-CO_2 in 2010 based on a one standard deviation increase in the coefficient, using the default parameters for PAGE09 under Ramsey discounting with an uncertain pure rate of time preference and rate of relative risk aversion.

United States Department of Agriculture

Recreation Economic Values for Estimating Outdoor Recreation Economic Benefits From the National Forest System

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General Technical Report PNW-GTR-957

August 2017

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Cover photo by Emily Jane Davis

Abstract

Rosenberger, Randall S.; White, Eric M.; Kline, Jeffrey D.; Cvitanovich, Claire. 2017. Recreation economic values for estimating outdoor recreation economic benefits from the National Forest System. Gen. Tech. Rep. PNW-GTR-957. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 33 p.

Natural resource professionals are often tasked with weighing the benefits and costs of changes in ecosystem services associated with land management alternatives and decisions. In many cases, federal regulations even require land managers and planners to account for these values explicitly. Outdoor recreation is a key ecosystem service provided by national forests and grasslands, and one of significant interest to the public. This report presents the most recent update of the Recreation Use Values Database, based on an exhaustive review of economic studies spanning 1958 to 2015 conducted in the United States and Canada, and provides the most up-to-date recreation economic values available. When combined with data pertaining to recreation activities and the quantity of recreation use, the recreation economic values can be used for estimating the economic benefits of outdoor recreation. The recreation economic value estimates provided in this report, whether from past research literature or from values constructed using our meta-analysis benefit function, are average consumer surplus per person per activity day.

Keywords: Benefit transfer, economic value, ecosystem services, outdoor recreation, recreation benefits, nonmarket valuation, national forest planning and management, NEPA.

Preface

This report was sponsored by the National Center for Natural Resource Economics Research. The center is a virtual collaborative effort of the Washington office and the regional research stations within U.S. Department of Agriculture, Forest Service, Research and Development. The center was founded to respond rapidly to emerging natural resource economic issues of national significance by leveraging expertise across the Forest Service. The center sponsors research with funding from client organizations and regional research station contributions.

Contents

Introduction

Outdoor recreation is one of the most widely recognized ecosystem services provided by national forests and grasslands and is identified as one of five uses under the Multiple-Use Sustained-Yield Act of 1960. The forest reserves, which would eventually become the first national forests, were originally reserved in the late 19th century to conserve timber and water. Those places also rather quickly became destinations for people seeking both primitive and developed recreation opportunities (Waugh 1918). Today's National Forest System (NFS) receives more than 148 million visits annually with visitors engaging in a variety of outdoor pursuits (USDA FS 2017). The continuing role of the Forest Service in providing sustainable recreation opportunities to the public is evident in the agency's current strategic plan. Developing and maintaining sustainable recreation opportunities is identified as one way to achieve the agency's strategic objectives: "Strengthen Communities" and "Connect People to the Outdoors" (USDA FS 2015). Meeting these objectives requires understanding what recreation activities occur on national forests and grasslands, who is involved in that recreation, and how much do they value their recreation experiences. Recreation activities and numbers of participants on national forests are tracked by the National Visitor Use Monitoring (NVUM) program (English et al. 2002). Other federal and state agencies have their own monitoring programs that also provide estimates of recreation use and activity participation. The economic values that people hold for specific recreation activities are primarily tracked through periodic updates to the Recreation Use Value Database (RUVD) (e.g., Rosenberger and Loomis 2001) and in the scientific literature.

Natural resource professionals are often tasked with weighing the benefits provided by natural resources against the costs of management.

Natural resource professionals are often tasked with weighing the benefits provided by natural resources against the costs of management to produce those benefits. Although the social and economic values of ecosystem services, including outdoor recreation opportunities, are widely recognized, they can be difficult to quantify. Yet in many circumstances, federal regulations require land managers and planners to account for those values explicitly. Within the Forest Service, for example, the Renewable Resources Planning Act of 1974 (superseded by the Government Performance and Results Act of 1993), which informs management of national forests and grasslands, includes an assessment phase and a program analysis phase (USDA FS 2000). The assessment phase identifies the supply of, and demand for, renewable resources on the nation's forests and grasslands. The program analysis phase evaluates the benefits and costs associated with the Forest Service's various programs. These requirements demand credible benefit estimates for key ecosystem services associated with Forest Service management and planning. More broadly, the need for credible benefit estimates is underscored by the President Barack Obama administration's 2015 memorandum directing federal agencies to factor the values of ecosystem services into all federal planning and decisionmaking (Office of Management and Budget 2015).

The economic benefits of recreation use of NFS lands can be estimated for given locations using original studies or information transferred from prior studies conducted elsewhere. The latter method—known as "benefit transfer"—applies benefit estimates obtained through primary research for one location to other unstudied locations of interest. Benefit transfer is used by public agencies and other practitioners when (1) available time, funding, or expertise for conducting original studies are limited; (2) there are available data from existing studies conducted elsewhere; and (3) the application of benefit transfer, given the available studies and location of interest, is deemed reasonable by analysts. Benefit transfer and published recreation economic values can also be used to meet the needs of state and local resource management agencies, as well as nongovernment organizations and private consultants.

This report is intended to meet the continuing need for current recreation benefit information by updating the Rosenberger and Loomis (2001) and Loomis (2005) databases of recreation economic values. This update reflects the most recent version of the RUVD, based on an exhaustive review of economic studies spanning 1958 to 2015 conducted in the United States and Canada. The report thus provides the most current and comprehensive set of recreation economic values available. Specifically, this report provides (1) a brief review of economic concepts and benefit transfer methods, (2) estimates of recreation economic values by primary recreation activity and Forest Service region, and (3) additional context and guidance for analysts using these estimates. The appendix provides technical information about benefit transfer and nonmarket values, and an overview of the RUVD itself. Additional information about the RUVD can be found online at: http://recvaluation.forestry.oregonstate.edu/.

The economic value of any given recreation activity is a monetary measure of the economic benefits received by an individual or group doing that activity.

Recreation Economic Value

The economic value of any given recreation activity is a monetary measure of the economic benefits received by an individual or group doing that activity. For any one individual, the net economic value of a given recreation activity is measured as the maximum amount the individual is willing to pay to participate in the activity, less the actual cost incurred by the individual to participate in that activity. The economic value of recreation differs from the economic impact of recreation.

Economic impact (or economic contribution) measures how spending by recreationists affects economies within a given geography (e.g., community, region, state, or nation) by virtue of the influence that spending has on employment and income. Economists typically use an analytical method called economic impact (or input/output) analysis to evaluate economic impacts. In this report, we are focused only on the economic value of recreation benefits and not recreation economic impacts. The economic impacts associated with national forest recreation are reported by other sources (e.g., White et al. 2016).

Benefit-cost analysis is a common method for evaluating the potential influence that planning and management alternatives and decisions might have on outdoor recreation. For example, benefit-cost analysis can be used to address such questions as: What is the relative worth (i.e., benefits generated) from investments in recreation opportunities, settings, and resources? Benefit-cost analysis can include both market and nonmarket values. Market values are those that are readily identifiable and addressed in typical market transactions and usually involve observable prices or the transfer of money, such as the construction costs and entrance fees. Nonmarket values are those that are not addressed or represented in typical market transactions and can include things such as the value someone has for the opportunity to view nature or the loss of well-being from residents who must endure more traffic from people engaging in recreation. Benefit-cost analysis can be used to consider present benefits and costs as well as those that might be experienced in the future. In this report, we focus on the computation of recreation economic values by developing "direct use values" representing the benefits to individual recreationists directly engaged in outdoor recreation activities. These values represent "access" to a recreation site or to an activity, relative to that location or activity not being available or accessible to recreationists. Thus, these economic values measure the total net benefits of doing the recreation activity rather than the total net benefits from changes in the quality or characteristic of that recreation. The resulting recreation economic values enable scientists, resource analysts, and other practitioners to apply benefit transfer methods to compute the economic value of recreation benefits based on recreation participant numbers reported or projected for a location or activity over a given period. The application of these average values to economic assessments is discussed further in the appendix.

Benefit Transfer Methods

Benefit transfer methods include value transfer and function transfer. Value transfer is the use of a single estimate of value or a weighted average of multiple estimates of value obtained from previously published studies and research literature. Value transfer can be an attractive method for estimating recreation economic benefits when time, funding, and expertise are insufficient to conduct an original study. Moreover, new estimates of economic value based on original or primary research are not needed if resulting value estimates are unlikely to statistically differ from estimates derived from benefit transfer methods. However, original or primary research may provide additional information necessary to evaluate or assess management implications at a site—how values relate to changes in resource or site quality, proposed management options, or other attributes held constant in the benefit transfer estimation process, for example.

Function transfer is the use of a statistical model to derive recreation economic values. The model is estimated from participant or survey data available from one or more previously published studies and is adjusted for characteristics of the site or collection of sites being considered. Function transfers can also rely on data summarizing value estimates reported in a body of literature (such as the RUVD), using a technique known as meta-analysis. Function transfer using meta-analysis can be a more statistically rigorous and robust method for conducting benefit transfer, but is dependent on the availability of information about the characteristics of a specific site, or collection of sites, being considered. Rosenberger and Loomis (2001, 2017) provide a thorough conceptual background for different benefit transfer methods. Additional information about the mechanics of benefit transfer methods can be found in the appendix of this report.

Research studies have tested the validity and reliability of benefit transfer methods, and all methods generally do well.

Many research studies have tested the validity and reliability of benefit transfer methods, and all methods generally do well. Function transfers typically outperform value transfers in terms of validity and reliability. A summary of related literature shows median benefit transfer error for function transfers at 36 percent compared to value transfers at 45 percent (Rosenberger 2015). There is significant variability around both median transfer error estimates, which may in part be due to the experimental nature of these evaluations in academic (or research) settings. In actual benefit transfers conducted by economists and analysts, we feel that good judgment will help to avoid excessive transfer errors. The smallest transfer errors are generally found in benefit transfer applications where the study site and the policy site are similar.

How Economic Values for NFS Recreation Were Estimated

We developed estimates of the economic values of recreation benefits for 14 outdoor recreation activity sets (table 1). These recreation activity sets are based on outdoor recreation activities currently recognized by the Forest Service NVUM program

Table 1—Definitions and National Visitor Use Monitoring categories of primary recreation activities represented in the Recreation Use Values Database

Primary activity	Definition	National Visitor Use Monitoring activity represented
Backpacking	Camping at primitive or dispersed backcountry sites	Primitive camping, backpacking
Biking	Mountain and leisure biking	Bicycling
Cross-country skiing	Cross-country skiing	Cross-country skiing and snowshoeing
Developed camping	Camping at sites with developed amenities such as fire pits, electricity, toilets, picnic tables, and parking	Developed camping
Downhill skiing	Downhill skiing and snowboarding	Downhill skiing and snowboarding
Fishing	Freshwater fishing: all species, bodies of water, and angling techniques	Fishing
Hiking	Hiking, walking, jogging, and trail running that does not include backcountry camping	Hiking and walking
Hunting	Big game, small game, and waterfowl hunting	Hunting
Motorized boating	All types of motorized boating	Motorized water activities
Nature related	Nature watching and visitor center use	Nature center activities, nature study, viewing wildlife, viewing natural features, visiting historic sites
Nonmotorized boating	Floating, kayaking, rafting, and all types of nonmotorized boating	Nonmotorized water activities
Off-highway vehicle use, snowmobiling	Snowmobiling and off-road and all-terrain vehicle riding	Off-highway vehicle use, motorized trail activity, snowmobiling, other motorized activity
Other recreation	Primary and general recreation activities not accounted for in other categories	Relaxing, horseback riding, gathering forest products, resort use, other nonmotorized activities, other activities
Picnicking	Picnicking	Picnicking

(USDA Forest Service 2017). Several of the activity sets represent a narrow group of activities (e.g., downhill skiing and snowboarding) while others correspond to a mix of outdoor recreation activities (e.g., off-highway vehicle motorized trail use including snowmobiling). The 14 activity sets also correspond well to recreation activity groupings typically included in the Forest Service's Resource Planning Act (RPA) assessments for recreation (e.g., Bowker et al. 2012), as well as Statewide Comprehensive Outdoor Recreation Plan (SCORP) reports completed for individual states (e.g., California State Parks 2014, Oregon Parks and Recreation Department 2013, Washington State Recreation and Conservation Office 2013).

Data for estimating recreation economic values for the NFS were drawn from the RUVD. The RUVD is based on an exhaustive review of recreation economic value studies spanning 1958 to 2015 conducted in the United States and Canada.

The data were developed following recommended best practices for meta-analysis practitioners (Stanley et al. 2013). The current version of the RUVD contains 3,194 individual recreation economic value estimates from 422 individual studies. For our purposes, we narrowed these estimates to the 14 NVUM recreation activity sets (table 2) by (1) eliminating 180 estimates for Canada; (2) eliminating 231 estimates for irrelevant activities (e.g., saltwater fishing and beach activities); and (3) removing 74 outlier estimates (i.e., unreasonably small or large values, which significantly affect average values) as less than $5 or greater than $500 per person per activity day. These changes resulted in the 2,709 estimates from 342 studies summarized in table 2. It is common for a single study to report several recreation economic value estimates, hence the disparity in the number of estimates and studies.

Table 2—Summary statistics for average recreation economic value estimates of consumer surplus[a] per primary activity day per person from recreation demand studies, 1958 to 2015

Activity	Number of studies[b]	Number of estimates[c]	Mean value estimate	Median value estimate	Standard error of the mean	Range of value estimates	
						Minimum	Maximum
Backpacking	6	41	$17.04	$9.83	2.44	$6.30	$60.16
Biking	13	36	$98.94	$63.48	17.43	$11.78	$499.34
Cross-country skiing	3	5	$36.84	$31.43	6.93	$20.12	$60.18
Developed camping	22	82	$22.99	$16.12	2.47	$5.08	$166.11
Downhill skiing	5	13	$77.63	$30.54	25.62	$7.85	$277.86
Fishing	120	913	$72.59	$53.27	2.22	$5.36	$464.82
Hiking	37	111	$78.19	$47.17	7.97	$5.02	$451.64
Hunting	64	618	$76.72	$63.12	2.38	$5.04	$419.60
Motorized boating	20	83	$42.48	$19.72	6.63	$5.02	$437.18
Nature related	47	431	$63.46	$47.10	2.79	$5.04	$441.26
Nonmotorized boating	23	83	$114.12	$48.95	13.54	$5.18	$473.02
Off-highway vehicle use, snowmobiling	14	49	$60.61	$51.19	9.58	$9.06	$462.96
Other recreation	66	220	$62.06	$30.33	5.02	$5.12	$390.74
Picnicking	8	24	$31.98	$23.62	6.62	$5.03	$149.13

[a] All value estimates in 2016 dollars. These figures are general descriptive statistics from studies contained in the Recreation Use Values Database. These figures are intended to give information about the range and central tendencies of values in the research literature for recreation activities common to national forests and grasslands. The values in this table should not be used for benefit transfer purposes; instead use the values in table 3.

[b] Total number of studies is 342 (some studies report separate value estimates for two or more primary activities).

[c] Total number of estimates is 2,709.

We developed estimates of the average recreation economic values per person per day for each Forest Service region and the NFS as a whole.

The distribution of study numbers across the 14 activity sets reflects the relative numbers of scientific studies focused on different recreation activities and does not reflect the relative popularity or importance of any one activity set over another. Wildlife-related activities, such as fishing and hunting, have historically been the focus of much recreation benefit research, for example. Conversely, downhill skiing and backpacking have received relatively less attention in the research literature. Most studies included in the database focused on recreation in rural, rather than urban, places. There are wide ranges of recreation economic value estimates across most activities. The range of value estimates reflects variation across individual study sites (e.g., site quality, attributes, and recreation facilities) and study participants, as well as differences in study methods. Accounting for this variation is one reason why meta-analysis is especially attractive for developing economic estimates of recreation values.

We developed estimates of the average recreation economic values per person per day for each Forest Service region and the NFS as a whole. We developed the estimates by fitting a meta-regression statistical model to the economic estimates of values for recreation activities that are relevant to national forests, and associated data contained in the RUVD. The regression measured the effect or relationship of select independent variables from the RUVD to the recreation economic value data characterizing the standardized consumer surplus per person per day as:

$$\text{Value/person/primary activity day} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ \beta_k X_k$$

where there are k explanatory variables (k = 1…K). The βs measure the statistical relationship between the variation in the explanatory variable to the variation in the value estimates, also known as partial effects. The estimates of economic value for all primary recreation activities and regions were then constructed by weighting the measured partial effect (coefficient) of relevant policy site features by database fixed values—the nonactivity and nonregion variables were held constant at their representation in the data (i.e., at their mean value). We then summed across these weighted partial effects to derive recreation economic value. This produces a recreation economic value estimate that adjusts the baseline estimate (by holding all other nonactivity and nonregion effects constant at their mean value) by activity- and region-specific partial effects.

For example, a recreation economic value for developed camping in Region 1 (Northern Region) was derived by setting the partial effects for developed camping and Region 1 at their full level (weights = 1) and removing the partial effects of other recreation activities and regions (weights = 0), while holding all the effects of all other variables at their mean value. We repeated the process for all activities for all regions and the NFS as a whole. The recreation economic values estimated in this manner are intended to be used only to represent the value associated with recreationists' **primary** recreation activities; they do not represent the value for ancillary, or secondary, activities and should not be used to estimate economic benefits for those activities. The recreation economic values we report are robust to the uniqueness of any single study given they rely on contributions from all related studies in the metadata and are systematically adjusted based on measurable differences across the sites being studied. Additional details on this meta-analysis function, along with example applications, are provided in the appendix.

We stress that the recreation economic value estimates provided in this report are average values of consumer surplus per person, per primary activity day. Consumer surplus, or net willingness to pay (i.e., total willingness to pay minus cost to engage in the activity), is a measure of the welfare an individual gains by engaging in an activity or purchasing a good. This measure is commonly used for benefit-cost analysis or economic efficiency analysis by federal agencies such as the U.S. Army Corps of Engineers, Bureau of Reclamation, U.S. Environmental Protection Agency, and the Forest Service (see Forest Service Handbook SFH 1909.17). Additional technical notes on this concept are provided in the appendix.

Economic Values of Recreation Benefit

Average recreation economic values are reported for each of the 14 primary recreation activities for each Forest Service region, and the NFS as a whole in table 3. Nationally, recreation economic values range from about $45 per person per day for camping and backpacking to about $120 per person per day for nonmotorized boating. On average, a day of recreating on national forest lands provides about $80 in benefit to the recreationist. Average recreation economic values across all activities for individual Forest Service regions were calculated as the weighted average of the share of each region's recreation use in each primary activity. Region-level recreation use was drawn from current NVUM estimates (USDA FS 2017). Average recreation economic values for Forest Service regions range from about $63/day for Region 5 (Pacific Southwest Region) national forests to about $77/day for Regions 1 and 4 (Intermountain Region) national forests to $103 for Region 10 (Alaska Region) national forests. The regional-level recreation economic values are influenced by the types of activities popular in each region and the underlying values for those activities.

Analysts need to pay attention to units of measure when applying the recreation economic values reported here to compute aggregate recreation benefits. We report the recreation economic values on an "activity day" basis (i.e., benefit per

Table 3—Estimates of the average economic value of recreation benefits (use value) by primary activity and Forest Service region (average consumer surplus per person per primary activity day)

	Forest Service region									
Primary activity	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R8**	**R9**	**R10**	**National**
Backpacking	39.59	32.81	40.89	42.81	26.64	33.15	32.61	21.10	65.09	44.00
Biking	93.18	86.40	94.48	96.40	80.23	86.74	86.20	74.70	118.69	97.60
Cross-country skiing	62.96	56.18	64.26	66.18	50.01	56.52	55.98	44.47	88.46	67.37
Developed camping	42.06	35.28	43.36	45.27	29.11	35.61	35.07	23.57	67.56	46.47
Downhill skiing	88.67	81.89	89.97	91.88	75.72	82.23	81.68	70.18	114.17	93.08
Fishing	77.96	71.18	79.26	81.18	65.01	71.52	70.98	59.47	103.46	82.37
Hiking	90.90	84.12	92.20	94.12	77.95	84.46	83.91	72.41	116.40	95.31
Hunting	83.86	77.08	85.16	87.07	70.90	77.41	76.87	65.37	109.36	88.27
Motorized boating	64.82	58.04	66.12	68.03	51.87	58.37	57.83	46.33	90.32	69.23
Nature related	66.57	59.79	67.87	69.79	53.62	60.13	59.59	48.09	92.08	70.99
Nonmotorized boating	115.37	108.59	116.67	118.59	102.42	108.93	108.38	96.88	140.87	119.78
Off-highway vehicle use/snowmobiling	56.89	50.11	58.19	60.11	43.94	50.45	49.91	38.40	82.39	61.30
Other recreation	71.45	64.67	72.75	74.66	58.49	65.00	64.46	52.96	96.95	75.86
Picnicking	55.62	48.84	56.92	58.83	42.67	49.17	48.63	37.13	81.12	60.03
Weighted average	76.24	71.88	76.20	77.04	63.19	68.64	66.70	55.93	103.00	79.96

Note: All value estimates are in 2016 dollars. These estimates are computed using a statistical meta-regression model. They represent the average value of the economic benefit to recreationists using national forests and grasslands. These figures represent the value only for those recreationists who engage in the listed activities as their primary activity; these values should not be applied to secondary or ancillary activities done by recreationists. These values do not represent the economic activity generated by national forest recreation.

person per day). An activity day is one person recreating for some portion of a day. For example, an individual whose primary recreation activity is picnicking and who engages in that activity for 2 hours on one day is one primary activity day of picnicking. Six people with the primary activity of picnicking who each spent 2 hours on one day doing that activity is six primary activity days of picnicking. One individual with the primary activity of camping who camps overnight for one night would equal two primary activity days of camping.

Currently, recreation use estimates for most federal agencies managing outdoor recreation opportunities are reported in terms of “visits.” For the Forest Service, a national forest visit is defined as “one person participating in one or more recreation activities on a national forest or grassland for an unspecified period of time” (USDA FS 2017). A visit begins when someone enters the national forest and ends when the individual leaves the national forest for the last time that day. A national forest visit may last 1 hour or several days. Analysts will need to convert visits to primary activity days to obtain a quantity of recreation use with which to multiply by the recreation economic values. We provide conversion factors for doing this in table 4 and example computations in the next section of this report. The conversion factors were computed using the NVUM data by estimating the average number of calendar days per visit reported by visitors engaged in each NVUM recreation activity. The values presented here should only be applied to the primary activities of visitors. For instance, recreationists whose primary activity is hiking likely participate in other activities (e.g., viewing nature, viewing wildlife, and photography) during their hikes. However, for those visitors, only the recreation economic value of "hiking" counts for their visit.

Guidance for Analysts

The recreation economic values provided in table 3 may be used in a variety of ways. By themselves, the values show the average economic value of recreation benefit (i.e., consumer surplus) per activity day that accrues to an individual engaged in a type of recreation activity within a Forest Service region. These average value estimates are what we would **expect** the economic benefit to be, conditional on available information and holding all else constant. This expected, or average, value is an estimate within the distribution of all estimates with the highest likelihood of being observed. Thus, these recreation economic value estimates may be multiplied by the number of activity days a location receives to derive the aggregate benefit of recreation. Applications at national, regional, and forest-level aggregations include a mix of recreation sites with different qualities and characteristics, and the use of average values is typically most appropriate at this level of analysis.

To apply the recreation economic values, analysts will multiply the value per person per day by the estimated annual activity days in that primary activity. For national forests under current conditions, the number of activity days can be estimated using visit estimates by activity provided by NVUM reports and conversion factors to translate visits into activity days reported in table 4. Other reliable information on the number of recreation visits can also be used. Reliable information on visits may include counts of recreation use (in per-person activity days) estimated from fee envelopes or permits where all use is covered by those measures, studies by university or agency scientists where the methods are clearly described and replicable, and "engineered" estimates that clearly show assumptions and describe data sources.

We urge users to **not** interpret the relative economic values of activities as indicative of which activities are "best" to promote through management. Just because the average economic value for nonmotorized boating is larger than the average economic value for picnicking, for example, does not necessarily mean

Table 4—Activity days per national forest visit, by primary activity and Forest Service region

	Forest Service region									
Primary activity	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R8**	**R9**	**R10**	**National**
Backpacking	2.4	2.5	2.1	2.7	2.8	2.6	2.4	2.5	2.7	2.4
Bicycling	1.1	1.1	1.1	1.2	1.1	1.2	1.1	1.1	1.1	1.1
Cross-country skiing	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	2.0	1.0
Developed camping	2.7	2.7	2.6	2.5	2.8	2.8	2.8	2.9	2.5	2.7
Downhill skiing	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.1	1.0
Driving for pleasure	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.1
Fishing	1.3	1.2	1.3	1.5	1.3	1.3	1.1	1.3	1.3	1.3
Gathering forest products	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.1
Hiking, walking	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Horseback riding	1.3	1.3	1.1	1.4	1.2	1.4	1.6	1.4	1.0	1.3
Hunting	1.3	1.3	1.6	1.6	1.5	1.5	1.2	1.2	1.5	1.3
Motorized trail activities	1.3	1.3	1.2	1.4	1.3	1.3	1.1	1.1	1.0	1.3
Motorized water activities	1.3	1.1	1.1	1.2	1.3	1.4	1.2	1.1	1.1	1.3
Nature center activities	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0
Nonmotorized water activities	1.7	1.1	1.2	1.7	1.4	1.3	1.2	1.3	1.1	1.7
Off-highway vehicle use	1.2	1.2	1.2	1.5	1.2	1.3	1.2	1.2	1.0	1.2
Other motorized activities	1.5	1.2	1.1	1.0	1.2	1.2	1.1	1.1	1.1	1.5
Other nonmotorized	1.1	1.2	1.0	1.2	1.2	1.1	1.1	1.1	1.1	1.1
Picnicking	1.2	1.1	1.1	1.1	1.2	1.2	1.1	1.1	1.2	1.2
Primitive camping	2.8	2.4	2.4	2.5	2.3	2.6	2.3	2.7	2.0	2.8
Relaxing	1.6	1.5	1.4	1.5	1.5	1.5	1.3	1.4	1.4	1.6
Resort use	2.5	2.1	2.6	2.5	3.2	2.3	3.1	2.2	3.1	2.5
Snowmobiling	1.0	1.2	1.0	1.1	1.2	1.2	1.0	1.1	1.1	1.0
Viewing natural features	1.1	1.1	1.1	1.2	1.2	1.1	1.1	1.0	1.1	1.1
Viewing wildlife	1.1	1.1	1.1	1.2	1.1	1.2	1.1	1.1	1.1	1.1
Visiting historic sites	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	2.9	1.1
Other activities	1.1	1.2	1.1	1.2	1.1	1.1	1.0	1.2	1.1	1.1
No activity reported	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Weighted activity average	1.2	1.1	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.2

Conversion coefficients are the average number of calendar days per national forest visit. These figures can be used to convert Forest Service national forest visits into activity days. The values in the weighted activity average row are average values for each region weighted by the percentage of visits for each primary activity for each region as estimated from National Visitor Use Monitoring. Those values can be used to convert aggregate regional or national level visit estimates to activity days without needing to account for primary activity type.

that management efforts should focus on nonmotorized boating at the expense of opportunities for picnicking. Additionally, managers should also consider the supply of different recreation opportunities. There may be many nonmotorized boating opportunities, and few or no picnic facilities, implying that the incremental benefit from additional picnic sites may be relatively high compared to adding boating sites. Further, there may be numerous people who picnic compared to people who participate in nonmotorized boating activities, meaning that, in aggregate, the total benefit from picnicking is much great than that of boating, despite the average recreation economic value for boating being comparatively large.

These average recreation economic values may not always be appropriate for site-level analyses (e.g., those focused on a specific lake, campground, or trail), but they can be a starting point. The average values here are computed from a wide range of studies conducted in actual recreation settings with varying characteristics and quality. These average economic values may not always be representative of the conditions (including quality) at an individual recreation site or specific recreation setting. The average recreation economic values reported here could be reasonably applied for site-specific analyses if that site was similar to an “average” site studied in the RUVD. In cases where greater specificity is required in the economic value estimate, analysts may want to scale up or down the average value. We recommend that analysts considering rescaling of average values lean toward making conservative alterations, as very low and very high estimates of recreation economic values are the rarest kinds estimated from primary research. An alternative approach would be to use a single point estimate transfer by matching specific studies in the RUVD with the policy site of interest (see the appendix for a description of the steps for conducting point estimate transfers).

The average recreation economic values reported here are likely inappropriate for analyses that involve changes in the quality of recreation sites and settings or the cost of accessing them. For example, the recreation economic values reported here would not be helpful in estimating the benefits to recreationists from a project to increase the screening between campsites that improved the quality of the camping experience. To do that analysis, a primary study would have to be done, or the analyst would need to find a study in the RUVD that covered a comparable site. The recreation economic values reported here might be appropriate for a study focused on added benefit from increasing the number of sites in a campground that was at full capacity (and therefore increases the number of visits) if the addition of sites did not change the quality or cost of camping there. Finally, the recreation economic values here are likely inappropriate to estimate the benefit (or loss) to visitors from a change in fees to access a recreation site.

Example Applications

We provide two examples of how the recreation economic values reported in table 3 can be used to compute aggregated economic benefits of recreation. The first example is an estimate of the aggregated economic benefits of recreation provided collectively by the national forests in each Forest Service region; the second is an estimate of the aggregated economic benefit of recreation provided by a single national forest.

Estimating the Economic Benefit of Recreation for a Single Forest Service Region

We use Forest Service Region 2 (Rocky Mountain Region) as an example for computing aggregated economic benefits for an entire Forest Service region. The aggregate benefit to users who recreate on national forests in Region 2 can be computed by multiplying the number of recreation visits by the conversion coefficient from table 4 and by the average recreation economic value estimate for the region from table 3 as:

Region 2 NVUM 2015 use estimate (1,000s)	X	Conversion coefficient (table 4)	X	Economic value (table 3)	=	Aggregated recreation benefit value ($1,000s)

or:

28,291 visits	X	1.1	X	$71.88	=	$2,236,913

Given these inputs, the economic benefit to individuals who recreated on Region 2 national forests in 2015 is computed as $2.24 billion. That means that the money spent by federal agencies to provide recreation opportunities in Region 2 national forests provided $2.24 billion in well-being to those people who recreated. The $2.24 billion figure does **not** represent the economic contribution or economic activity generated by recreation at Region 2 national forests; computing economic contribution would require an economic impact analysis.

Estimating the Economic Benefit of Recreation for a Single National Forest

We use the Medicine Bow National Forest to show the procedure for estimating the aggregate economic benefit of recreation for an individual national forest (table 5). The computation begins with the estimate of total annual recreation use on the Medicine Bow National Forest (534,871 visits) and the percentage distribution of that use by primary activity. Both the recreation use figure and the distribution of use by recreation activity are drawn from NVUM estimates (USDA FS 2017).

Table 5—Estimate of the annual, aggregate economic benefits accruing to individuals recreating on the Medicine Bow National Forest

Primary activity	Primary activity	National forest visits	Conversion coefficient (table 4)	Primary activity days	Use value (table 3)	Economic benefit[a]
	Percent				*- - - - - Dollars - - - - -*	
Backpacking	0.0	161	2.5	403	32.81	13,209
Bicycling	2.5	13,372	1.1	14,709	86.40	1,270,853
Cross-country skiing	16.8	90,034	1.0	90,034	56.18	5,058,131
Developed camping	0.9	4,804	2.7	12,972	35.28	457,654
Downhill skiing	9.6	51,105	1.0	51,105	81.89	4,185,002
Driving for pleasure	6.0	32,092	1.1	35,301	64.67	2,282,947
Fishing	2.6	14,072	1.2	16,887	71.18	1,201,981
Gathering forest products	0.2	919	1.1	1,010	64.67	65,343
Hiking/walking	15.0	80,231	1.1	88,254	84.12	7,423,903
Horseback riding	1.9	9,976	1.3	12,969	64.67	838,724
Hunting	7.2	38,767	1.3	50,397	77.08	3,884,575
Motorized trail activities	1.7	9,253	1.3	12,029	50.11	602,786
Motorized activities	0.2	918	1.1	1,010	58.04	58,633
Nature center activities	0.0	0	1.0	0	64.67	0
Nature study	0.1	501	1.1	551	64.67	35,605
No activity reported	0.2	1,303	1.0	1,303	64.67	84,258
Nonmotorized water activities	0.2	964	1.1	1,061	108.59	115,183
Off highway vehicle use	4.1	22,094	1.2	26,512	50.11	1,328,540
Other motorized activities	0.2	856	1.2	1,027	50.11	51,461
Other nonmotorized activities	0.6	3,170	1.2	3,804	64.67	246,023
Picnicking	1.0	5,286	1.1	5,814	48.84	283,971
Primitive camping	0.8	4,258	2.4	10,220	32.81	335,302
Relaxing	4.3	22,999	1.5	34,499	64.67	2,231,062
Resort use	0.0	0	2.1	0	64.67	0
Snowmobiling	9.0	48,138	1.2	57,766	50.11	2,894,658
Other activities	6.0	32,092	1.2	38,511	64.67	2,490,488
Viewing natural features	8.0	42,790	1.1	47,069	59.79	2,814,234
Viewing wildlife	0.9	4,716	1.1	5,187	59.79	310,145
Visiting historic sites	0.0	0	1.1	0	59.79	0
Total	100.0	534,871		620,404		40,564,669

[a] Economic benefit values are in 2016 dollars. Visitation figures are from National Visitor Use Monitoring round 3 (fiscal years 2009 to 2014).

Practitioners should focus on the primary recreation activity of visits rather than any secondary (or "participating") activities.

The number of visits by recreation activity is computed by multiplying the appropriate primary activity percentage by the estimate of total use on the national forest. The visits-by-activity figure is then multiplied by the conversion coefficient for each activity for Region 2 (where the Medicine Bow National Forest is located) drawn from table 4 to compute the number of activity days for each activity. The appropriate economic benefit estimate for each activity is drawn from table 3 using the crosswalk to NVUM activities shown in table 2. The economic benefit for each activity is calculated by multiplying activity days by the use value figure. The aggregate economic benefit of recreation on the entire Medicine Bow National Forest is the sum of all the benefit values for each primary activity.

Characterizing and understanding recreation use will continue to be a necessary step in managing national forests.

Recreationists on the Medicine Bow National Forest receive in total $40.6 million in economic benefits from recreating there. Again, that figure does **not** represent the economic impact or economic activity generated from recreation on the national forest, but rather the economic value of the benefit to those who recreated.

Conclusions

Outdoor recreation has been, and likely will continue to be, an important use of national forests, and one that connects the U.S. public and international tourists with the many benefits that public forest lands have to offer. Characterizing and understanding recreation uses of national forests thus will continue to be a necessary step in managing national forests to meet their multiple-use mandate. The economic value estimates reported here thus provide a critical resource for forest planners, managers, and policymakers charged with developing and implementing the stewardship of U.S. public forest lands.

Acknowledgments

This project was directly supported by funds provided by the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. It also was indirectly supported through collaborative arrangements with the U.S. Geological Survey's project updating the Benefit Transfer Toolkit funded by the U.S. Department of the Interior, Bureau of Land Management. We thank J.M. Bowker, Ross Arnold, Chris Miller, Kawa Ng, and David Simpson for their helpful reviews and suggestions.

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Appendix

The RUVD summarizes recreation economic value estimates from more than 50 years of economic research.

This appendix provides additional technical information about the methods and techniques described in this document. It begins with a history of the Recreation Use Value Database (RUVD), and then summarizes key economic concepts. A more detailed discussion of benefit transfer methods and how to conduct them is provided, followed by the technical details of the meta-analysis function transfer used in constructing table 3.

History of the Recreation Use Values Database

The RUVD summarizes recreation economic value estimates from more than 50 years of economic research (work published from 1958 to 2015) characterizing the value of outdoor recreation in the United States and Canada. The RUVD includes all documented estimates of recreation economic values published in journal articles, technical reports, book chapters, working papers, conference proceedings, or graduate theses (Stanley 2001). Included studies encompass a variety of methods, regional and activity foci, sample sizes, and site characteristics.

The RUVD is the result of seven separate literature reviews, although it was completely reconstructed in 2006. The first review covered literature on outdoor recreation and forest amenity use values from the 1960s to 1982, with 93 benefit estimates (Sorg and Loomis 1984). The second literature review covered 1968 to 1988, (Walsh et al. 1988) increasing the benefit estimate count to 287. A third literature review, conducted by MacNair (1993), covered estimates from 1968 to 1993 and formally coded information on study attributes. A fourth literature review, conducted by Loomis and others (1999), used an expanded coding protocol and merged with the MacNair database. Kaval and Loomis (2003) updated this expanded database, with emphasis on underrepresented recreation activities. In 2006, the RUVD was rebuilt using an expanded coding protocol with new variables and the database was again updated with new and overlooked valuation studies. Finally, in 2015 the RUVD was updated to include studies from 2006 to 2015. This effort, following the best practice guidelines established by Stanley et al. (2013), brought the number of studies included to 422 and estimates to 3,194.

Primary studies were included if (1) they estimated access values (i.e., with vs. without access to the resource or activity); (2) they followed well-established economic practices for stated or revealed preference, or mixed estimation models (e.g., Champ et al. 2017); (3) they were conducted in the United States or Canada; and (4) they reported an economic value that could be converted into a standardized consumer surplus dollar value per person per day. The RUVD includes the standardized economic value as well as identified information on the document source and study, site, activity, and methodology attributes of each study. Additional information about the RUVD, including studies and coding protocol, can be found at http://recvaluation.forestry.oregonstate.edu/.

Consumer Surplus

Consumer surplus is the economic value of a recreation activity above what must be paid by the recreationist to enjoy the activity (fig. 1). Looking at conditions when demand is D_0, consumer surplus is the area below the demand function (D_0) and above the price or expenditure line (B), or area BCD. Consumer surplus is also referred to as net willingness to pay, or willingness to pay in excess of the cost of the good. Total economic use value is consumer surplus plus the costs of participation, or area 0ACD in figure 1 when demand is D_0 and A is the number of days of participation. Consumer surplus is generally estimated in primary research by inferring it from revealed preference data (i.e., generate the demand function and then calculate consumer surplus), or directly estimated using stated preference data (i.e., where people state their maximum net willingness to pay within constructed market conditions). For more information on nonmarket valuation methods, see Champ et al. (2017).

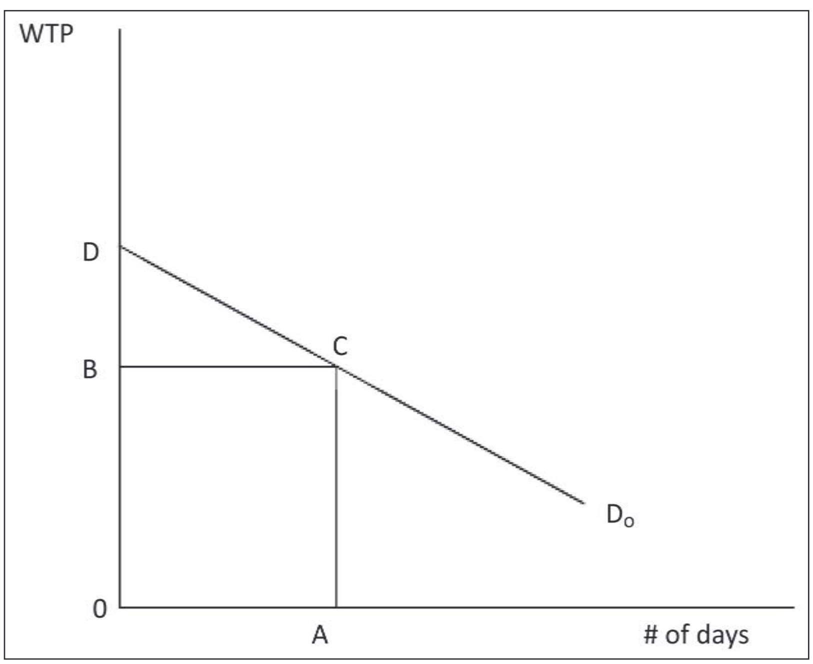

Figure 1—Consumer surplus in demand.

Benefit Transfer

There are two broad approaches to benefit transfer: (1) value transfer and (2) function transfer (fig. 2). Value transfers encompass the transfer of (1-a) a single benefit estimate from a study site, or (1-b) a measure of central tendency (e.g., average or median) for several benefit estimates from a study site or sites, or (1-c) administratively approved estimates. Administratively approved value estimates are discussed in conjunction with the measure of central tendency discussion (hereafter average value transfer will refer to both (1-b) and (1-c)). Function transfers are the transfer of (2-a) a benefit or demand function from a study site, or (2-b) a meta regression analysis function derived from several study sites. Function transfers are adapted to fit the context of the policy site with respect to socioeconomic characteristics, extent of market and environmental impact, and other measurable characteristics that may capture or define the differences between sites with this information and the one where it is needed (i.e., being transferred to). The adapted function is then used to construct a benefit measure for the policy site.

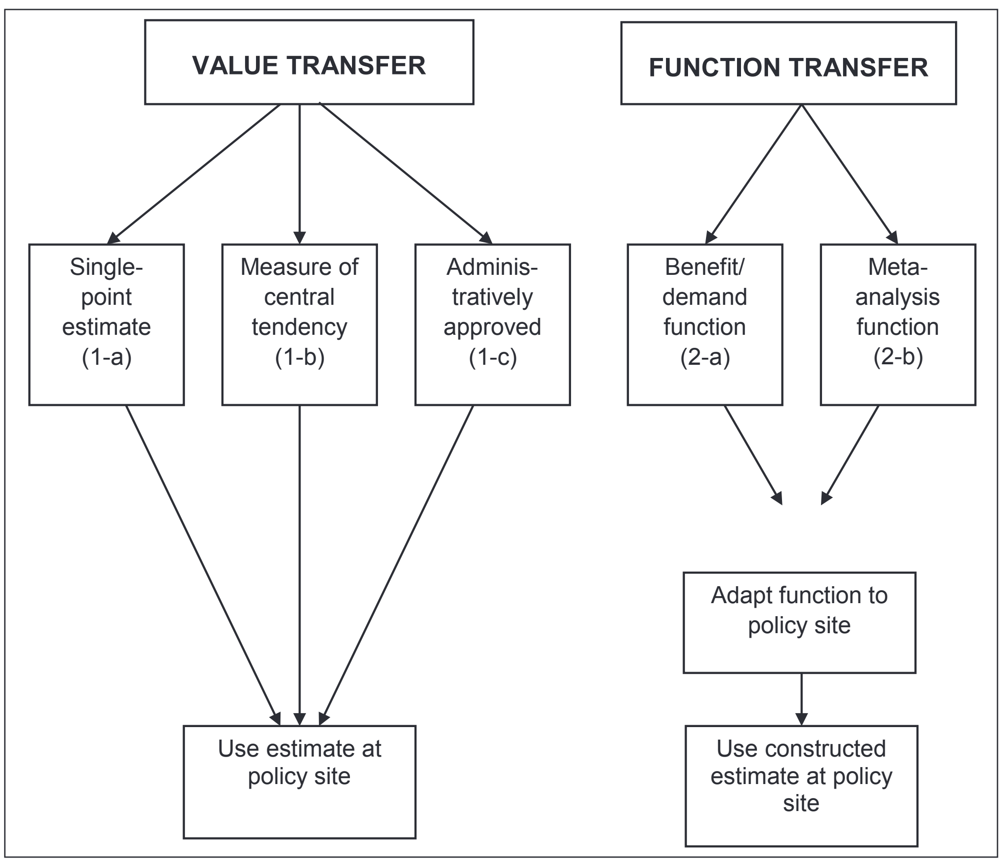

Figure 2—Benefit transfer approaches (adapted from Rosenberger and Loomis 2001).

Applications of benefit transfer methods may or may not be structurally (i.e., directly) related to underlying utility theoretic approaches. The continuum of structural linkages is identified in Bergstrom and Taylor (2006). Additional discussions and comprehensive information on benefit transfers are found in Johnston (2015) and others, including Johnston and Rosenberger (2010), and Rosenberger and Loomis (2017).

Value transfer methods—

Single-point-estimate transfer—A single-point-estimate benefit transfer uses an estimate from a single relevant primary research study (or range of point estimates if more than one study is relevant). The steps to performing a single-point-estimate transfer include identifying and quantifying the management or policy-induced changes on recreation use, and locating and transferring an appropriate "unit" consumer surplus measure. The following is a more detailed list of the steps involved in single-point-estimate transfers:

1. Identify the resources affected by a proposed action.
2. Translate resource impacts to changes in recreational use.
3. Measure recreation use changes.
4. Search the literature for relevant study sites.
1. Assess relevance and applicability of study site data.
5. Select a benefit measure from a single relevant study or a range of benefit measures if more than one study is relevant.
6. Multiply benefit measure by total change in recreation use.

The context surrounding each benefit transfer can be unique, meaning there is no universal protocol that can be objectively followed in any situation.

The simplicity with which these steps are presented may be misleading. Finding a valid and reliable benefit measure can be complex and require the analyst to make many judgments on the comparative structure between two or more sites. These judgments often rely on limited available information about the original study context and may require additional information be gathered about the sites and study methods.

Similarity of sites is a key element in the defense of point-transferred values. Defensibility can be defined on two feasibility dimensions–technical and political. Technical feasibility is inversely related to the degree of technical and theoretical consistency between the study site context and the policy site context. Political feasibility is highly context- and scale-dependent, accounting for an array of social and cultural factors. The context surrounding each benefit transfer can be unique, meaning there is no universal protocol that can be objectively followed in any situation. However, quite often information can be transferred with varying levels of confidence (Johnston and Rosenberger 2010).

Average value transfer methods—An average value transfer is based on using a measure of central tendency of all or subsets of relevant and applicable studies as the transfer measure for a policy site issue. The primary steps to performing an average value transfer include identifying and quantifying the management or policy-induced changes on recreation use, and locating and transferring a "unit" average consumer surplus measure. The following is a more detailed list of the steps involved in average value transfers:

1. Identify the resources affected by a proposed action.
2. Translate resource impacts to changes in recreational use.
3. Measure recreation use changes.
4. Search the literature for relevant study sites.
5. Assess relevance and applicability of study site data.
6. Use average value for the region or use an average of a subset of study measures.
7. Multiply benefit measure by total change in recreation use.

Federal public land agencies commonly use administratively approved average values in assessing management and policy actions. The U.S. Department of Agriculture Forest Service has used Resources Planning Act (RPA) values since 1980 (USDA FS 1991). These RPA values have been provided for groups of activities and Forest Service regions of the country. Similarly, the U.S. Bureau of Reclamation and U.S. Army Corps of Engineers have relied on U.S. Water Resources Council (1973, 1979, 1983) "unit day values" for decades. Although some of the unit day values may not have been based directly on the emerging literature on outdoor recreation economic values and measures, they have all been influenced to a certain degree by this literature. Average value estimates, however, are no better than the data on which they are based. All the issues that could be raised concerning the credibility of any single measure are also relevant for an average value based, in part, on that measure.

Benefit-function-transfer methods—Benefit-function transfers use a model to statistically relate benefit measures to study factors, such as characteristics of the user population and the resource being evaluated. Benefit-function transfers usually come from two sources. First, a benefit function or demand function has been estimated and reported for a recreation activity in a geographic location through primary research. Second, a meta-analysis function can be estimated from several independent primary research projects. In either case, the transfer process entails adapting the function to the characteristics and conditions of the policy site, constructing a benefit measure based on this adaptation of the function, and using the measure for evaluating the policy site.

Demand-function transfer—The transfer of an entire demand function is conceptually more sound than value transfers, because recreation benefit estimates and use rates are a complex function of site and user characteristics, and spatial and temporal dimensions of recreation site quality and site choice. When transferring a point estimate from a study site to a policy site, it is assumed or implied that the two sites are identical across the various factors that determine benefit derived in recreational use of the two sites. An average value transfer assumes the benefits of the policy site are around the mid-level of benefits measured for the study sites incorporated into the average value calculation. However, this is not always the case. The invariance surrounding the transfer of benefit measures alone makes these transfers insensitive or less robust to significant differences between the study site(s) and the policy site. Therefore, the main advantage of transferring an entire demand function to a policy site is the increased relevance of tailoring a benefit measure to fit the characteristics of the policy site. It is in the adaptation stage of constructing a benefit measure from a study site demand function that the additional value of the transfer method is realized. The following is a more detailed list of steps for demand- and benefit-function transfers:

1. Identify the resources affected by a proposed action.
2. Translate resource impacts to changes in recreational use.
3. Measure recreation use changes.
4. Search the literature for relevant study sites.
5. Assess relevance and applicability of study site data and whether demand or benefit function is specified.
6. Adapt demand or benefit function to policy site characteristics and construct benefit measure.
7. Multiply constructed benefit measure by total change in recreation use.

Disadvantages of the method are primarily due to data collection and model specification in the original research effort. Factors in the demand function may be relevant to the study site but not to the policy site. Also, factors that influence demand at the policy site may not have been collected at the study site or were not significant in determining demand at the study site. These factors significantly affect the constructed benefit measures at a policy site.

The specification of demand functions can significantly affect the reliability of their use under varying circumstances. To employ a demand function transfer, the analyst must use insight and judgment concerning the applicability and transferability of demand functions, the details of which are beyond the scope of this report.

Meta-regression analysis is the statistical summarizing of relationships between benefit measures and quantifiable characteristics of studies.

The adaptation of a demand function from a study site to a policy site can be complex and lead to a large error. This error can be influenced by dissimilarities between site and user population characteristics of the study site and policy site. Critical demand/benefit-function transfer requires strong knowledge of economic methodology and estimation of consumer surplus. Therefore, it is highly recommended that when attempting to perform a demand-function transfer you either have the requisite knowledge or solicit the aid of someone who does.

Meta-regression analysis benefit-function transfer—Meta-regression analysis is the statistical summarizing of relationships between benefit measures and quantifiable characteristics of studies. The data for a meta-analysis are generally summary statistics from study site reports and include quantified characteristics of the user population, study site's environmental resources, and valuation methodology used. Coding of the studies included in the literature review lends itself directly to the estimation of a meta-analysis benefit function. However, interpretation of original study results can be a source of error in meta-analysis databases (Stanley et al. 2013).

Meta-analysis has been traditionally concerned with understanding the influence of methodological- and study-specific factors on research outcomes and providing summaries and syntheses of past research. A more recent use of meta-analysis is the systematic use of the existing value estimates from the literature for benefit transfer. Essentially, meta-analysis regression models can be used to construct benefits at policy sites. Meta-analysis has several conceptual advantages over other benefit-transfer methods such as point-estimates and demand-function transfers, which generally revolve around the advantages of broader and more diverse data for adapting meta-regression models to specific policy site valuation needs. The specific steps to conducting a meta-regression analysis function transfer are as follows:

1. Identify the resources affected by a proposed action.
2. Translate resource impacts to changes in recreational use.
3. Measure recreation use changes.
4. Adapt meta-regression analysis benefit function to policy site characteristics and construct benefit measure.
5. Multiply constructed benefit measure by total change in recreation use.

Meta-analysis has many advantages over unit transfer: it uses information from many studies, providing more rigorous value measures sensitive to the underlying distribution of estimates; multiactivity, multisite meta-analyses can construct estimates for regions in which no studies were conducted for an activity; and methodological differences can be controlled when calculating a value. An example of this method is provided in this report. It is the method used to construct the economic values in table 3.

Meta-Regression Analysis Detailed Methods

Panel data and model specification—

Quantitative literature reviews such as meta-analysis may utilize pools of data with panel characteristics (Rosenberger and Loomis 2000). The RUVD includes many empirical studies (e.g., single observations) that provide several estimates of recreation economic value, fewer studies that provide only one estimate, and a handful of studies that provide many (greater than 20) estimates of value. Using a fixed-effects model to correct for intrastudy panel effects, or a random-effects model to correct for interpanel effects is one option. However, these options can add complexity to modeling and decrease degrees of freedom. Random-effects models assume the random error associated with each panel (e.g., primary study) is uncorrelated with other variables, for example region or valuation method. Past meta-analysis has also elected to use only one estimate per study or to average all estimates into one weighted estimate per study (Nelson and Kennedy 2009). However, this approach leaves a lot of information out of the meta-regression. Where individual studies publish multiple estimates, these estimates generally represent different activities at one site, different user groups at one or more sites, or the same activity at multiple sites.

Identification of panel effects or stratification within any panel data can be difficult. In this case, we use a simple correction to identify potential panel effects by publication. A cluster-robust covariance estimator with pooled ordinary least squares (OLS) corrects for potential nonindependence without requiring any assumptions about the error. Clustering covariances by activity, region, or document (individual publication) increased the standard error (SE) of some variables and decreased SE of others but made little difference in the significance of most variables. This indicates there may be some within-group correlation by region, activity, or even publication but not enough to prevent the use of OLS.

Meta-regression—

Ordinary least-squares linear regression is a widely used method for relating the distribution of a dependent variable, here the estimates of use value in the RUVD, with the variation in one or more independent variables. Conventional OLS assumes the dependent variable has similar variance across the range of independent variable values; observations of the dependent variable are independent from one another; and the explanatory variables have no linear relationship. The independent variables included in the model are described in table 6 and include aspects of survey methodology and site characteristics. Our OLS model uses a linear-linear

Table 6—Meta-regression analysis variables definitions

Variable name	Description
Dependent variable:	
Value	Consumer surplus per person per activity day (2016 dollars)
Sample characteristics variables:	
Nonresidents	= 1 if sample contains nonresident visitors only; = 0 otherwise
Residents[a]	= 1 if sample contains local resident visitors only; = 0 otherwise
Mixed residents/nonresidents	=1 if sample contains a mix of resident and nonresident visitors; = 0 otherwise
User sample	=1 if sample derived from user list (e.g., fishing/hunting license holders); = 0 otherwise
Onsite sample	=1 if visitors sampled on-site; = 0 otherwise
General population sample	=1 if sample derived from a general population (e.g., random sample of state residents); = 0 otherwise
Methodology variables:	
Revealed preference	=1 if revealed preference valuation method used; = 0 otherwise
Stated preference	=1 if stated preference valuation method; = 0 otherwise
Substitutes modeled	=1 if substitute sites included in valuation model; = 0 otherwise
Zonal travel cost	=1 if zonal travel cost method used; = 0 otherwise
Individual travel cost	=1 if individual travel cost method used; = 0 otherwise
Resource/site variables:	
Lake	=1 if value reported for a lake/reservoir environment; = 0 otherwise
Forest	= 1 if value reported for a forested environment; = 0 otherwise
Wetland	= 1 if value reported for a wetland environment; = 0 otherwise
River	= 1 if value reported for a river/stream environment; = 0 otherwise
Regional variables:	
Forest Service (FS) Region 1	= 1 if value reported for FS Region 1; = 0 otherwise
FS Region 2	= 1 if value reported for FS Region 2; = 0 otherwise
FS Region 3	= 1 if value reported for FS Region 3; = 0 otherwise
FS Region 4	= 1 if value reported for FS Region 4; = 0 otherwise
FS Region 5	= 1 if value reported for FS Region 5; = 0 otherwise
FS Region 6	= 1 if value reported for FS Region 6; = 0 otherwise
FS Region 8	= 1 if value reported for FS Region 8; = 0 otherwise
FS Region 9	= 1 if value reported for Forest Service Region 9; = 0 otherwise
FS Region 10	= 1 if value reported for FS Region 10; = 0 otherwise
National	= 1 if value reported for national level; = 0 otherwise
Multiple regions	= 1 if value reported for multiple FS Regions; = 0 otherwise

Table 6—Meta-regression analysis variables definitions (continued)

Variable name	Description
NVUM primary recreation activity variables	
Developed camping	= 1 if value reported for developed camping; = 0 otherwise
Backpacking	= 1 if value reported for backpacking; = 0 otherwise
Picnicking	= 1 if value reported for picnicking; = 0 otherwise
Nature related	= 1 if value reported for nature-related; = 0 otherwise
Cross-country skiing	= 1 if value reported for cross-country skiing; = 0 otherwise
Fishing	= 1 if value reported for fishing; = 0 otherwise
Hunting	= 1 if value reported for hunting; = 0 otherwise
Off-highway vehicle use/snowmobiling	= 1 if value reported for off-highway vehicle use use/snowmobiling; = 0 otherwise
Nonmotorized boating	= 1 if value reported for nonmotorized boating; = 0 otherwise
Motorized boating	= 1 if value reported for motorized boating; = 0 otherwise
Hiking	= 1 if value reported for hiking; = 0 otherwise
Biking	= 1 if value reported for biking; = 0 otherwise
Downhill skiing	= 1 if value reported for downhill skiing; = 0 otherwise
Other recreation activity	= 1 if value reported for other recreation activity; = 0 otherwise

Note: Omitted variables are bold.

NVUM = National Visitor Use Monitoring.

functional form to relate the dependent and independent variables as follows.

Equation: $$CS/Day = \sum\beta X_{ik} = \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots \beta_J X_{iK} + \varepsilon_i \quad (2)$$

where there are i estimates, j individual studies and k explanatory variables (k = 1…K) that explain consumer surplus per day (CS/Day). The meta-regression follows the simple equation above where i = 2,709, j =342, and K = 32, where regional and activity comprised 23 of the explanatory independent variables. All statistical analysis was performed in Stata (SE version 14).

Data coding and independent variable selection—

The RUVD includes a master coding sheet with 126 fields. The main coding categories include study, benefit measure, methodology specifics, activity, site characteristics, and user demographics. Table 6 lists and defines the variables from this pool that were included in the meta-regression. Most of the variables are qualitative dummy variables coded as 0 or 1, where 0 means the study does not have a characteristic and 1 means that it does. Independent variables were included in the optimized meta-regression if they were significant at an 80 percent level of confidence or better. A general-to-specific process was used, which began with the full specification of the model using all coded variables. Least significant variables were removed sequentially until remaining variables were significant at the 80 percent confidence level or better ($p \leq 0.20$). The choice of the minimum significance level is arbitrary, but it does reduce the risk of not detecting a difference even though Type I errors are increased at an equal rate. This optimization reduces overspecification of the model when retaining variables whose coefficients are not significantly different than zero. Regional and activity category variables were retained regardless of significance as the purpose of this meta-regression is to construct values for benefits transfer by region and activity, not to study the influence of region and activity on consumer surplus values. The results of this model are presented in table 7.

Outliers—

Outliers are a common occurrence in metadata (Nelson 2015) and the economic values within the RUVD vary widely. Outliers can become influential data points, affecting the meta-regression and weighted means in ways that cloud inference. Based on examination of the methods behind these outliers, and some reasonable assumptions about daily recreation economic values, consumer surplus per day estimates below $5 and above $500 were removed from the meta-analysis

Results—

Table 7 provides results of the meta-regression model fit to the data and used in constructing the values in table 3. The next section provides examples of how average values are constructed, with particular attention to treatment of the region and activity-specific variables. However, as noted elsewhere, the first eight variables, measuring partial effects of study methods and modeling assumptions, population, and site characteristics, are held constant at their mean values. In general, the model accounts for more than 20 percent of the observed variation in the benefit estimates, which is consistent with prior meta-analyses of recreation benefits (Rosenberger and Loomis 2001).

The meta-regression analyzes information on all studies in the database and relates independent variables of interest, such as activity, region, or survey methodology, to the dependent variable, estimated recreation benefit (measured as consumer surplus). Theoretically, when a variable helps explain the variation in recreation benefit measures, its regression coefficient will be significant in the model. Combining these significant variables in a multivariate model provides a transparent and consistent way to estimate average values based on a policy site's specific characteristics. Given the large sample size, the overall model performance has a grand mean—that is, the mean of the sample means—with ±2.5 percent margin of error. Thus, the meta-regression analysis model provides more robust estimates than an average value transfer (e.g., table 3 values).

Table 7–Optimized meta-analysis benefit-transfer model

Variable	Coefficient	Robust SE[a]	Mean of variable
Nonresidents	45.05[b]	9.94	0.07
User sample	22.25[b]	8.27	0.21
Revealed preference	28.06[b]	8.83	0.48
Substitutes modeled	-15.95[b]	6.25	0.25
Zonal travel cost	-47.78[b]	9.53	0.21
Lake	-23.15[b]	7.13	0.19
Forest	-11.84	8.85	0.16
Wetland	187.47[b]	8.87	0.01
Forest Service (FS) Region 1	15.50	11.87	0.04
FS Region 2	8.72	9.51	0.09
FS Region 3	16.80	12.53	0.07
FS Region 4	18.72	12.96	0.09
FS Region 5	2.55	12.04	0.04
FS Region 6	9.06	12.65	0.06
FS Region 8	8.52	8.74	0.19
FS Region 9	-2.98	8.59	0.31
FS Region 10	41.01	22.87	0.03
National	19.92	13.13	0.03
Developed camping	-29.39[b]	10.22	0.02
Backpacking	-31.85[b]	10.63	0.03
Picnicking	-15.83[b]	7.90	0.01
Nature related	-4.87	9.02	0.16
Cross-country skiing	-8.48	9.96	0.01
Fishing	6.51	9.00	0.34
Hunting	12.41	10.10	0.23
Off-highway vehicle use/snowmobiling	-14.55	13.45	0.02
Nonmotorized boating	43.92	30.99	0.03
Motorized boating	-6.63	16.15	0.03
Hiking	19.45	12.63	0.04
Biking	21.74	27.72	0.01
Downhill skiing	17.22	35.75	0.01
Constant	54.77[b]	12.89	1

Summary statistics: N = 2,709, adjusted $R^2 = 0.20$, Root mean squared error = 61.44.

[a] Cluster robust standard error computed in Stata 14.1 using individual study as cluster (n = 342).

[b] Variable is statistically significant at the $p < 0.05$ level or better. Overall margin of error is ±2.5 percent.

Also keep in mind that many qualitative variables reflecting other attributes of the study, site and resource, methods, and values estimates do not exceed the 80 percent significance threshold when specifying the meta-regression model. Empirically these variables are not related to variations in consumer surplus for this set of data, but they may be theoretically significant. Unfortunately, retaining all variables would result in increased multicollinearity and overspecification of the model. Please keep this in mind when conducting single-study transfers where assessing the degree of similarity between sites depends greatly on their characteristics regardless of their significance in the meta-regression model.

Total aggregate benefits are likely greater for locals than nonlocals.

The estimated parameters show the partial effect of each variable on the variation in the dependent variable—value per person per day. For example, people who travel greater distances (nonresidents) from home to recreation sites have higher values, ceteris paribus, than local residents. However, the total aggregate benefits to local residents are likely higher owing to the ability to visit more often at lower overall cost, but people who generally travel greater distances have selected their destination over other sites and activities that are generally closer to home. Also along this same line of reasoning, studies that incorporate substitute sites (substitutes modeled) generally produce lower estimated values, ceteris paribus, as economic theory would expect (see Loomis and Walsh 1997, Rosenthal 1987).

Additional detail and application—

The meta-analysis function is used to construct values by holding all independent or explanatory variables constant at their mean values (last column, table 7), except for the relevant regional and activity variables. These effects are weighted by their mean values—each variable's coefficient is multiplied by its weight, providing the partial consumer surplus owing to that variable. These partial values are then summed along with the constant (intercept) to construct values. To construct estimates for a particular region, that region's variable would be equal to 1, and the full value of its coefficient would be summed into the constructed value.

This procedure is illustrated in the examples presented in table 8 where we calculate the average value of a day of hiking in California (FS Region 5 [Pacific Southwest Region]) and a day of camping in Georgia (FS Region 8 [Southern Region]). The example predictions in table 8 may look simplistic—this is because we have averaged out the many other nonregion and nonactivity variables in the model. However, note that the data behind the meta-analysis is not all specific to hiking or camping, or California or Georgia. Therefore, each of the constructed average values is an estimate for a generic activity similar to hiking in California or to camping in Georgia. There is often a direct correlation between the degree of specificity in the constructed value and the overall representation of a variable

Table 8—Example adaptation of meta-analysis benefit function

		Hiking in California		Camping in Georgia	
Variable	Coefficient	Adaption value	Partial CS	Adaption value	Partial CS
FS Region 1	15.50	0	0	0	0
FS Region 2	8.72	0	0	0	0
FS Region 3	16.80	0	0	0	0
FS Region 4	18.72	0	0	0	0
FS Region 5	2.55	1	2.55	0	0
FS Region 6	9.06	0	0	0	0
FS Region 8	8.52	0	0	1	8.52
FS Region 9	-2.98	0	0	0	0
FS Region 10	41.01	0	0	0	0
Developed camping	-29.39	0	0	1	-29.39
Backpacking	-31.85	0	0	0	0
Picnicking	-15.83	0	0	0	0
Nature related	-4.87	0	0	0	0
Cross-country skiing	-8.48	0	0	0	0
Fishing	6.51	0	0	0	0
Hunting	12.41	0	0	0	0
OHV use/snowmobiling	-14.55	0	0	0	0
Nonmotorized boating	43.92	0	0	0	0
Motorized boating	-6.63	0	0	0	0
Hiking	19.45	1	19.45	0	0
Biking	21.74	0	0	0	0
Downhill skiing	17.22	0	0	0	0
Constant	54.77	1	54.77	1	54.77
Net of all other variables	NA	NA	1.17	NA	1.17
Total			$77.94		$35.07

CS = consumer surplus, FS = Forest Service, NA = not applicable, and OHV = off-highway vehicle.

in the database. This is due to the statistically discovered variability across these activities, or lack thereof. For example, there are 111 estimates for hiking and 82 estimates for camping included in the database, not all of which are in Region 5 or Region 8. Therefore, the constructed averages take into account the distribution of all values for hiking or camping relative to all values for Regions 5 and 8. These example applications illustrate the degree to which these constructed values are generic estimates when holding everything in the model constant except for region and activity.

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CATO INSTITUTE BLOG

FEBRUARY 28, 2024 4:59PM

The Political Economy of EPA's Updated Social Cost of Carbon

By **Travis Fisher**

The social cost of carbon dioxide (SCC): Who needs it? As it turns out, anyone who cares about enacting climate policies that improve the lives of our fellow human beings probably needs it. Conceptually, the SCC is the number that represents the negative (or positive) externality of emitting an additional ton of carbon dioxide into the atmosphere.

The idea of the SCC is to take the cost-benefit analysis framework and apply it to the economic impacts of greenhouse gas emissions over decades or even centuries (not just CO_2, but also CH_4, N_2O, etc. — I will use decades or even centuries (not just CO_2 but also CH_4, N_2O, etc.—I will use SCC as shorthand for the social cost of greenhouse gases [SC-GHG]).

The corollary is that the SCC is the yardstick by which climate policies should be measured—if the CO_2 abatement cost of a given policy is higher than the SCC, that policy presents a losing proposition to society, according to the economic theory of **externalities**. Alternatively, if a policy can reduce CO_2 emissions at a cost lower than the SCC, textbook economics would tell us to go for it. If one were to establish a CO_2 tax at the economically efficient level (the SCC), one would first need to know what the SCC is.

The trouble with anything so central to energy and climate policy is that advocates from all sides tell us drastically different things: the SCC is either the most **useless** number you've never heard of or the most **important**; it's either **negligible** or **sky-high** (four times higher than original estimates!); it's either part of a radical new push to enact a **global carbon tax** or simply a science-based tool for evaluating and enacting **economically optimal** climate policy.

My concern is that the SCC framework can be manipulated to generate a wide range of outcomes. After reviewing the Environmental Protection Agency's (EPA's) most recent **update** to the SCC (and previous attempts to **reduce** or **raise** it), it's clear the EPA's process presents a conflict of interest. Let's sift through the details.

Theoretical Framework for the SCC

Below is a short summary of what the SCC is and how scholars estimate it (experts, please feel free to send me a strongly worded letter for oversimplifying this!). Key ingredients for estimating the SCC include:

1. Models of local and global economies, including economic outputs like gross domestic product and environmental outputs like CO_2 emissions,

2. Models of the global climate, including the equilibrium climate sensitivity (the temperature increase from increases in atmospheric CO_2 concentrations),

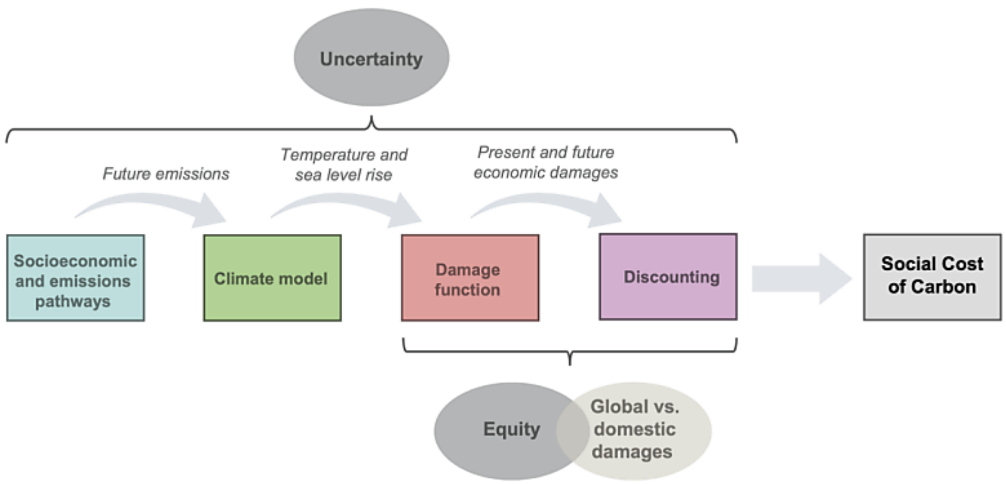
3. Models connecting (1) and (2) to establish a "damage function"—the stream of monetized future costs and benefits from additional CO_2

emissions (like higher sea levels and temperatures, etc.), and

4. A model to convert future economic impacts into a net present value, typically through the application of a discount rate.

If the above framework sounds like a litigator's field day, it's because each of the key ingredients (among others) is subject to strong disagreement. Unfortunately, it's even more complicated than it looks. Other questions that don't have crisp answers include the geographic scope of inquiry (subnational, national, or global) and the relevant time period to study (how far to look into the future).

A recent paper by Drs. Michael Greenstone and Tamma Carleton outlines the SCC framework graphically. Note that each stage of developing the SCC features uncertainty.



Source: https://bfi.uchicago.edu/wp-content/uploads/2021/01/BFI_WP_202104.pdf

History of Federal SCC Estimates

Moving from the theoretical to the practical, the paper by Greenstone and Carleton also explains the origin of the SCC in federal policy:

> Following the Supreme Court's decision in *U.S. Environmental Protection Agency (EPA) vs. Massachusetts (2007)*, the US government has been required to issue at least some regulations to

> government has been required to issue at least some regulations to reduce greenhouse gas emissions, but at the time of the decision it lacked a consistent SCC with which to inform its judgments. In 2009, the Obama Administration issued a temporary SCC and formed an Inter-agency Working Group (IWG) tasked with developing a robust SCC, based on the best available science and economics.

And the Brookings Institution **offers** a concise history of the magnitudes of the SCC as estimated by the US federal government:

> The Obama administration initially estimated the social cost of carbon at $43 a ton globally, while the Trump administration only considered the effects of carbon emissions within the United States, estimating the number to be between $3 and $5 per ton. As it stands, the official estimate from the Biden administration is $51, but in November 2022, the EPA proposed a nearly fourfold increase to $190.

The Trump administration established the low water mark for the SCC by changing some of the modeling assumptions, namely restricting its analysis to domestic (vs. global) economic impacts and using higher discount rates (3 percent and 7 percent). Interestingly, the SCC estimates by the Interagency Working Group (IWG) in the Obama era and early Biden era are closer to the Trump-era SCC than they are to the recent update by the EPA, which again changed inputs and assumptions to re-estimate the SCC. Over the past decade, the federal government's estimates of the SCC have ranged from near zero to $190 per ton.

What's Included in EPA's Update?

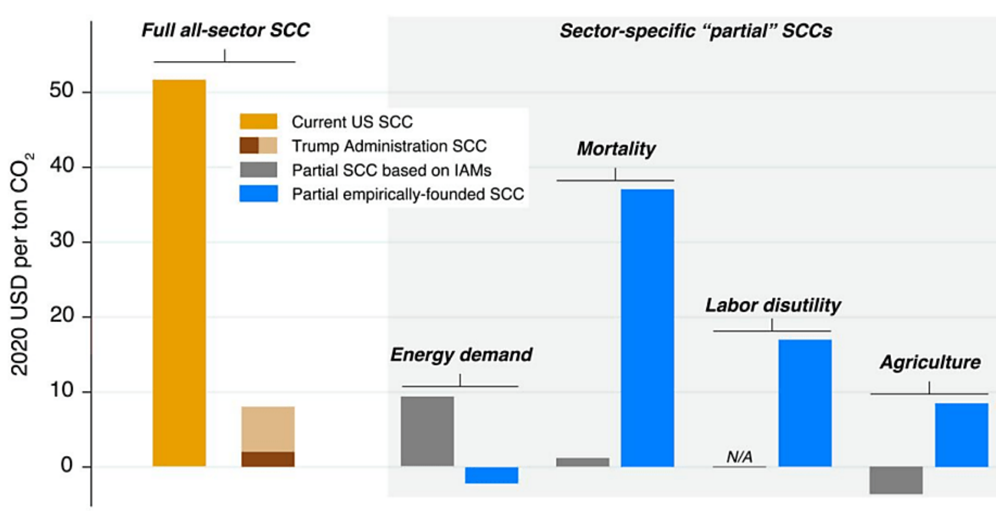
In line with efforts already underway by the **National Academies** of Science, Engineering and Medicine, **Resources for the Future**, and academic **economists**, the EPA recently went through a formal rulemaking process to update the SCC. The EPA is still part of the IWG but is moving forward with a separate (and faster) change to its SCC estimate. Here's how the EPA characterizes its update in a November 2023 **report**:

> These estimates reflect recent advances in the scientific literature on climate change and its economic impacts, and incorporate

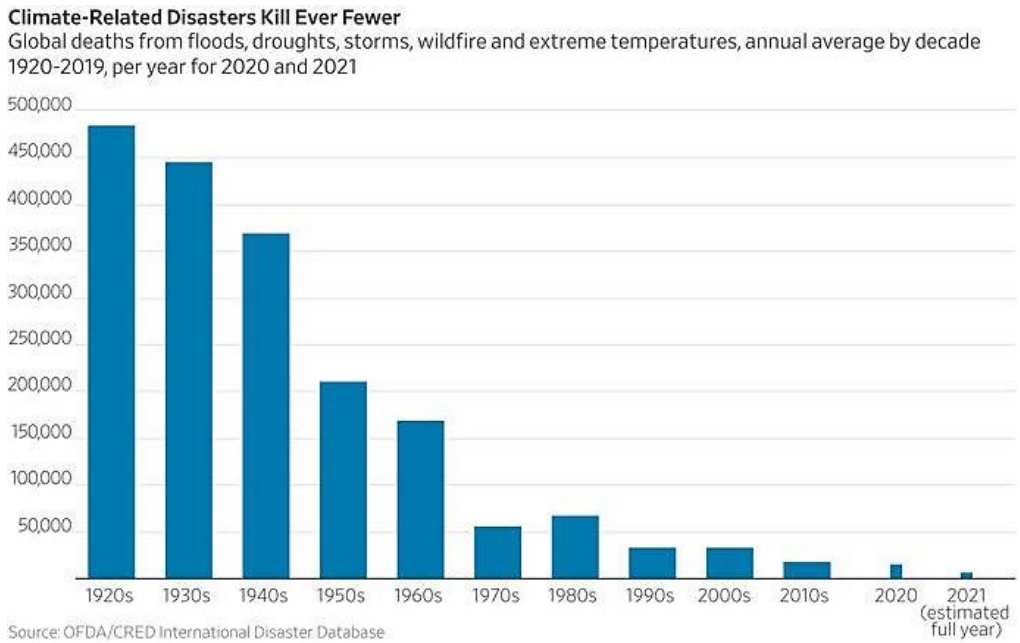
> recommendations made by the National Academies of Science, Engineering, and Medicine (National Academies 2017). The SC-GHG allows analysts to incorporate the net social benefits of reducing emissions of greenhouse gases (GHG), or the net social costs of increasing GHG emissions, in benefit-cost analysis and, when appropriate, in decision-making and other contexts.

In its new estimate of the SCC, the EPA adjusted several model parameters. The most impactful changes include the use of a different set of damage functions—particularly ones that feature increased human mortality from climate change—and the application of a lower discount rate (using 2 percent rather than 3 percent, which accounts for the majority of the difference between the previous SCC estimates of approximately $50 per ton and the $190 update).

Regarding changes to mortality estimates, the EPA report states on page 48: "The building block of the global mortality damage function is the estimation of temperature's impact on mortality rates using historical data." The report reiterates the large impact of modeled mortality rates on page 80 by stating "net mortality risk increases are the largest share of marginal damages across the categories considered in each damage module." The paper by Drs. Greenstone and Carleton provides a helpful graphical breakdown of the changes in the new damage functions.



However, the long-term global trend in climate-related deaths is steeply declining over the past century. Energy researchers like Alex Epstein **argue** that human beings' ability to adapt to a changing climate—what he calls "climate mastery"—largely negates any potential harm from changes in the “climate mastery”—largely negates any potential harm from changes in the global climate. In the same vein, the chart below is from an article in the *Wall Street Journal* by Bjorn Lomborg titled *We’re Safer From Climate Disasters Than Ever Before*. Lomborg is right. The global data tell a different story from the one EPA relied upon to increase the SCC.



Source: **https://www.wsj.com/articles/climate-activists-disasters-fire-storms-deaths-change-cop26-glasgow-global-warming-11635973538**

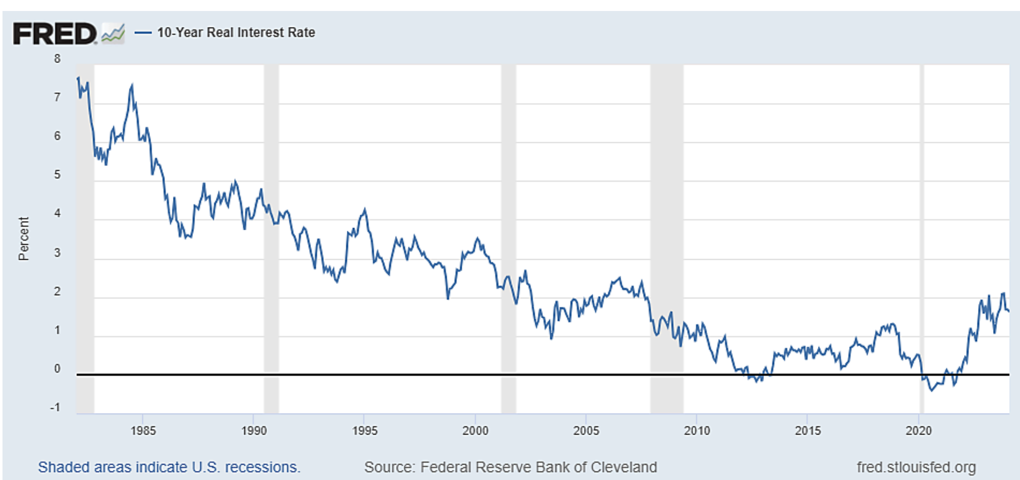
Regarding changes to the discount rate, we should first appreciate the significant impact discount rates have on SCC estimates. Below is the SCC schedule from page 4 of the EPA report, showing the updated SCC by emission year and discount rate. Note that reducing the discount rate from 2 percent to 1.5 percent causes the 2020 SCC to rise from $190 per ton to $340 per ton (nearly an 80 percent increase in the SCC from a 0.5 percentage point reduction in the discount rate).

	SC-CO_2 *(2020 dollars per metric ton of CO_2)*		
Emission	Near-term rate		
Year	2.5%	2.0%	1.5%
2020	120	190	340

2030	140	230	380
2040	170	270	430
2050	200	310	480
2060	230	350	530
2070	260	380	570
2080	280	410	600

The EPA claims to follow the latest empirical trends by lowering the discount rate to match the risk-free real interest rate. The EPA's new estimate tracks recent guidance by the White House Office of Management and Budget (OMB), which made similar revisions in its guidance document regarding cost-benefit analyses performed by all federal agencies (called OMB **Circular A-4**). An accessible discussion of the broader regulatory implications of a lower discount rate can be found **here**.

The EPA is correct that the long-term trend in the risk-free interest rate in the United States is downward, as shown below. However, it will be instructive to see whether the OMB and the EPA will acknowledge the recent uptick in the 10-year real interest rate (and update the SCC again if this rate continues to rise). And it's interesting—arguably inconsistent—that an estimate of the global SCC would rely exclusively on US interest rates.



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There is ample room for debate about whether this is the correct discount rate to use in inter-generational cost-benefit analyses. For example, a philosophical reason to apply a higher discount rate to future costs and benefits: high uncertainty about what the world will look like decades or centuries from now. Estimating the future costs and benefits of climate change requires understanding the future itself. Given the pace of technological advancement since the industrial revolution, the task of accurately modeling the distant future may be impossible.

Consider that many climate models offer estimates of the costs and benefits of GHGs out to the year 2300. The year 2024 is as far from 2300 as it is from the year 1748. Imagine colonists in 1748 fretting over the correct level of a greenhouse gas tax to implement for the benefit of the people of the year 2024. At a long enough time horizon, the SCC modeling exercise becomes absurd because the future scenario fades from fuzzy to unknowable. No one living in the year 1748 had an accurate picture of the year 2024, so how much weight should we give our predictions of the costs and benefits impacting people in the year 2300?

EPA's Conflict of Interest

The choice of model parameters is inherently political because it requires value judgments, such as deciding how heavily to weigh the economic impacts on future generations. Because small tweaks in these value judgments (like the discount rate) can significantly skew SCC estimates, the entity responsible for estimating the SCC should not have a vested interest in the outcome of the analysis.

Unfortunately, the EPA is simultaneously advancing the federal government's estimate of the SCC and finalizing GHG regulations emissions from power plants and vehicle tailpipes. The EPA should not be allowed to give itself carte blanche to establish the magnitude of the benefits of its own regulations. If the EPA remains involved in establishing the SCC, it should work with the IWG and a wide range of stakeholders. The EPA's conflict of interest is obvious—it could use updated SCC estimates in cost-benefit analyses to justify whatever level of GHG regulation it wants. In essence, it gets to pick the benefits in the cost-benefit analysis.

Industry observers have highlighted the usefulness to the EPA and the Biden administration of establishing a high SCC estimate. *New York Times* reporter Coral Davenport stated (around the 17-minute mark at **this** Brookings Institution forum in April 2023):

> The Biden administration is preparing, in the next couple of weeks, to propose what I think will be the most aggressive standard the US has ever seen on US auto emissions. It will be designed to essentially end sales of the internal combustion engine in our lifetime. ...[T]hat is a transformation of a cornerstone of the US economy as we have known it for the last century. How do you economically justify that? One way you do that is you come in with the social cost of carbon at $192 per ton. If you can justify, if you can say this rulemaking that will phase out the internal combustion engine and force automakers to change everything they've done, force all of us to buy EVs—almost whether or not we want to—if you say the cost of every ton of carbon dioxide that comes out of that tailpipe is $192—hurts us all $192—boom, you basically have your economic justification for this powerful rulemaking.

Even some advocates of aggressive climate policy have **rejected** the exclusive use of the SCC and **said** cost-benefit analyses "as practiced now are little more than a 'political exercise' to help agencies sell their policies... not to identify the best policy alternatives." If the SCC will be used as economic justification for sweeping new rulemaking, then the agency responsible for the rulemaking should not also be responsible for establishing the SCC.

Conclusion

The SCC is indispensable in concept but extremely malleable and borderline unworkable in practice. However, difficulty in estimating an important thing doesn't make the thing itself any less important. It does make the estimator's job harder, though, and we should be honest about the potential for abuse (by administrations from both political parties) baked into the SCC framework. At the very least, the EPA should not be allowed to print its own regulatory currency by raising the SCC.

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General Technical Report NE-343

Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States

James E. Smith
Linda S. Heath
Kenneth E. Skog
Richard A. Birdsey

Abstract

This study presents techniques for calculating average net annual additions to carbon in forests and in forest products. Forest ecosystem carbon yield tables, representing stand-level merchantable volume and carbon pools as a function of stand age, were developed for 51 forest types within 10 regions of the United States. Separate tables were developed for afforestation and reforestation. Because carbon continues to be sequestered in harvested wood, approaches to calculate carbon sequestered in harvested wood products are included. Although these calculations are simple and inexpensive to use, the uncertainty of results obtained by using representative average values may be high relative to other techniques that use site- or project-specific data. The estimates and methods in this report are consistent with guidelines being updated for the U.S. Voluntary Reporting of Greenhouse Gases Program and with guidelines developed by the Intergovernmental Panel on Climate Change. The CD-ROM included with this publication contains a complete set of tables in spreadsheet format.

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Cover

Eric Fiegenbaum provided the cover artwork.

Manuscript received for publication 21 December 2005

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

April 2006

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Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States

Contents

Preface

In 2002, President George W. Bush directed the Department of Energy and the Department of Agriculture to revise the system for reporting and registering reductions in greenhouse gas emissions. Increasing carbon sequestration by forests and harvested products is equivalent to reducing emissions, and represents a significant opportunity for the private sector to voluntarily take action. Rules and guidelines are needed to provide a basis for consistent estimation of the quantity of carbon sequestered and emissions reduced by forestry activities, and can be used to determine the value of tradable credits. The value of registered carbon credits can provide increased income for landowners, support rural development, and facilitate sustainable forest management.

Many prospective reporting entities require information and decision-support software to evaluate prospects and develop plans for implementing forestry activities, and to estimate rates of carbon sequestration for reporting purposes. Estimating the quantity of carbon sequestered could be a difficult and expensive task, possibly requiring the establishment of a monitoring system based on remote sensing, field measurements, and models. However, there are situations for which a simpler estimation process is acceptable, requiring only a basic familiarity with definitions and accounting rules.

In practice, reporters may choose the simplest available methods that provide estimates with a degree of accuracy that meets reporting objectives. The information provided in this publication can be used to estimate carbon emissions, emission reductions, or sequestration about a forestry activity—data on the forest area affected, type of activity, and region of interest. The quality of the results will depend largely on the quality of the activity data and how closely actual activities are reflected in the factors. The intent in providing this information is to provide consistent and reliable estimates and to simplify the reporting process.

The tables in this publication represent significant updates of similar tables used for more than a decade to analyze forest carbon sequestration activities (Birdsey 1996). Since the previous tables were published, advances have been made in methods that estimate how various carbon components of forest ecosystems change over time, and how carbon in harvested products is retained in use or emitted to the atmosphere. This publication further documents the General Guidelines for reporting greenhouse gas information under Section 1605(b) of the Energy Policy Act of 1992.

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Introduction

International agreements recognize forestry activities as one way to sequester carbon, and thus mitigate the increase of carbon dioxide in the atmosphere; this may slow possible climate change effects. The United States initiated a voluntary reporting program in the early 1990's (U.S. Dep. Energy 2005). A system for developing estimates of the quantity of carbon sequestered in forest stands and harvested wood products[1] throughout the United States is a vital part of the voluntary program. This system must be relatively easy to use, transparent, economical, and accurate. In this publication, we present methods and regional average tables that meet these criteria.

Carbon is sequestered in growing trees, principally as wood in the tree bole. However, accrual in forest ecosystems also depends on the accumulation of carbon in dead wood, litter, and soil organic matter. When wood is harvested and removed from the forest, not all of the carbon flows immediately to the atmosphere. In fact, the portion of harvested carbon sequestered in long-lasting wood products may not be released to the atmosphere for years or even decades. If carbon remaining in harvested wood products is not part of the accounting system, calculation of the change in carbon stock for the forest area that is harvested will incorrectly indicate that all the harvested carbon is released to the atmosphere immediately. Failing to account for carbon in wood products significantly overestimates emissions to the atmosphere in the year in which the harvest occurs.

We adopted the approach of Birdsey (1996), who developed tables of forest carbon stocks and carbon in harvested wood to provide basic information on average carbon change per area. The tables are commonly referred to as "look-up tables" because users can identify the appropriate table for their forest, and look up the average regional carbon values for that type of forest. We have updated the tables by using new inventory surveys, forest carbon and timber projection models, and a more precise definition of carbon pools. We also include additional forest types and background information for customizing the tables for a user's specific needs.

The look-up tables are categorized by region, forest type, previous land use, and, in some cases, productivity class and management intensity. Users must identify the categories for their forest, estimate the area of forestland, and, if needed, characterize the amount of wood harvested from the area in a way that is compatible with the format of the look-up tables. The average carbon estimates per area in the look-up tables must be multiplied by the area or, as appropriate, harvested volumes, to obtain estimates in total carbon stock or change in carbon stock.

The estimates in the look-up tables are called "average estimates," indicating that they should be used when it is impractical to use more resource-intensive methods to characterize forest carbon, that is, particularly when more specific information is not available. Because these tables represent averages over large areas, the actual carbon stocks and flows for specific forests, or projects, may differ. The look-up tables should not be used when conditions for a project or site differ greatly from the classifications specified for the tables. Some users may require an alternative to an "all-or-nothing" use of the tables because they may have some information and need to use the tables to supplement, or fill in gaps, in carbon stocks. Alternatively, users may require slight alterations to the tabular data provided. Therefore, we also include the underlying assumptions and appropriate citations so that the tables can be adjusted to data availability and information requirements of individual activities.

The focus of this document is to explain the methodology in a transparent way and present sets of look-up tables for quantifying forest carbon when site-specific information is limited. In the sections that follow, we introduce the tables and provide general guidance for their use. First, tables of forest ecosystem carbon are presented; these are followed by tables to calculate the disposition of carbon in harvested wood products. Additional information on methods and data sources

[1]Traditionally, the phrase "forest products" includes paper, but the phrase "wood products" does not. The literature for forest carbon has not recognized this distinction. Thus, we use the phase "wood products" to include all forest products including paper.

follows these tables. This organization was adopted so that readers interested in using the tables can do so quickly. Both metric and English units are used for measures of area and volume.[2] However, all values for carbon mass are expressed in metric units—tonnes (t)—unless specified otherwise. English units are included because most of the necessary input quantities are commonly expressed in units such as cubic feet/acre (for stand-level growing-stock volume) or thousand square feet of ⅜-inch plywood (a primary wood product), for example. Carbon stocks and stock changes are usually discussed and reported in metric units of carbon mass; this can lead to carbon in forests expressed as tonnes/hectare or in the United States as metric tons/acre. The forest ecosystem carbon tables are in Appendices A, B, and C; ancillary information on carbon in harvested wood is in Appendix D. Spreadsheet versions of the tables are on the CD-ROM that is included with this publication.

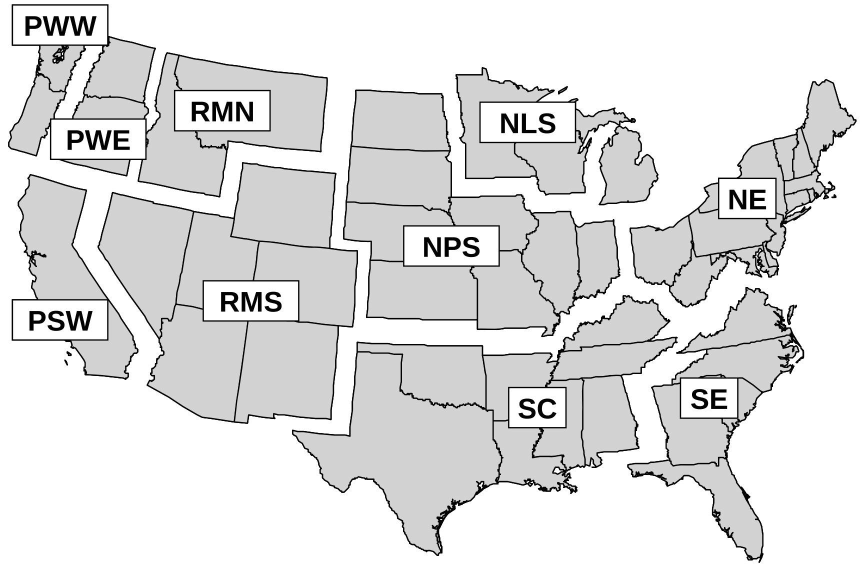

Figure 1.—Definition of regions: Pacific Northwest, West (PWW); Pacific Northwest, East (PWE); Pacific Southwest (PSW); Rocky Mountain, North (RMN); Rocky Mountain, South (RMS); Northern Prairie States (NPS); Northern Lake States (NLS); Northeast (NE); South Central (SC); and Southeast (SE). Note that regions are merged for some tables, these combinations include: NLS and NPS as North Central; PWW, PWE, and PSW as Pacific Coast; RMN and RMS as Rocky Mountain; SC and SE as South; and RMN, RMS, PWE, and PSW as West (except where stated otherwise).

Forest Ecosystem Carbon Tables

Tables of estimates of forest carbon stock are provided for common forest types within each of 10 U.S. regions (Fig. 1). Six distinct forest ecosystem carbon pools are listed: live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic carbon. These pools are defined in Table 1. An example of the forest ecosystem tables is provided as Table 2, with the complete set in Appendices A and B. The first two columns in each table are age and growing-stock volume; the remaining columns represent carbon stocks for the various carbon pools and are dependent on age or growing-stock volume. Pools are quantified as carbon densities, that is, tonnes per unit area (acres or hectares).

The use of the tables can be summarized in three steps: 1) identify the most appropriate table for the particular carbon sequestration project; 2) extract the tabular information required for estimating carbon sequestration by the project; and 3) complete any necessary custom modifications or post-processing needed to suit data requirements. The information in the tables is based on a national-level, forest carbon accounting model (FORCARB2; Heath and others 2003, Smith and others 2004a), a timber projection model (ATLAS; Mills and Zhou 2003, Mills and Kincaid 1992, updated for Haynes 2003), and the USDA Forest Service, Forest Inventory and Analysis (FIA) Program's database of forest surveys (FIADB; USDA For. Serv. 2005, Alerich and others 2005). Details are provided in the methods section.

The two basic sets of tables in Appendices A and B differ only with respect to assumptions associated with previous land use. The first set displays carbon stocks on forest land remaining forest land, also called "reforestation" or "regrowth" of a stand following a clearcut harvest (Table 2, for example, and Appendix A). The second set displays accumulation of carbon stocks for a stand established

[2]A tonne (t) is defined as 10^6 grams, or 2,204.62 pounds (lb). Other metric and English equivalents include 0.404686 hectare (ha) = 1 acre (ac), 2.54 centimeter (cm) = 1 inch (in), 0.0283168 cubic meter (m^3) = 1 cubic foot (ft^3), and 0.907185 tonne = 1 short ton = 2,000 pounds.

Table 1.—Classification of carbon in forest ecosystems and in harvested wood

Forest ecosystem carbon pools	
Live trees	Live trees with diameter at breast height (d.b.h.) of at least 2.5 cm (1 inch), including carbon mass of coarse roots (greater than 0.2 to 0.5 cm, published distinctions between fine and coarse roots are not always clear), stems, branches, and foliage.
Standing dead trees	Standing dead trees with d.b.h. of at least 2.5 cm, including carbon mass of coarse roots, stems, and branches.
Understory vegetation	Live vegetation that includes the roots, stems, branches, and foliage of seedlings (trees less than 2.5 cm d.b.h.), shrubs, and bushes.
Down dead wood	Woody material that includes logging residue and other coarse dead wood on the ground and larger than 7.5 cm in diameter, and stumps and coarse roots of stumps.
Forest floor	Organic material on the floor of the forest that includes fine woody debris up to 7.5 cm in diameter, tree litter, humus, and fine roots in the organic forest floor layer above mineral soil.
Soil organic carbon	Belowground carbon without coarse roots but including fine roots and all other organic carbon not included in other pools, to a depth of 1 meter.
Categories for disposition of carbon in harvested wood	
Products in use	End-use products that have not been discarded or otherwise destroyed, examples include residential and nonresidential construction, wooden containers, and paper products.
Landfills	Discarded wood and paper placed in landfills where most carbon is stored long-term and only a small portion of the material is assumed to degrade, at a slow rate.
Emitted with energy capture	Combustion of wood products with concomitant energy capture as carbon is emitted to the atmosphere.
Emitted without energy capture	Carbon in harvested wood emitted to the atmosphere through combustion or decay without concomitant energy recapture.

Table 2.—Example reforestation table with regional estimates of timber volume and carbon stocks on forest land after clearcut harvest for maple-beech-birch stands in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/ha*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	32.0	27.7	69.6	61.8
5	0.0	7.4	0.7	2.1	21.7	20.3	69.6	52.2
15	28.0	31.8	3.2	1.9	11.5	16.3	69.6	64.7
25	58.1	53.2	5.3	1.8	7.8	17.6	69.6	85.7
35	89.6	72.8	6.0	1.7	6.9	20.3	69.6	107.8
45	119.1	87.8	6.6	1.7	7.0	23.0	69.6	126.0
55	146.6	101.1	7.0	1.7	7.5	25.3	69.6	142.7
65	172.1	113.1	7.4	1.7	8.2	27.4	69.6	157.7
75	195.6	123.8	7.7	1.7	8.8	29.2	69.6	171.2
85	217.1	133.5	7.9	1.7	9.5	30.7	69.6	183.2
95	236.6	142.1	8.1	1.7	10.1	32.0	69.6	193.9
105	254.1	149.7	8.3	1.6	10.6	33.1	69.6	203.4
115	269.7	156.3	8.5	1.6	11.1	34.2	69.6	211.7
125	283.2	162.1	8.6	1.6	11.5	35.1	69.6	218.8

on land that was not forest, called “afforestation” (Appendix B). The separate set of afforestation tables accounts for lower carbon densities of down dead wood, forest floor, and soil carbon in the initial years after forest establishment on nonforest land. However, as stands mature, the level of carbon stocks in these pools approaches the regional averages represented in the reforestation tables.

The tables in Appendices A and B provide estimates of carbon stock. The net change in carbon stock (sometimes called flux) associated with a growing forest can be determined by dividing the difference between two carbon stocks by the time interval between them. (See Examples 1 and 2 for information on using these tables.)

Example 1.—Obtain values for carbon stock and net stock change for stands of maple-beech-birch in the Northeast.

Use Table 2 to determine values for live tree carbon stock at years 25 and 45 and calculate net stock change over the interval.

Reading directly from the table, live tree carbon stocks are 53.2 and 87.8 t/ha for years 25 and 45, respectively.

Net annual stock change in live tree carbon between year 25 and 45, which is from the difference in stocks divided by the length of the interval between stocks:

Net annual stock change = (87.8 – 53.2) / 20 = 1.7 t/ha/yr

The positive value for stock change indicates a net increase in carbon over the interval; this is consistent with the sign convention used for net stock change in this document. This tabular approach is applicable to all carbon pools in Appendices A, B, and C. Users must first classify the forest of interest and choose the most appropriate table.

Example 2.—Obtain an estimate of carbon stock when the value is not explicitly provided on a table, for stands of maple-beech-birch in the Northeast.

Use Table 2 to calculate live tree carbon stock of a stand with volume of wood (growing-stock volume) of 150 m^3/ha. This value is obtained by linearly interpolating between rows 7 and 8 of Table 2. The estimate of live tree carbon is between rows 7 and 8 because 150 m^3/ha is also between those two rows, and live tree carbon is a function of volume (Fig. 2).

Linear interpolation identifies a value for carbon stock between 101.1 and 113.1 t/ha that is linearly proportional to the position of 150 between 146.6 and 172.1 (from rows 7 and 8 of Table 2).

Live tree carbon (if volume is 150 m^3/ha)

$= (150.0 - 146.6) / (172.1 - 146.6) \times (113.1 - 101.1) + 101.1$

$= 0.133 \times 12.0 + 101.1 \quad = 102.7$ t/ha

The value 0.133 means the carbon stock is 13.3 percent of the distance between the two stocks listed on the table, 101.1 and 113.1 t/ha.

Modifications to Forest Ecosystem Tables

The forest ecosystem tables provide regional averages as scenarios of forest growth and carbon accumulation, but they need not be used as the sole source of information on forest yield or carbon. For instance, a landowner may independently acquire estimates of growth or carbon accumulation that are specific to a particular carbon sequestration project. In this case, an appropriate use of the tables is to combine available data and to selectively use columns of carbon stocks to fill gaps in information.

Users must have a general understanding of the relationships between the columns of the table to most appropriately substitute site-specific information for a carbon pool. Some columns can be viewed as independent or dependent variables, depending on the carbon pool of interest. If new data are incorporated in a table, any dependent columns (carbon pools) probably will require minor adjustments (recalculations). Figure 2 illustrates the basic relationships underlying calculations of carbon stock. Stand age and growing-stock volume are from the ATLAS model and based on FIA data such that they reflect region, forest type, and typical forest management regimes. Pools of live and standing-dead tree carbon are estimated directly from growing-stock volume. Carbon stocks of understory or down dead wood are estimated directly from live tree carbon and are only indirectly affected by growing-stock volume.

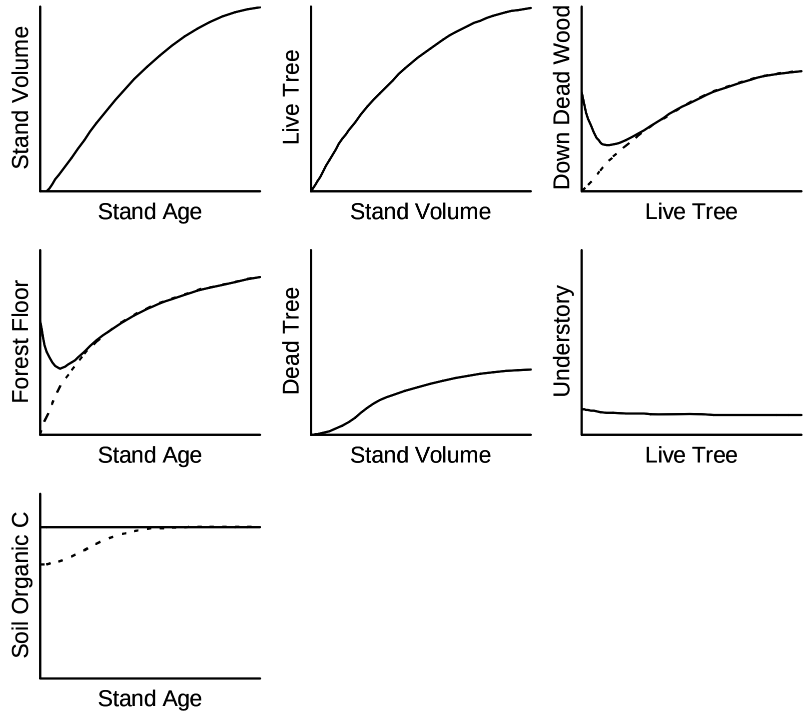

Figure 2.—Graphs indicating the basic relationships between the components of the forest ecosystem carbon tables. Figures are not drawn to scale; numerical representation for each graph is available from the tables. Dashed lines are qualitative representation of where afforestation tables (Appendix B) differ from the reforestation tables (Appendix A). Note that stand volume refers to growing-stock volume of live trees.

Growing-stock volume (stand volume in Figure 2) is the merchantable volume of wood in live trees as defined by FIA (Smith and others 2004c, Alerich and others 2005). Briefly, trees contributing volume to this stand-level summary value are commercial species that meet specified standards of size and quality or vigor. Users with other volume estimates for their stands must consider how to translate the volumes to be consistent with growing-stock volume. Thus, a landowner interested in applying these carbon estimates to another growth table should link tree carbon from the tables presented here to the new (separately obtained) estimates of growing-stock volume rather than to stand age (see Example 3). The methods section further explains how to use selected carbon pools from the table.

Tables for Harvested Wood Products Carbon

Harvested wood products serve as reservoirs of carbon that are not immediately emitted to the atmosphere at the time of harvest. The amount of carbon sequestered in products depends on how much wood is harvested and removed from the forest, to what products the harvested wood is allocated, and the half-life of wood in these products (Row and Phelps 1996, Skog and others 2004). The central focus of the carbon in harvested wood products estimates is the carbon change from two pools: carbon in products in use and carbon in landfills. Carbon in harvested wood is initially processed or manufactured into primary wood products, such as lumber and paper.

Example 3.—Modify a table to include independently obtained information about a forest carbon project

In this example, assume you have a project with loblolly pine established after clearcut harvest on existing forest land in the South Central region. The volume yields (Wenger, 1984) are:

Age	Mean volume
years	*m³/ha*
0	0.0
10	30.6
15	122.6
20	187.9
25	238.9
30	277.9

The appropriate carbon table is Table A47, which is partially duplicated for this example. The goal is to construct a hybrid table from the new growth and yield estimates (columns 1-2) and the appropriate estimates for each of the carbon pools (columns 3-8).

A47.—Regional estimates of timber volume and carbon stocks for loblolly and shortleaf pine stands on forest land after clearcut harvest in the South Central

Age	Mean Volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/ha*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	9.2	12.2	41.9	25.6
5	0.0	10.8	0.7	4.7	7.7	6.5	41.9	30.3
10	19.1	23.1	1.3	3.9	6.8	6.4	41.9	41.5
15	36.7	32.4	1.6	3.5	6.2	7.5	41.9	51.2
20	60.4	42.2	1.8	3.3	5.9	8.7	41.9	61.9
25	85.5	52.0	2.0	3.1	5.8	9.8	41.9	72.8
30	108.7	59.6	2.1	3.0	5.8	10.7	41.9	81.2
35	131.2	66.6	2.3	2.9	5.9	11.5	41.9	89.1
40	152.3	73.1	2.3	2.9	6.0	12.2	41.9	96.4

To construct the modified table, copy the first two columns directly from the new yield table and then interpolate some of the carbon pool densities from Table A47. Estimates for live- and standing dead trees are dependent on growing-stock volume (as indicated in Fig. 2). These values can be determined by linear interpolation as described in Example 2. Similarly, understory and down dead wood stocks, which are dependent on the updated live tree carbon stocks (Fig. 2), can be determined by interpolation. For example, the value of down dead wood carbon stock in row two is based on linearly interpolating between rows three and four of Table A47, that is, down dead wood = (29.2 - 23.1) / (32.4 - 23.1) × (6.2 - 6.8) + 6.8 = 6.4 t/ha. Interpolation is not necessary for estimates of forest floor or soil organic carbon. Forest floor is a function of stand age, and soil organic carbon is 41.9 t/ha.

The resulting modified defaults for South Central loblolly pine based on separately obtained growth and yield:

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/ha*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	9.2	12.2	41.9	25.6
10	30.6	29.2	1.5	3.6	6.4	6.4	41.9	47.1
15	122.6	63.9	2.2	2.9	5.8	7.5	41.9	82.3
20	187.9	83.7	2.5	2.8	6.3	8.7	41.9	104.0
25	238.9	98.2	2.7	2.6	7.0	9.8	41.9	120.3
30	277.9	109.1	2.8	2.6	7.6	10.7	41.9	132.8

These are then incorporated into end-use products, such as houses and newspapers. Intact primary and end-use products are considered "in use" until they are discarded, and a portion of these discarded products go to landfills. Additionally, a portion of carbon initially sequestered as products is eventually returned to the atmosphere through mechanisms such as combustion and decay. This emitted carbon is classified according to whether it occurred through a process of combustion with some concomitant energy recapture. This distinction between the two paths for carbon emitted to the atmosphere is included to assess potential displacement of other fuel sources. The four categories for the disposition of carbon in harvested wood are defined in Table 1. Note that the carbon in the four categories sum to 100 percent of the carbon harvested and removed from the forest.

The path that transforms trees-in-forests to wood-in-products can be described by the diagram in Figure 3. Quantities defined for the first three boxes in the diagram can serve as starting points, or data sources, for determining the disposition of carbon in wood products. Consistent with this, we provide factors for starting calculations of carbon in harvested wood products on the bases of forestland, the amount of industrial roundwood harvested, or the quantity of primary wood products produced by mills, depending on the data available (see definitions and details in the methods section). The forestland, or land-based, estimates are an extension of the forest ecosystem tables presented above. The other two starting points can be classified as product-based calculations, which are based on harvested logs or the output of mills. It is important to note that calculations from all three starting points (Fig. 3) focus on the same quantities of products in use or in landfills, and they all rely on the same model of allocation and longevity of end uses. They differ only in the level of detail available as the principal source of information on harvested wood—the path from input data to final disposition (Fig. 3). In the methods section, we provide the interrelated methods for calculating carbon in harvested wood for each of these starting points. Additionally, Appendix D provides background data and details on these calculations for wood products.

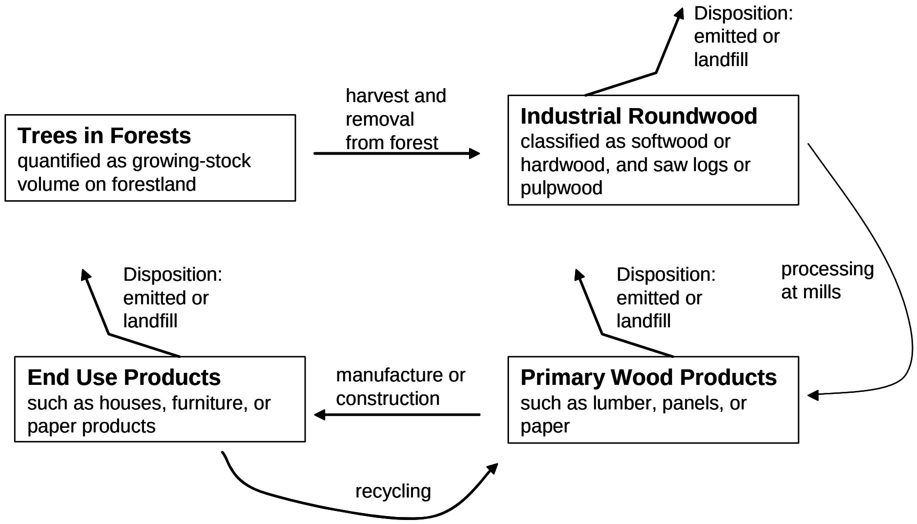

Figure 3.—The transition of carbon in forest trees to end-use products represented by a sequence of distinct pools separated by processes that move carbon between pools. Calculations of carbon in harvested wood products may start with any of the first three pools: trees in forests, industrial roundwood, or primary wood products.

Land-Based Estimates

The land-based estimates are provided as an additional set of forest ecosystem tables with harvest scenarios, which provide carbon estimates for harvested wood products over an interval after harvest (see Table 3 and Appendix C). At harvest, a large portion of carbon in tree biomass is allocated to the harvested wood pools, a second portion is assumed to decay rapidly after harvest (emitted at harvest), and the remainder stays on site in the forest as down dead wood or forest floor. The "emitted at harvest" carbon is assumed emitted at site soon after harvest; this is included to distinguish it from the two products emissions categories, which are emissions associated with processing, use, or disposal of harvested wood after removal from the site. Tree biomass allocated to harvested wood is removed from the site for processing, and it is allocated to the four disposition categories defined in Table 1. Changes in the allocation of this pool of harvested carbon among the categories are tracked over time following harvest (see columns 10, 11, 12, and 13 of Table 3). Note that the harvested products carbon pools are also quantified as carbon densities, that is, tonnes per unit area (acres or hectares), because they are derived from land-based carbon densities.

These land-based estimates of carbon in harvested wood need not be limited to the examples in Table 3 or Appendix C. Similar calculations are possible for other harvest quantities, stand ages, or forest types. Factors for estimating and allocating harvested carbon from the forest ecosystem tables are included in Tables 4, 5, and 6. These are used to calculate the disposition of carbon in harvested wood products (see Example 4). The stand-level volume of growing stock in live trees, such as 172.1 m^3/ha in Table 3, is used as a starting point to estimate total carbon in harvested wood. Growing-stock volume from the ecosystem table is converted to categories of industrial roundwood carbon mass according to factors in Tables 4 and 5. The disposition of this carbon in wood products is then allocated according to Table 6. Additional information on the use or adaptation of the harvest scenario tables can be found in the methods section that follows, Example 4, and Appendix D.

Product-Based Estimates

Harvest information is often available in the form of wood delivered to mills or the output of mills. These product amounts may be used as the starting point for calculating the disposition of carbon. Specifically, these starting points are industrial roundwood logs or primary

Table 3.—Example harvest scenario table with regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for maple-beech-birch stands in the Northeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m³/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	2.1	0.0	0.0	52.2					
5	0.0		7.4	0.7	2.1	0.5	4.2	52.3					
15	28.0		31.8	3.2	1.9	2.3	10.8	53.7					
25	58.1		53.2	5.3	1.8	3.8	15.8	56.0					
35	89.6		72.8	6.0	1.7	5.2	19.7	58.9					
45	119.1		87.8	6.6	1.7	6.2	22.7	61.8					
55	146.6		101.1	7.0	1.7	7.2	25.3	64.4					
65	0.0	172.1	0.0	0.0	2.1	32.0	27.7	66.3	34.5	0.0	39.7	14.1	7.5
5	0.0		7.4	0.7	2.1	21.7	20.3	67.1	22.9	4.7	43.1	17.5	
15	28.0		31.8	3.2	1.9	11.5	16.3	68.2	13.2	8.1	46.2	20.7	
25	58.1		53.2	5.3	1.8	7.8	17.6	68.9	10.3	8.8	47.1	22.0	
35	89.6		72.8	6.0	1.7	6.9	20.3	69.2	8.7	9.1	47.5	22.9	
45	119.1		87.8	6.6	1.7	7.0	23.0	69.4	7.6	9.4	47.8	23.5	
55	146.6		101.1	7.0	1.7	7.5	25.3	69.5	6.7	9.6	47.9	24.0	
65	0.0	172.1	0.0	0.0	2.1	32.0	27.7	69.5	40.4	9.8	87.8	38.5	7.7

NOTE: Emitted column is shown as positive values so that all nonsoil columns can be summed to check totals.

wood products (such as lumber, panels, or paper) as indicated in Figure 3. Thus, quantities are of total carbon and not directly linked to forest area. The disposition of carbon in products based on an initial quantity, or carbon mass, of industrial roundwood is allocated according to Table 6. The specific carbon content of primary wood products is calculated from factors in Table 7. The disposition of carbon over time for these primary products is according to factors in Tables 8 and 9, which provide the fractions of carbon from original primary products that remain in use or in landfills, respectively. Again, additional information on the use or adaptation of the tables for product-based calculations can be found in the section that follows, Examples 5 and 6, and Appendix D.

Methods and Data Sources for Tables

The purpose of this section is to provide detailed information on data sources, models, and assumptions used in developing the tables or calculations described earlier. Also, we outline linkages between the carbon calculations. These further illustrate how the tables were developed and updated, how the methods were applied, and provide information needed to further modify or customize the tabular carbon summaries.

In these tables, we provide estimates for as many as ten carbon pools. Forest structure provides a convenient modeling framework for assigning carbon to one of six distinct forest ecosystem pools: live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic carbon (Table 1). These pools are consistent with guidelines of the Intergovernmental Panel on Climate Change (Penman and others 2003). The disposition of carbon in harvested wood is summarized in four categories that describe the end-fate of the harvested wood: products in use, landfills, emitted with energy capture, and emitted without energy capture (see definitions in Table 1).

Example 4.—Calculate carbon in harvested wood products remaining in use at 15 years after harvest based on volume of growing stock at time of harvest

Starting with an example from the Pacific Northwest, we will calculate the disposition of carbon in harvested wood products that are still in use at 15 years after harvest from the Douglas-fir forest described in Table C12. More specifically, we will show the steps involved to calculate that 53.3 t/ha of harvested carbon are in use at 15 years after harvest, starting from a harvested growing-stock volume of 718.8 m^3/ha (Table C12). We use factors from Tables 4, 5, and 6. These calculations are land-based estimates of carbon in harvested wood products based on the "trees in forests" starting point identified in Figure 3. Additional details on expanding these calculations to other harvested wood categories within the table or to other forest types are in Appendix D.

The sequence of steps required to determine carbon in use at year 15 are: 1) convert growing-stock volume to carbon mass according to four categories; 2) convert carbon in growing-stock volume to carbon in industrial roundwood; and 3) determine carbon remaining in products at the appropriate year.

<u>Step 1</u>: We assume that an average harvest for a forest type group produces roundwood logs that can be classified as softwood or hardwood as well as saw logs and pulpwood. The conversion from volume of wood to carbon mass depends on the specific carbon content of wood. Factors in Table 4 are used to allocate the 718.8 m^3/ha of growing-stock volume to four separate classes of carbon. For example, carbon in the softwood saw log part of growing-stock volume is the product of: growing-stock volume, the softwood fraction of growing-stock volume, the saw log fraction of softwood, softwood specific gravity, and the carbon fraction of wood, which is 50 percent carbon by dry weight. The calculations from Table 4 are:

Softwood saw log carbon in growing-stock volume
= 718.8 × 0.959 × 0.914 × 0.440 × 0.5 = 138.61 t/ha
Softwood pulpwood carbon in growing-stock volume
= 718.8 × 0.959 × (1 – 0.914) × 0.440 × 0.5 = 13.04 t/ha
Hardwood saw log carbon in growing-stock volume
= 718.8 × (1 – 0.959) × 0.415 × 0.426 × 0.5 = 2.61 t/ha
Hardwood pulpwood carbon in growing-stock volume
= 718.8 × (1 – 0.959) × (1 – 0.415) × 0.426 × 0.5 = 3.67 t/ha

Thus, total carbon stock in 718.8 m^3/ha of growing-stock volume is 183.60 t/ha.

<u>Step 2</u>: We need to represent carbon in these four categories in terms of carbon in industrial roundwood, which excludes bark and fuelwood. However, not all growing-stock volume is removed from the site of harvest as roundwood, and some industrial roundwood is from non-growing stock sources. Factors in Table 5 are used to obtain carbon in industrial roundwood. For example, carbon in industrial roundwood is the product of: carbon in growing-stock volume, the fraction of growing-stock volume that is removed as roundwood, and the ratio of industrial roundwood to growing-stock volume removed as roundwood. The calculations from Table 5 are:

Softwood saw log carbon in industrial roundwood = 138.61 × 0.929 × 0.965 = 124.26 t/ha
Softwood pulpwood carbon in industrial roundwood = 13.04 × 0.929 × 1.099 = 13.31 t/ha
Hardwood saw log carbon in industrial roundwood = 2.61 × 0.947 × 0.721 = 1.78 t/ha
Hardwood pulpwood carbon in industrial roundwood = 3.67 × 0.947 × 0.324 = 1.13 t/ha

Thus, total carbon stock in industrial roundwood is 148.36 t/ha.

<u>Step 3</u>: The disposition of carbon in harvested wood products is described by Table 6, which allocates carbon according to region, industrial roundwood category, and years since harvest and processing. The allocation factors for product in use at year 15 for Pacific Northwest, West apply here. The two hardwood categories are pooled in this region. The calculation for carbon density of products in use is the sum of the products of industrial roundwood carbon and the corresponding allocation factor, these are:

Carbon in products in use at year 15
= (124.26 × 0.423) + (13.31 × 0.020) + ((1.78 + 1.03) × 0.174) = 53.33 t/ha.

Example 5.—Calculate the disposition of carbon in harvested wood products at 100 years after harvest and processing from industrial roundwood data

Using Table 6, assume that a harvest in the Northeast produced 2,000 t dry weight of industrial roundwood. This represents 1,000 t of carbon because wood is assumed to be 50 percent carbon. The roundwood was harvested in the following proportions: 79 t carbon as softwood sawtimber, 51 t as softwood pulpwood, 465 t of hardwood sawtimber, and 405 t of hardwood pulpwood. Also assume that these quantities represent industrial roundwood without bark and exclude fuelwood; thus, Table 6 is the correct choice to calculate the disposition of carbon.

The four industrial roundwood categories are allocated to the classifications for the disposition of carbon in wood products by the appropriate factors for 100 years after production from the Northeast portion of Table 6.

Total carbon in use
$= (79 \times 0.095) + (51 \times 0.006) + (465 \times 0.035) + (405 \times 0.103) = 65.80$ t
Total carbon in landfills
$= (79 \times 0.223) + (51 \times 0.084) + (465 \times 0.281) + (405 \times 0.158) = 216.56$ t
Total carbon emitted with energy recapture
$= (79 \times 0.338) + (51 \times 0.510) + (465 \times 0.387) + (405 \times 0.336) = 368.75$ t
Total carbon emitted without energy recapture
$= (79 \times 0.344) + (51 \times 0.400) + (465 \times 0.296) + (405 \times 0.403) = 348.43$ t

Total carbon in industrial roundwood after 100 years is the sum of the four pools. Note that the total in this example is 999.5 t and not the 1,000 t we started with; this is due to rounding.

Forest Ecosystem Carbon

Forest ecosystem carbon is significantly affected by the following factors: region of the United States, forest type, previous land use, management, and productivity. The development and format of the tables are based on Birdsey (1996): current stand-level carbon and growth-and-yield models were compiled as forest carbon yield tables. Forest types correspond to definitions in the FIADB and represent common productive forests within each region.

The first two columns in each forest ecosystem table represent an age-volume relationship (also known as a yield curve) based on information from the timber projection model ATLAS (Mills and Kincaid 1992 with updates for Haynes 2003). ATLAS uses data on timber growth and yield and FIA data to develop a set of tables of growing-stock volume for projecting large-scale forest inventories representing U.S. forests for various policy scenarios. The yields (age-volume) represented in Appendices A, B, and C are broad averages; the basic set is from the appendix tables in Mills and Zhou (2003). Stand ages included in the tables are from the ATLAS yields, and these were limited to 90 years in the South and 125 years elsewhere. We assume all age-volume relationships are based on an average level of planting or stand establishment, that is, after clearcut harvest (reforestation) or as a part of stand establishment (afforestation). Additional tables are included for Southern pines and some Pacific Northwest forests to reflect stands with relatively higher productivity or more intensive management practices (see specific tables in Appendices A through C). These yields are based on ATLAS and timber projections prepared for Haynes (2003).

Example 6.—Calculate stocks of carbon in harvested wood products based on having primary wood products data such as products from a mill

Given the information on softwood lumber and softwood plywood produced from 2000 to 2003 (in the following tabulation) we use Tables 7, 8, and 9 to calculate: 1) carbon in the primary products, 2) the accumulation of carbon stocks over a period of 4 years, and 3) total carbon stocks after 100 years. Note that Tables 8 and 9 provide the fraction of primary product remaining for a given number of years after processing; this example assumes that harvest and processing are at the beginning of each year (2000-2003) and estimates for the amount remaining apply to the end of each year. This is an application of calculating the disposition of carbon in harvested wood based on quantities of primary wood products, as described in Figure 3.

Step 1: Determine initial carbon stocks for two primary products based on given quantities produced each year over the 4-year period by using factors from Table 7. For example, 93,000 thousand board feet softwood lumber × 0.443 = 41,199 t carbon.

The initial carbon stocks for two primary products, softwood lumber and softwood plywood:

Year	Quantity of primary product		Carbon stock	
	Softwood lumber	Softwood plywood	Softwood lumber	Softwood plywood
	thousand board feet	*thousand square feet, 3/8-inch basis*	*tonnes carbon*	*tonnes carbon*
2000	93,000	183,000	41,199	43,188
2001	85,000	175,000	37,655	41,300
2002	95,000	170,000	42,085	40,120
2003	100,000	173,000	44,300	40,828

Step 2: Calculate carbon stocks in end uses and landfills for each product for each year after production for the period 2000-2003 based on inputs of wood harvested and processed in each year. Use Tables 8 and 9 to determine stocks for each year since processing. Note that each of the 20 intermediate values in the following tabulation is based on the sum of carbon contributed from softwood lumber and softwood plywood. For example, the carbon stocks of primary products produced in 2001 are 37,655 t of softwood lumber and 41,300 t of softwood plywood. From this, a total of 3,820 t are in landfills at the end of 2003 (after 3 years). The quantity is calculated as: 3,820 t = (37,655 × 0.051) + (41,300 × 0.046).

Disposition of carbon in primary wood products over four years:

Year of production	Carbon in end uses at end of:				Carbon in landfills at end of:			
	2000	2001	2002	2003	2000	2001	2002	2003
2000	82,238	80,130	78,150	76,255	1,433	2,824	4,088	5,352
2001		76,947	74,977	73,127		1,339	2,640	3,820
2002			80,106	78,049			1,399	2,757
2003				82,952				1,451
Total	82,238	157,078	233,233	310,382	1,433	4,163	8,127	13,379

Thus, total carbon stocks for the end of 2002 are 241,360 t, with 233,233 t in end uses and 8,127 t in landfills. The balance of the cumulative total carbon in products from 2000 through 2002 has been emitted to the atmosphere, that is, 245,547 t initially in primary products minus the 241,360 t sequestered equals 4,187 t emitted from the primary products by 2002.

Step 3: Calculate carbon remaining in end uses or in landfills at 100 years after each of the harvest years. The estimates are based on initial stocks of carbon in each primary product multiplied by the respective fraction remaining as obtained from Tables 8 and 9. For example, carbon in primary product from harvest and processing in 2000 and in use at 100 years is 20,222 t = (41,199 × 0.234) + (43,188 × 0.245).

Year of production	Carbon in:	
	End uses	Landfills
	tonnes carbon	
2000	20,222	33,961
2001	18,930	31,770
2002	19,677	33,092
2003	20,369	34,273
Total	79,198	133,096

Thus, of the 245,547 t of carbon in primary products produced from 2000 through 2002, 24 percent remain sequestered in products in use, 40 percent in landfills, and 36 percent emitted to the atmosphere.

Carbon estimates are derived from the individual carbon-pool estimators in FORCARB2 (Heath and others 2003, Smith and others 2004a, Smith and Heath 2005). FORCARB2 is essentially a national empirical simulation and carbon-accounting model that produces stand-level, inventory-based estimates of carbon stocks for forest ecosystems and regional estimates of carbon in harvested wood. Estimates of carbon in live and standing dead trees are based on the methods of Jenkins and others (2003) and Smith and others (2003). A new set of stand level volume-to-biomass equations[3] was calibrated to the FIADB available on the Internet as of July 29, 2005 (USDA For. Serv. 2005). These are the bases for the carbon values for live and standing dead trees provided here. However the volume-based estimates of tree carbon from FORCARB2 required minor modification for the tables because many yield curves specify zero volume at both 0 and 5 years. This produced discontinuities over time in the estimates of tree carbon, usually in the second and third age classes. Carbon in tree biomass is accruing even if sapling trees remain below the threshold for classification of growing-stock volume[4] but above the classification size where trees are considered part of the understory. Therefore, tree carbon at the first row of the table is set to zero, and carbon for year 5 (and occasionally the third age class) is based on a modification of the volume-based estimates. Briefly, a subset of the FIADB with younger stands was used to develop age-based regressions with biomass from tree data (Jenkins and others 2003); these regressions converged with the volume-based estimates, usually by age 10 to 15. We used a ratio of the two estimates to smooth estimates between the second and third age classes.

Estimates in carbon density in understory vegetation are based on Birdsey (1996); estimates of carbon density in down dead wood were developed by FORCARB2 simulations. Estimates of these two pools are based on region, forest type, and live-tree biomass. (For additional discussion or example values, see Smith and others (2004b) and Smith and Heath (2005)). The carbon density of forest floor is a function of region, forest type, and stand age (Smith and Heath 2002). Estimates of soil organic carbon are based on the national STATSGO spatial database (USDA Soil Conserv. Serv. 1991) and the general approach described by Amichev and Galbraith (2004). These represent average soil organic carbon by region and forest type in the Forest Service's Renewable Resources Planning Act (RPA) 2002 Forest Resource Assessment database. For additional information, see USDA For. Serv. (2005) and Smith and others (2004c).

[3]Contact the authors for additional information on the volume-to-biomass equations updated from Smith and others (2003).

[4]The minimum tree size for growing stock is 5 inches d.b.h.; significant tree carbon can accumulate in a stand before trees reach this threshold.

Slight modifications to the direct application of FORCARB2 estimators were incorporated to develop the reforestation (Table 2 and Appendix A) and afforestation (Appendix B) tables. The reforestation tables are based on the assumption that at harvest, a portion of slash becomes down dead wood or forest floor at the start of the next rotation; these additional components then decay with time in the new stand (Smith and Heath 2002). The initial carbon densities for down dead wood and forest floor are listed in the first row of the Appendix A tables. Values for down dead wood are proportional to levels at the time of harvest and added logging residue (based on Johnson (2001)). Decay rates for down dead wood and forest floor are calculated from Turner and others (1995) and Smith and Heath (2002). The afforestation tables are based on the reforestation tables with the assumption that the residual carbon of down dead wood and forest floor material remaining after harvest does not exist at the start of the afforested stands. Thus, these pools are set to zero at the first row of the table. Accumulation of soil organic carbon in previously nonforest land (the afforestation tables) is based on the accumulation function described in West and others (2004) with the assumption that soil carbon density is initially at 75 percent of the average forest value, which is within the range of values associated with soil organic carbon after deforestation (Lal 2005). Users with more specific data about soil organic carbon or effects of previous land use can easily modify the tables to reflect this information.

The tables are designed to accommodate modification or replacement of selected data. Estimates for years or stand volumes not defined explicitly can be determined with linear interpolation (Example 2). The separate carbon pools, according to column, allow the user to extract or substitute values as needed to complement separately obtained site-specific information. However, users should be aware of the relationships between the parts as described in Figure 2 to substitute columns.

Figure 2 can be used as a guide in customizing tables. As an example, a user with a model of stand growth for a particular project but still wishing to use the carbon estimates from a table should: 1) choose an appropriate carbon table by matching forest type, 2) make the appropriate substitutions of new data, and 3) then recalculate the carbon columns affected by the substitution. After the age and volume columns are replaced, recalculations based on interpolation are required for carbon pools of live and standing dead trees, understory vegetation, and down dead wood. Forest floor is determined by stand age, and values of soil carbon depend on assumptions that apply to reforestation or afforestation (Fig. 2). The substitutions and recalculations can be made by using a spreadsheet. Example 3 expands on this discussion and provides a numerical example.

As illustrated in Figure 2, most of the relationships between columns of the tables are nonlinear. As a consequence, small errors are possible when interpolating between two points, such as in the volume to tree carbon pairs. However, these errors likely will be minimal. The nonlinearity can produce more significant errors if the tables are applied to aggregate summaries of large forest areas, that is, substantially greater than 10,000 ha (Smith and others 2003). As a result, it is best to apply the tables to relatively smaller forest areas versus calculating large aggregate volume and area.

Harvested Wood Carbon

The basic information required for calculating the disposition of carbon in harvested wood products based on each of the three starting points (Fig. 3) are in Tables 4 through 9. The purpose of this section is to provide sufficient background so that a user can apply these tables. However, some users may want to modify the estimates to incorporate alternate data or assumptions, so we also provide background data and detailed explanations in Appendix D of how these tables are generated.

Methods for calculating the disposition of carbon in harvested wood and the starting points for making such calculations are organized according to the diagram in Figure 3. These starting points, which correspond to possible sources of data (independent variables) are: 1) the volume of wood in a forest available for harvest and subsequent processing (for example, growing-stock volumes in Tables 2 and 3); 2) industrial roundwood harvest from a forest in the form of saw logs and pulpwood, which is a measure of wood available for processing at mills; and 3) primary wood products, that is products produced at mills, such as lumber, panels, or paper. We discuss methods and application of each of these, beginning with estimates based on primary wood products as inputs.

The model that allocates carbon over time since harvest is the same for all three starting points, and this model is based on primary wood products (see Appendix D for details). Thus, the disposition is a function of primary wood product and time. Any of the additional calculations necessary for the "upstream" (see Figure 3) starting points are essentially required to translate input carbon to primary wood product equivalents. Conversely, calculations at "downstream" starting points do not quantify all pools of harvested carbon. For example, a portion of the wood harvested from a forest ecosystem is processed into primary wood products, but carbon in other biomass remains on site as logging residue or is removed from site as fuelwood or what ultimately becomes waste in the production of primary products. Thus, identifying pools such as fuelwood is necessary for starting from the forest ecosystem to partition carbon and obtain the quantity going to primary products. Quantifying fuelwood is not possible, and unnecessary, for starting from data on a quantity of primary wood products.

Before applying tables to calculate carbon in harvested wood, users should identify: 1) the starting point most appropriate for the data available, and 2) the type of summary values or results that are appropriate to the carbon accounting method and the forest carbon project. Each starting point requires slightly different input data and each accounts for somewhat different pools of carbon. Compatibility between available data and the appropriate starting point depends on identifying these differences. In addition to having different starting points to compute carbon stocks or stock change, there may be differences in information needs, such as for carbon reporting. Carbon accounting requirements may specify tracking carbon harvested in one or more years and reporting carbon sequestered at one or more later years. For example, one may be interested in tracking products associated with a particular year or may be interested in the cumulative effects of successive harvests. Alternatively, an accounting method that focuses on the long-term effects of current rates of harvest and processing on future stocks of carbon in harvested wood products requires estimates of carbon in use or in landfills at 100 years after harvest (Miner, in press). Thus, all of our projection tables extend through 100 years.

Consideration of imports or exports of harvested wood can complicate the calculations. The effect of considering the movement of harvested wood or wood products over boundaries depends on the approach used to account for carbon. Basic carbon accounting approaches, as presented by the Intergovernmental Panel on Climate Change (Penman and others 2003) are: stock-change, atmospheric-flow, and production. The accounting method presented here is a production approach: the disposition of carbon is estimated for all wood produced, including exports. Imports are excluded from accounting under the production approach. Currently, the IPCC does not provide guidelines on accounting methods for trade in harvested carbon. However, the additional information required to account for imports or exports is essentially the long-term disposition of the specific quantities of carbon imported or exported. For example, applying the calculations described in this document to exports explicitly assumes that the disposition of carbon is identical to that in products retained in the United States.

Primary Wood Products

Primary wood products such as lumber, plywood, panels, and paper are the products of mills; they provide a product-based starting point for calculating the disposition of carbon in harvested wood products (Fig. 3). Specific primary products are identified in Table 7. Manufacturing or construction incorporates these primary products into end-use products such as houses, furniture, or books. Each end-use product has an expected lifespan, and after use the primary products may be recovered for additional use, burned, or otherwise disposed of. After disposal, carbon in products is allocated to disposal pools, which ultimately leads to long-term storage in landfills or to emission to the atmosphere. Thus, the disposition of primary wood products are modeled through partitioning and residence times of a succession of intermediate pools to the final disposition categories as defined in Table 1.

Table 7 includes factors for converting primary wood products into total mass of carbon. For example, 1,000 ft^2 of ⅜-inch softwood plywood averages 0.236 tonne of carbon. Tables 8 and 9 indicate the fraction of each primary product that remains in use or in landfills, respectively, for a given number of years after harvest and production, with the assumption that harvest and production are at time zero. The tables represent national averages. Table 8 indicates the fraction of each primary product remaining in an end use product for up to 100 years after harvest and processing. For example, column 2 of Table 8 indicates that after 10 years, 77.7 percent of softwood lumber remains in an end-use product; end uses include residential or other construction, furniture, and wood containers. The change in carbon between the initial quantity of primary products and the amount specified in later years in Table 8 represents products taken out of use; these are then either sequestered in landfills or emitted to the atmosphere. Table 9 indicates the fraction of each primary product sequestered in landfills for up to 100 years after harvest and processing. In the example of softwood lumber at 10 years, the fraction is 14.1 percent (column 2 of Table 9). Thus, the remaining 8.2 percent of carbon (100-77.7-14.1) in softwood lumber has been emitted to the atmosphere by year 10.

Recycling of paper products is an assumption built into Tables 8 and 9. (See Appendix D for details on paper recycling.) The value of including the effect of recycling on the disposition of carbon in harvested wood products can depend on the carbon accounting information needed. For example, recycling can affect quantities in use or in landfills if calculations are focused on a single cohort of carbon such as paper originally produced in a specific year. That is, accounting for effects of recycling can matter if tracking carbon from a single year or owner is important. We include recycling of paper because recycling is relatively common, its effects may be important, and statistics are available to include recycling in the calculations.

Tables 8 and 9 can be used to calculate net annual change of carbon in harvested wood products, the cumulative effect of successive annual harvests, and carbon remaining at 100 years. The change in carbon stocks between successive years is net annual flux. The tables are based on the assumption that harvest and processing occur in the same year (year set to zero); they provide annual steps for 50 years. Values can be interpolated for annualized estimates between years 50 and 100. Cumulative effects of annual harvests are obtained by repeating calculations for each harvest and summing stock or stock change estimates for each year of interest. A numerical application for calculating the disposition of carbon in primary wood products is provided in Example 6, in which the cumulative effect of annual production at a mill is calculated. See Appendix D for additional information on model assumptions, values used to describe allocation and longevity, and calculations of the factors in Tables 7 through 9.

Industrial Roundwood

Roundwood[5] is logs, bolts or other round sections cut from trees for industrial manufacture or consumer use (Johnson 2001). Most roundwood is processed by mills, and it is this quantity of harvested wood that provides the industrial roundwood starting point in Figure 3. Classification of harvested wood as roundwood is commonly a part of regional or State-wide statistics on timber harvesting or processing (Johnson 2001, Smith and others 2004c). A regional linkage between industrial roundwood and the primary wood products model (discussed earlier) is the basis for establishing the disposition of carbon from roundwood. The allocation of industrial roundwood to domestically produced primary wood products was constructed from Adams and others (2006). The resulting model of the allocation of carbon in industrial roundwood according to region and roundwood category is represented as Table 6.

Table 6 was developed in the style of similar tables in Birdsey (1996), which are based on Row and Phelps

[5]The definition and classification of roundwood as it is used here is important to quantifying and allocating carbon in harvested wood products. Calculations are based on wood in logs for industrial manufacture. This is the majority of roundwood. The definition of roundwood can also include fuelwood, but fuelwood and bark on industrial roundwood are specifically excluded from “industrial roundwood” as used in this document. Roundwood can be classified as sawtimber versus pulpwood (for example, Birdsey 1996, Row and Phelps 1996) but the more common usage is sawtimber versus poletimber (for example, Johnson 2001) or saw logs versus pulpwood.

(1996). Inputs are carbon mass in industrial roundwood according to region and roundwood category. Total industrial roundwood is allocated to the four disposition categories (see definitions in Table 1), and changes in allocation are tracked as fractions over years 1 through 100 after manufacture or processing. Industrial roundwood is classified by region (Fig. 1) and category: softwood saw logs, softwood pulpwood, hardwood saw logs, and hardwood pulpwood. Saw logs come from larger diameter trees and generally are utilized for solid wood products; pulpwood comes from smaller diameter trees and usually is used for pulpwood products. Some industrial roundwood classifications are pooled across regions for Table 6; this is done where production of a particular type is relatively low. Industrial roundwood, as classified for Table 6, excludes bark on logs and wood used as fuelwood. The allocation of emitted carbon to the fraction associated with energy capture is based on the allocation patterns in Birdsey (1996). A numerical application of Table 6 is provided in Example 5. See Appendix D for additional background information and sample calculations used to generate Table 6.

Growing-Stock Volumes of Forest Ecosystems

The land-based starting point for calculating the disposition of carbon in harvested wood products is from the forest ecosystem carbon tables (for example, Table 3), as described in Figure 3 (trees in forests). Calculations starting with wood in forests are distinctly different from starting with products in two respects: 1) inputs are land-based measures of merchantable wood in a forest (growing-stock volume), and 2) estimates of carbon in harvested wood also include the portion of roundwood identified as fuelwood as well as bark on all logs (industrial roundwood and fuelwood). The bases for linking forest ecosystems to roundwood, and thus the disposition of carbon in products, are compilations of summary values from harvest statistics (Johnson 2001) and estimates of tree biomass (Jenkins and others 2004) applied to current FIADB survey data.

Converting growing-stock volume to carbon mass in industrial roundwood is based on factors in Tables 4 and 5. Table 4 is used to partition growing-stock volume according to species type (softwood or hardwood) and size of logs. This is followed by converting volume to carbon mass according to the carbon content of wood. These values for carbon in growing-stock volume are extended to estimates of carbon in industrial roundwood according to factors in Table 5. The disposition of carbon is then based on Table 6.

The harvest scenario tables were constructed from the ecosystem tables by appending a reforestation table (from Appendix B) to an afforestation table (from Appendix A) at a stand age designated as a clearcut harvest. Carbon in harvested wood products was added by applying factors in Tables 4 through 6. The Appendix C tables are examples of how forest carbon stocks can include carbon in harvested wood; these are not recommendations for rotation length or timing of harvest. Assumptions and background data for compiling Tables 4, 5, and 6 (as well as the other starting points for calculating carbon in harvested wood products) are included in Appendix D. Despite differences in input data and extent of harvested carbon included, all three starting points rely on the same model of allocation and longevity of end uses. They differ only in the level of detail available as the principal source of information on harvested wood (Fig. 3).

Uncertainty

Estimates of carbon stocks and stock changes are based on regional averages and reflect the current best available data for developing regional estimates. Quantitative expressions of uncertainty are not available for most data summaries, coefficients, or model results presented in the tables. However, uncertainty analyses were developed for previous similar estimates of carbon, from which our tables were developed (Heath and Smith 2000, Skog and others 2004, Smith and Heath 2005). Similar quantitative uncertainty analyses are being developed for these estimates of carbon stocks and stock changes in forests and harvested wood products.

Precision is partly dependent on the scale of the forest carbon sequestration project of interest. Overall, precision is expected to be lower as these methods are applied to smaller scale projects rather than regional summaries. That is, precision depends on the degree of specificity in information about a particular forest or project. It may be useful to distinguish between two basic components of uncertainty in the application of these tables. Uncertainty about the regional averages, which are based on data summaries or models, can influence estimates for specific projects, which generally are small subsets of a region. However, variability within region likely will have a much greater influence on uncertainty than regional values. This is shown in Figure 4, which is an example of the volume-to-biomass relationships used to estimate tree carbon from merchantable volume (columns 2 and 3 in Table 2). Each point represents an individual permanent FIA inventory plot where the 95-percent confidence interval about the mean of carbon in live trees is generally less than 5 percent of the mean. The regression line represents the regional average; the 95-percent confidence intervals about this mean are indicated in Table 10. These two relative intervals reflect regional variability in biomass relative to volume. For example, the 99th percentile of stand growing-stock volumes for this forest in the FIADB is 361 m^3/ha and the mean carbon density for these plots is likely between 192 and 197 t/ha (Fig. 4, ±1.4 percent of the expected 194 t/ha). The distinction between uncertainty about coefficients and regional or temporal variability may also apply to calculating the disposition of carbon in harvested wood products as well. Uncertainty about the actual allocation of industrial roundwood to primary products may not be as important as year-to-year change or how activity at a single mill compares with the region as a whole.

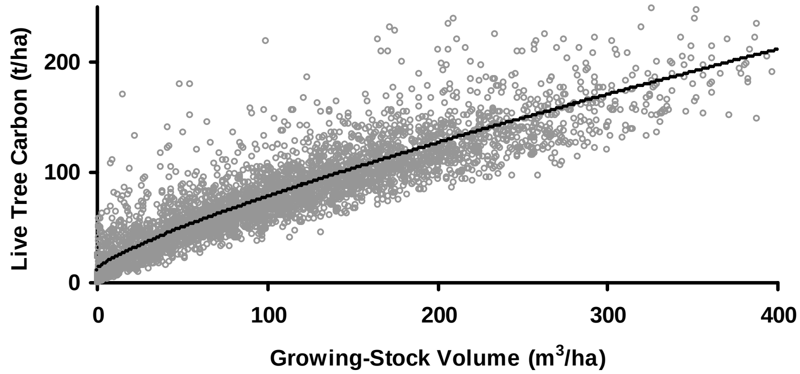

Figure 4.—A component of uncertainty associated with representing an average forest stand in the ecosystem tables. Individual points represent live tree carbon density for FIA permanent inventory plots for maple-beech-birch forests for the Northeast; the line represents carbon in tree biomass as predicted by growing-stock volume as used in Tables 2 and 3.

Conclusions

Summing the two estimates, forest ecosystem carbon and carbon in harvested wood products, gives the total effect of forest carbon sequestration for an activity. To assure accuracy, conducting modest inventories will help show the adequacy of the tables in characterizing carbon sequestration.

Carbon estimates depend on available data. Tables of average values cannot perfectly replicate each individual stand. Growth and yield information applicable to a particular stand can provide greater precision than regional averages. Similarly, carbon stocks in wood products that are calculated from quantities of primary wood products are likely to be more precise than products calculations starting simply from area of forest. However, the link between forest and sequestration in products may be less clear when starting from primary wood products. Forest composition, site conditions, and climate differ by regions, and climate, timber markets, and forest management priorities are subject to change from year to year. The methods described in this publication are most useful in identifying a general expected magnitude of carbon in forests, and to help plan carbon sequestration projects to achieve a certain goal.

Table 4.—Factors to calculate carbon in growing stock volume: softwood fraction, sawtimber-size fraction, and specific gravity by region and forest type group[a]

Region	Forest type	Fraction of growing-stock volume that is softwood[b]	Fraction of softwood growing-stock volume that is sawtimber-size[c]	Fraction of hardwood growing-stock volume that is sawtimber-size[c]	Specific gravity[d] of softwoods	Specific gravity[d] of hardwoods
Northeast	Aspen-birch	0.247	0.439	0.330	0.353	0.428
	Elm-ash-cottonwood	0.047	0.471	0.586	0.358	0.470
	Maple-beech-birch	0.132	0.604	0.526	0.369	0.518
	Oak-hickory	0.039	0.706	0.667	0.388	0.534
	Oak-pine	0.511	0.777	0.545	0.371	0.516
	Spruce-fir	0.870	0.508	0.301	0.353	0.481
	White-red-jack pine	0.794	0.720	0.429	0.361	0.510
Northern Lake States	Aspen-birch	0.157	0.514	0.336	0.351	0.397
	Elm-ash-cottonwood	0.107	0.468	0.405	0.335	0.460
	Maple-beech-birch	0.094	0.669	0.422	0.356	0.496
	Oak-hickory	0.042	0.605	0.473	0.369	0.534
	Spruce-fir	0.876	0.425	0.276	0.344	0.444
	White-red-jack pine	0.902	0.646	0.296	0.389	0.473
Northern Prairie States	Elm-ash-cottonwood	0.004	0.443	0.563	0.424	0.453
	Loblolly-shortleaf pine	0.843	0.686	0.352	0.468	0.544
	Maple-beech-birch	0.010	0.470	0.538	0.437	0.508
	Oak-hickory	0.020	0.497	0.501	0.448	0.565
	Oak-pine	0.463	0.605	0.314	0.451	0.566
	Ponderosa pine	0.982	0.715	0.169	0.381	0.473
Pacific Northwest, East	Douglas-fir	0.989	0.896	0.494	0.429	0.391
	Fir-spruce-m.hemlock	0.994	0.864	0.605	0.370	0.361
	Lodgepole pine	0.992	0.642	0.537	0.380	0.345
	Ponderosa pine	0.996	0.906	0.254	0.385	0.513
Pacific Northwest, West	Alder-maple	0.365	0.895	0.635	0.402	0.385
	Douglas-fir	0.959	0.914	0.415	0.440	0.426
	Fir-spruce-m.hemlock	0.992	0.905	0.296	0.399	0.417
	Hemlock-Sitka spruce	0.956	0.909	0.628	0.405	0.380
Pacific Southwest	Mixed conifer	0.943	0.924	0.252	0.394	0.521
	Douglas-fir	0.857	0.919	0.320	0.429	0.483
	Fir-spruce-m.hemlock	1.000	0.946	0.000	0.372	0.510
	Ponderosa Pine	0.997	0.895	0.169	0.380	0.510
	Redwood	0.925	0.964	0.468	0.376	0.449
Rocky Mountain, North	Douglas-fir	0.993	0.785	0.353	0.428	0.370
	Fir-spruce-m.hemlock	0.999	0.753	0.000	0.355	0.457
	Hemlock-Sitka spruce	0.972	0.735	0.596	0.375	0.441
	Lodgepole pine	0.999	0.540	0.219	0.383	0.391
	Ponderosa pine	0.999	0.816	0.000	0.391	0.374

Continued

Table 4.—continued

Region	Forest type	Fraction of growing-stock volume that is softwood[b]	Fraction of softwood growing-stock volume that is sawtimber-size[c]	Fraction of hardwood growing-stock volume that is sawtimber-size[c]	Specific gravity[d] of softwoods	Specific gravity[d] of hardwoods
Rocky Mountain, South	Aspen-birch	0.297	0.766	0.349	0.355	0.350
	Douglas-fir	0.962	0.758	0.230	0.431	0.350
	Fir-spruce-m.hemlock	0.958	0.770	0.367	0.342	0.350
	Lodgepole pine	0.981	0.607	0.121	0.377	0.350
	Ponderosa pine	0.993	0.773	0.071	0.383	0.386
Southeast	Elm-ash-cottonwood	0.030	0.817	0.551	0.433	0.499
	Loblolly-shortleaf pine	0.889	0.556	0.326	0.469	0.494
	Longleaf-slash pine	0.963	0.557	0.209	0.536	0.503
	Oak-gum-cypress	0.184	0.789	0.500	0.441	0.484
	Oak-hickory	0.070	0.721	0.551	0.438	0.524
	Oak-pine	0.508	0.746	0.425	0.462	0.516
South Central	Elm-ash-cottonwood	0.044	0.787	0.532	0.427	0.494
	Loblolly-shortleaf pine	0.880	0.653	0.358	0.470	0.516
	Longleaf-slash pine	0.929	0.723	0.269	0.531	0.504
	Oak-gum-cypress	0.179	0.830	0.589	0.440	0.513
	Oak-hickory	0.057	0.706	0.534	0.451	0.544
	Oak-pine	0.512	0.767	0.432	0.467	0.537
West[e]	Pinyon-juniper	0.986	0.783	0.042	0.422	0.620
	Tanoak-laurel	0.484	0.909	0.468	0.430	0.459
	Western larch	0.989	0.781	0.401	0.433	0.430
	Western oak	0.419	0.899	0.206	0.416	0.590
	Western white pine	1.000	0.838	0.000	0.376	--

-- = no hardwood trees in this type in this region.

[a]Estimates based on survey data for the conterminous United States from USDA Forest Service, Forest Inventory and Analysis Program's database of forest surveys (FIADB; USDA For. Serv. 2005) and include growing stock on timberland stands classified as medium- or large-diameter stands. Proportions are based on volume of growing-stock trees.

[b]To calculate fraction in hardwood, subtract fraction in softwood from 1.

[c]Softwood sawtimber are trees at least 22.9 cm (9 in) d.b.h., hardwood sawtimber is at least 27.9 cm (11 in) d.b.h. To calculate fraction in less-than-sawtimber-size trees, subtract fraction in sawtimber from 1. Trees less than sawtimber-size are at least 12.7 cm (5 in) d.b.h.

[d]Average wood specific gravity is the density of wood divided by the density of water based on wood dry mass associated with green tree volume.

[e]West represents an average over all western regions for these forest types.

Table 5.—Regional factors to estimate carbon in industrial roundwood logs, bark on logs, and fuelwood

Region[a]	Timber type	Industrial roundwood category	Ratio of industrial roundwood to growing-stock volume removed as roundwood[b]	Ratio of carbon in bark to carbon in wood[c]	Fraction of growing-stock volume removed as roundwood[d]	Ratio of fuelwood to growing-stock volume removed as roundwood[b]
Northeast	SW	Saw log	0.991	0.182	0.948	0.136
		Pulpwood	3.079	0.185		
	HW	Saw log	0.927	0.199	0.879	0.547
		Pulpwood	2.177	0.218		
North Central	SW	Saw log	0.985	0.182	0.931	0.066
		Pulpwood	1.285	0.185		
	HW	Saw log	0.960	0.199	0.831	0.348
		Pulpwood	1.387	0.218		
Pacific Coast	SW	Saw log	0.965	0.181	0.929	0.096
		Pulpwood	1.099	0.185		
	HW	Saw log	0.721	0.197	0.947	0.957
		Pulpwood	0.324	0.219		
Rocky Mountain	SW	Saw log	0.994	0.181	0.907	0.217
		Pulpwood	2.413	0.185		
	HW	Saw log	0.832	0.201	0.755	3.165
		Pulpwood	1.336	0.219		
South	SW	Saw log	0.990	0.182	0.891	0.019
		Pulpwood	1.246	0.185		
	HW	Saw log	0.832	0.198	0.752	0.301
		Pulpwood	1.191	0.218		

SW=Softwood, HW=Hardwood.

[a]North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

[b]Values and classifications are based on data in Tables 2.2, 3.2, 4.2, 5.2, and 6.2 of Johnson (2001).

[c]Ratios are calculated from carbon mass based on biomass component equations in Jenkins and others (2003) applied to all live trees identified as growing stock on timberland stands classified as medium- or large-diameter stands in the survey data for the conterminous United States from USDA Forest Service, Forest Inventory and Analysis Program's database of forest surveys (FIADB; USDA For. Serv. 2005, Alerich and others 2005). Carbon mass is calculated for boles from stump to 4-inch top, outside diameter.

[d]Values and classifications are based on data in Tables 2.9, 3.9, 4.9, 5.9, and 6.9 of Johnson (2001).

Table 6.—Average disposition patterns of carbon as fractions in industrial roundwood by region and roundwood category; factors assume no bark on industrial roundwood, which also excludes fuelwood

Year after production	Northeast, Softwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.569	0.000	0.240	0.190	0.513	0.000	0.306	0.181
1	0.542	0.014	0.246	0.197	0.436	0.025	0.334	0.204
2	0.517	0.027	0.252	0.203	0.372	0.046	0.359	0.223
3	0.495	0.039	0.257	0.209	0.317	0.063	0.381	0.239
4	0.474	0.050	0.262	0.214	0.271	0.077	0.399	0.253
5	0.455	0.060	0.266	0.219	0.232	0.088	0.415	0.265
6	0.438	0.069	0.270	0.223	0.197	0.098	0.429	0.276
7	0.422	0.078	0.274	0.227	0.167	0.106	0.441	0.286
8	0.406	0.085	0.277	0.231	0.139	0.113	0.452	0.296
9	0.392	0.093	0.281	0.235	0.114	0.118	0.463	0.305
10	0.379	0.099	0.284	0.238	0.093	0.123	0.472	0.313
15	0.326	0.126	0.296	0.252	0.037	0.128	0.497	0.338
20	0.288	0.144	0.304	0.264	0.021	0.122	0.505	0.352
25	0.259	0.158	0.311	0.273	0.016	0.114	0.509	0.362
30	0.234	0.168	0.316	0.281	0.014	0.107	0.510	0.369
35	0.214	0.176	0.321	0.289	0.013	0.102	0.510	0.376
40	0.197	0.183	0.324	0.296	0.012	0.098	0.510	0.381
45	0.182	0.189	0.327	0.302	0.011	0.094	0.510	0.385
50	0.169	0.194	0.330	0.307	0.010	0.092	0.510	0.388
55	0.158	0.198	0.332	0.312	0.009	0.090	0.510	0.391
60	0.148	0.202	0.333	0.317	0.009	0.088	0.510	0.393
65	0.139	0.205	0.335	0.321	0.008	0.087	0.510	0.395
70	0.131	0.208	0.336	0.325	0.008	0.086	0.510	0.396
75	0.124	0.211	0.337	0.328	0.007	0.086	0.510	0.397
80	0.117	0.214	0.337	0.332	0.007	0.085	0.510	0.398
85	0.111	0.216	0.338	0.335	0.007	0.085	0.510	0.399
90	0.106	0.219	0.338	0.338	0.006	0.085	0.510	0.399
95	0.100	0.221	0.338	0.341	0.006	0.084	0.510	0.400
100	0.095	0.223	0.338	0.344	0.006	0.084	0.510	0.400

Continued

Table 6.—continued

Year after production	Northeast, Hardwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.614	0.000	0.237	0.149	0.650	0.000	0.185	0.166
1	0.572	0.025	0.246	0.157	0.590	0.021	0.202	0.186
2	0.534	0.048	0.255	0.163	0.539	0.039	0.218	0.203
3	0.500	0.067	0.263	0.170	0.496	0.054	0.232	0.218
4	0.469	0.085	0.271	0.175	0.459	0.067	0.244	0.231
5	0.440	0.102	0.278	0.180	0.426	0.078	0.254	0.242
6	0.415	0.116	0.284	0.185	0.398	0.087	0.263	0.253
7	0.391	0.129	0.290	0.190	0.372	0.095	0.271	0.262
8	0.369	0.141	0.295	0.194	0.349	0.102	0.279	0.271
9	0.349	0.152	0.300	0.198	0.327	0.108	0.286	0.279
10	0.331	0.162	0.305	0.202	0.308	0.114	0.292	0.286
15	0.260	0.198	0.324	0.218	0.252	0.127	0.310	0.311
20	0.212	0.221	0.338	0.229	0.226	0.130	0.319	0.325
25	0.178	0.235	0.348	0.239	0.211	0.131	0.323	0.335
30	0.152	0.245	0.356	0.247	0.198	0.132	0.327	0.343
35	0.131	0.253	0.362	0.254	0.187	0.133	0.329	0.351
40	0.115	0.258	0.368	0.260	0.178	0.134	0.331	0.357
45	0.102	0.262	0.372	0.265	0.169	0.136	0.333	0.363
50	0.090	0.265	0.375	0.269	0.160	0.138	0.334	0.368
55	0.081	0.268	0.378	0.273	0.153	0.140	0.335	0.373
60	0.073	0.270	0.380	0.277	0.146	0.142	0.335	0.377
65	0.066	0.272	0.382	0.280	0.139	0.144	0.336	0.381
70	0.059	0.274	0.384	0.283	0.133	0.146	0.336	0.385
75	0.054	0.275	0.385	0.286	0.127	0.148	0.336	0.388
80	0.049	0.277	0.386	0.288	0.122	0.150	0.336	0.392
85	0.045	0.278	0.386	0.290	0.117	0.152	0.336	0.395
90	0.041	0.279	0.387	0.293	0.112	0.154	0.336	0.398
95	0.038	0.280	0.387	0.294	0.108	0.156	0.336	0.400
100	0.035	0.281	0.387	0.296	0.103	0.158	0.336	0.403

Continued

Table 6.—continued

Year after production	North Central, Softwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.630	0.000	0.249	0.121	0.514	0.000	0.305	0.180
1	0.599	0.016	0.257	0.127	0.438	0.025	0.332	0.204
2	0.570	0.032	0.265	0.133	0.374	0.046	0.356	0.223
3	0.544	0.045	0.272	0.138	0.320	0.063	0.377	0.240
4	0.520	0.058	0.279	0.143	0.274	0.077	0.396	0.254
5	0.499	0.069	0.285	0.147	0.235	0.088	0.411	0.266
6	0.478	0.080	0.291	0.151	0.200	0.097	0.425	0.278
7	0.459	0.090	0.296	0.154	0.170	0.105	0.437	0.288
8	0.442	0.099	0.301	0.158	0.143	0.112	0.448	0.297
9	0.425	0.107	0.306	0.162	0.118	0.118	0.458	0.306
10	0.410	0.115	0.310	0.165	0.096	0.122	0.467	0.314
15	0.349	0.145	0.327	0.178	0.041	0.127	0.491	0.340
20	0.306	0.166	0.339	0.189	0.024	0.121	0.500	0.354
25	0.272	0.181	0.348	0.198	0.020	0.113	0.503	0.364
30	0.245	0.193	0.356	0.206	0.018	0.107	0.504	0.372
35	0.222	0.202	0.362	0.213	0.016	0.101	0.504	0.378
40	0.203	0.210	0.367	0.220	0.015	0.097	0.504	0.383
45	0.187	0.216	0.371	0.226	0.014	0.094	0.504	0.387
50	0.173	0.221	0.374	0.231	0.014	0.091	0.504	0.391
55	0.161	0.225	0.377	0.236	0.013	0.089	0.504	0.393
60	0.151	0.229	0.379	0.241	0.012	0.088	0.504	0.395
65	0.141	0.233	0.381	0.245	0.012	0.087	0.504	0.397
70	0.133	0.236	0.382	0.249	0.011	0.086	0.504	0.399
75	0.125	0.239	0.383	0.253	0.010	0.086	0.504	0.400
80	0.118	0.241	0.384	0.257	0.010	0.085	0.504	0.401
85	0.112	0.244	0.385	0.260	0.009	0.085	0.504	0.401
90	0.106	0.246	0.385	0.263	0.009	0.085	0.504	0.402
95	0.101	0.248	0.385	0.266	0.009	0.085	0.504	0.402
100	0.096	0.250	0.385	0.269	0.008	0.084	0.504	0.403

Continued

Table 6.—continued

Year after production	North Central, Hardwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.585	0.000	0.253	0.162	0.685	0.000	0.165	0.150
1	0.544	0.024	0.262	0.170	0.630	0.020	0.181	0.169
2	0.507	0.046	0.271	0.177	0.582	0.038	0.196	0.184
3	0.473	0.065	0.279	0.183	0.541	0.052	0.209	0.198
4	0.443	0.082	0.286	0.189	0.506	0.064	0.219	0.210
5	0.416	0.097	0.293	0.194	0.476	0.075	0.229	0.220
6	0.391	0.111	0.299	0.199	0.448	0.084	0.237	0.230
7	0.368	0.124	0.305	0.203	0.424	0.092	0.245	0.239
8	0.347	0.135	0.310	0.208	0.401	0.099	0.252	0.247
9	0.328	0.146	0.315	0.212	0.381	0.106	0.259	0.255
10	0.310	0.155	0.320	0.216	0.362	0.111	0.265	0.262
15	0.242	0.189	0.338	0.231	0.306	0.127	0.282	0.285
20	0.197	0.210	0.350	0.243	0.278	0.132	0.291	0.299
25	0.165	0.224	0.360	0.252	0.259	0.136	0.296	0.309
30	0.140	0.233	0.367	0.260	0.244	0.138	0.300	0.317
35	0.121	0.239	0.373	0.267	0.231	0.141	0.303	0.325
40	0.106	0.244	0.378	0.272	0.219	0.144	0.306	0.331
45	0.093	0.248	0.381	0.278	0.208	0.147	0.308	0.337
50	0.083	0.251	0.384	0.282	0.198	0.150	0.309	0.343
55	0.074	0.253	0.387	0.286	0.189	0.153	0.311	0.348
60	0.066	0.255	0.389	0.290	0.180	0.156	0.312	0.353
65	0.060	0.257	0.390	0.293	0.172	0.159	0.313	0.357
70	0.054	0.259	0.391	0.296	0.164	0.161	0.313	0.361
75	0.049	0.260	0.392	0.299	0.157	0.164	0.314	0.365
80	0.045	0.261	0.393	0.301	0.150	0.167	0.314	0.368
85	0.041	0.262	0.393	0.304	0.144	0.170	0.315	0.372
90	0.038	0.263	0.393	0.306	0.138	0.172	0.315	0.375
95	0.035	0.264	0.393	0.308	0.133	0.175	0.315	0.378
100	0.032	0.265	0.393	0.309	0.127	0.177	0.315	0.381

Continued

Table 6.—continued

Year after production	Pacific Northwest, East, Softwood			
	All			
	In use	Landfill	Energy	Emitted without energy
0	0.637	0.000	0.197	0.166
1	0.601	0.016	0.207	0.176
2	0.569	0.031	0.215	0.185
3	0.541	0.043	0.223	0.192
4	0.516	0.055	0.230	0.199
5	0.494	0.065	0.236	0.205
6	0.473	0.074	0.242	0.211
7	0.454	0.083	0.247	0.216
8	0.437	0.090	0.251	0.221
9	0.420	0.098	0.256	0.226
10	0.405	0.104	0.260	0.231
15	0.351	0.127	0.274	0.248
20	0.315	0.143	0.283	0.260
25	0.287	0.154	0.289	0.270
30	0.264	0.163	0.294	0.279
35	0.245	0.170	0.298	0.287
40	0.228	0.177	0.301	0.294
45	0.213	0.182	0.304	0.301
50	0.199	0.188	0.306	0.307
55	0.187	0.192	0.308	0.313
60	0.176	0.196	0.309	0.318
65	0.166	0.200	0.310	0.323
70	0.157	0.204	0.311	0.328
75	0.149	0.207	0.311	0.333
80	0.141	0.210	0.312	0.337
85	0.134	0.213	0.312	0.341
90	0.128	0.216	0.312	0.345
95	0.121	0.219	0.312	0.348
100	0.116	0.221	0.312	0.351

Continued

Table 6.—continued

Year after production	Pacific Northwest, West, Softwoods							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.740	0.000	0.125	0.135	0.500	0.000	0.352	0.148
1	0.703	0.018	0.134	0.144	0.422	0.026	0.382	0.170
2	0.670	0.035	0.141	0.153	0.357	0.047	0.409	0.187
3	0.640	0.050	0.148	0.161	0.301	0.064	0.433	0.202
4	0.613	0.064	0.154	0.169	0.254	0.078	0.453	0.215
5	0.589	0.076	0.160	0.176	0.215	0.089	0.471	0.226
6	0.566	0.088	0.165	0.182	0.180	0.098	0.486	0.236
7	0.545	0.098	0.169	0.188	0.150	0.106	0.499	0.245
8	0.525	0.108	0.174	0.194	0.121	0.112	0.512	0.254
9	0.506	0.117	0.178	0.199	0.096	0.118	0.523	0.262
10	0.489	0.125	0.182	0.204	0.075	0.122	0.533	0.270
15	0.423	0.157	0.196	0.224	0.020	0.127	0.559	0.295
20	0.376	0.179	0.206	0.239	0.004	0.119	0.567	0.309
25	0.340	0.195	0.213	0.252	0.001	0.110	0.569	0.319
30	0.310	0.208	0.219	0.263	0.000	0.103	0.569	0.327
35	0.284	0.218	0.224	0.273	0.000	0.097	0.569	0.334
40	0.263	0.227	0.228	0.282	0.000	0.092	0.569	0.339
45	0.244	0.234	0.232	0.290	0.000	0.088	0.569	0.342
50	0.228	0.240	0.234	0.298	0.000	0.085	0.569	0.345
55	0.213	0.246	0.237	0.305	0.000	0.083	0.569	0.348
60	0.200	0.251	0.238	0.311	0.000	0.081	0.569	0.349
65	0.188	0.255	0.240	0.317	0.000	0.080	0.569	0.351
70	0.178	0.259	0.240	0.322	0.000	0.079	0.569	0.352
75	0.168	0.263	0.241	0.328	0.000	0.078	0.569	0.353
80	0.159	0.267	0.242	0.332	0.000	0.077	0.569	0.353
85	0.151	0.270	0.242	0.337	0.000	0.077	0.569	0.354
90	0.143	0.273	0.242	0.341	0.000	0.076	0.569	0.354
95	0.136	0.276	0.242	0.345	0.000	0.076	0.569	0.355
100	0.130	0.279	0.242	0.349	0.000	0.076	0.569	0.355

Continued

Table 6.—continued

Year after production	Pacific Northwest, West, Hardwood				Pacific Southwest, Softwood			
	All				All			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.531	0.000	0.288	0.181	0.675	0.000	0.170	0.156
1	0.481	0.021	0.305	0.193	0.637	0.018	0.180	0.166
2	0.438	0.040	0.319	0.204	0.602	0.034	0.189	0.175
3	0.400	0.055	0.332	0.213	0.572	0.048	0.197	0.183
4	0.367	0.069	0.343	0.221	0.545	0.061	0.204	0.191
5	0.338	0.081	0.352	0.229	0.521	0.072	0.210	0.197
6	0.312	0.091	0.361	0.235	0.498	0.082	0.216	0.204
7	0.289	0.100	0.369	0.241	0.478	0.092	0.221	0.209
8	0.268	0.109	0.377	0.247	0.458	0.101	0.226	0.215
9	0.248	0.116	0.383	0.252	0.440	0.109	0.231	0.220
10	0.231	0.122	0.390	0.257	0.424	0.116	0.235	0.225
15	0.174	0.142	0.409	0.275	0.363	0.143	0.250	0.243
20	0.143	0.152	0.420	0.285	0.323	0.161	0.260	0.257
25	0.122	0.157	0.427	0.294	0.292	0.173	0.268	0.267
30	0.107	0.160	0.432	0.301	0.266	0.183	0.273	0.277
35	0.095	0.162	0.436	0.306	0.245	0.192	0.278	0.285
40	0.085	0.164	0.440	0.312	0.226	0.198	0.282	0.293
45	0.076	0.166	0.442	0.316	0.210	0.204	0.285	0.300
50	0.069	0.167	0.444	0.320	0.196	0.210	0.288	0.306
55	0.062	0.169	0.445	0.324	0.184	0.214	0.290	0.312
60	0.057	0.170	0.446	0.327	0.173	0.218	0.292	0.317
65	0.052	0.171	0.447	0.330	0.162	0.222	0.293	0.322
70	0.048	0.172	0.447	0.333	0.153	0.226	0.294	0.327
75	0.044	0.173	0.447	0.336	0.145	0.229	0.295	0.331
80	0.040	0.174	0.448	0.338	0.137	0.232	0.296	0.335
85	0.037	0.175	0.448	0.340	0.130	0.235	0.296	0.339
90	0.035	0.176	0.448	0.342	0.124	0.238	0.296	0.343
95	0.032	0.177	0.448	0.344	0.117	0.240	0.296	0.346
100	0.030	0.177	0.448	0.345	0.112	0.243	0.296	0.349

Continued

Table 6.—continued

Year after production	Rocky Mountain, Softwood			
	All			
	In use	Landfill	Energy	Emitted without energy
0	0.704	0.000	0.209	0.087
1	0.664	0.019	0.223	0.094
2	0.628	0.036	0.235	0.101
3	0.595	0.051	0.247	0.107
4	0.567	0.065	0.256	0.112
5	0.541	0.077	0.265	0.118
6	0.517	0.088	0.273	0.122
7	0.495	0.098	0.280	0.127
8	0.474	0.107	0.287	0.131
9	0.455	0.116	0.294	0.135
10	0.438	0.124	0.300	0.139
15	0.373	0.152	0.320	0.154
20	0.330	0.171	0.333	0.165
25	0.297	0.185	0.343	0.175
30	0.271	0.195	0.350	0.184
35	0.248	0.204	0.356	0.192
40	0.229	0.211	0.360	0.200
45	0.213	0.217	0.364	0.207
50	0.198	0.222	0.367	0.213
55	0.185	0.227	0.369	0.219
60	0.174	0.231	0.371	0.225
65	0.163	0.235	0.372	0.230
70	0.154	0.238	0.373	0.235
75	0.146	0.241	0.373	0.240
80	0.138	0.244	0.373	0.244
85	0.131	0.247	0.373	0.249
90	0.124	0.250	0.373	0.253
95	0.118	0.253	0.373	0.256
100	0.112	0.255	0.373	0.260

Continued

Table 6.—continued

Year after production	Southeast, Softwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.636	0.000	0.260	0.104	0.553	0.000	0.276	0.171
1	0.601	0.017	0.270	0.112	0.482	0.024	0.300	0.193
2	0.570	0.032	0.279	0.119	0.422	0.044	0.323	0.211
3	0.541	0.045	0.288	0.125	0.370	0.061	0.342	0.227
4	0.516	0.057	0.296	0.131	0.327	0.074	0.359	0.241
5	0.493	0.068	0.303	0.136	0.290	0.085	0.373	0.252
6	0.472	0.078	0.310	0.140	0.257	0.094	0.385	0.263
7	0.453	0.087	0.315	0.145	0.229	0.102	0.396	0.273
8	0.435	0.095	0.321	0.149	0.202	0.109	0.407	0.282
9	0.418	0.103	0.326	0.153	0.178	0.115	0.416	0.291
10	0.402	0.110	0.331	0.157	0.158	0.119	0.425	0.298
15	0.345	0.136	0.347	0.172	0.102	0.127	0.448	0.323
20	0.306	0.153	0.357	0.184	0.083	0.123	0.456	0.337
25	0.276	0.166	0.364	0.194	0.075	0.118	0.460	0.347
30	0.251	0.176	0.370	0.203	0.070	0.113	0.462	0.355
35	0.231	0.184	0.374	0.211	0.066	0.110	0.463	0.361
40	0.213	0.190	0.378	0.219	0.063	0.107	0.463	0.367
45	0.198	0.196	0.381	0.226	0.060	0.105	0.463	0.372
50	0.184	0.201	0.383	0.232	0.057	0.104	0.463	0.376
55	0.172	0.206	0.384	0.238	0.054	0.103	0.463	0.380
60	0.162	0.209	0.385	0.244	0.052	0.103	0.463	0.383
65	0.152	0.213	0.386	0.249	0.049	0.103	0.463	0.385
70	0.144	0.216	0.386	0.254	0.047	0.103	0.463	0.387
75	0.136	0.219	0.386	0.259	0.045	0.103	0.463	0.389
80	0.128	0.222	0.386	0.263	0.043	0.103	0.463	0.391
85	0.122	0.225	0.386	0.267	0.041	0.104	0.463	0.392
90	0.116	0.227	0.386	0.271	0.040	0.104	0.463	0.393
95	0.110	0.230	0.386	0.274	0.038	0.105	0.463	0.395
100	0.104	0.232	0.386	0.277	0.036	0.105	0.463	0.396

Continued

Table 6.—continued

Year after production	Southeast, Hardwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.609	0.000	0.225	0.166	0.591	0.000	0.225	0.185
1	0.565	0.025	0.234	0.176	0.524	0.023	0.245	0.208
2	0.526	0.047	0.243	0.184	0.467	0.042	0.263	0.227
3	0.491	0.066	0.252	0.192	0.419	0.058	0.279	0.244
4	0.459	0.083	0.259	0.198	0.378	0.071	0.293	0.258
5	0.431	0.099	0.266	0.205	0.343	0.082	0.305	0.271
6	0.405	0.113	0.272	0.210	0.312	0.091	0.315	0.282
7	0.381	0.126	0.278	0.216	0.285	0.099	0.324	0.292
8	0.359	0.137	0.283	0.221	0.259	0.106	0.333	0.302
9	0.339	0.147	0.288	0.225	0.236	0.112	0.341	0.311
10	0.321	0.157	0.293	0.230	0.216	0.117	0.348	0.319
15	0.252	0.190	0.310	0.248	0.161	0.126	0.368	0.345
20	0.207	0.211	0.322	0.261	0.139	0.125	0.376	0.360
25	0.175	0.224	0.331	0.271	0.128	0.123	0.379	0.370
30	0.150	0.233	0.337	0.280	0.121	0.120	0.382	0.378
35	0.131	0.239	0.343	0.287	0.114	0.118	0.383	0.385
40	0.115	0.244	0.347	0.294	0.108	0.117	0.384	0.391
45	0.102	0.248	0.351	0.299	0.103	0.117	0.384	0.396
50	0.091	0.251	0.353	0.304	0.098	0.117	0.385	0.401
55	0.082	0.254	0.355	0.309	0.093	0.117	0.385	0.405
60	0.074	0.256	0.357	0.313	0.089	0.117	0.385	0.409
65	0.067	0.258	0.358	0.317	0.085	0.118	0.385	0.412
70	0.061	0.260	0.359	0.320	0.081	0.119	0.385	0.415
75	0.056	0.261	0.360	0.323	0.078	0.120	0.385	0.418
80	0.051	0.263	0.361	0.326	0.074	0.121	0.385	0.420
85	0.047	0.264	0.361	0.328	0.071	0.122	0.385	0.422
90	0.043	0.265	0.361	0.331	0.068	0.123	0.385	0.424
95	0.040	0.266	0.361	0.333	0.066	0.124	0.385	0.426
100	0.037	0.267	0.361	0.335	0.063	0.125	0.385	0.427

Continued

Table 6.—continued

Year after production	South Central, Softwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.629	0.000	0.228	0.143	0.570	0.000	0.266	0.164
1	0.594	0.016	0.237	0.153	0.501	0.024	0.290	0.185
2	0.563	0.030	0.246	0.160	0.442	0.043	0.312	0.203
3	0.536	0.043	0.254	0.167	0.393	0.059	0.330	0.218
4	0.511	0.055	0.261	0.174	0.350	0.073	0.346	0.231
5	0.489	0.065	0.267	0.179	0.314	0.084	0.360	0.242
6	0.469	0.074	0.272	0.184	0.282	0.093	0.373	0.253
7	0.451	0.083	0.277	0.189	0.254	0.101	0.383	0.262
8	0.433	0.090	0.282	0.194	0.228	0.108	0.394	0.271
9	0.417	0.098	0.287	0.199	0.204	0.114	0.403	0.279
10	0.402	0.104	0.291	0.203	0.184	0.118	0.411	0.287
15	0.347	0.129	0.305	0.219	0.129	0.127	0.434	0.311
20	0.310	0.145	0.314	0.231	0.108	0.125	0.443	0.325
25	0.282	0.156	0.320	0.242	0.099	0.120	0.447	0.334
30	0.258	0.166	0.325	0.251	0.093	0.117	0.449	0.342
35	0.238	0.173	0.329	0.259	0.087	0.114	0.450	0.349
40	0.221	0.180	0.332	0.267	0.083	0.112	0.451	0.354
45	0.206	0.186	0.334	0.274	0.079	0.111	0.451	0.360
50	0.193	0.191	0.336	0.280	0.075	0.110	0.451	0.364
55	0.181	0.195	0.338	0.286	0.071	0.110	0.451	0.368
60	0.170	0.200	0.339	0.292	0.068	0.110	0.451	0.371
65	0.160	0.203	0.340	0.297	0.065	0.110	0.451	0.374
70	0.151	0.207	0.340	0.302	0.062	0.110	0.451	0.377
75	0.143	0.210	0.340	0.307	0.059	0.111	0.451	0.379
80	0.135	0.213	0.340	0.311	0.057	0.112	0.451	0.381
85	0.128	0.216	0.340	0.315	0.054	0.112	0.451	0.383
90	0.122	0.219	0.340	0.319	0.052	0.113	0.451	0.384
95	0.116	0.221	0.340	0.322	0.050	0.114	0.451	0.386
100	0.110	0.224	0.340	0.325	0.048	0.114	0.451	0.387

Continued

Table 6.—continued

Year after production	South Central, Hardwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.587	0.000	0.237	0.176	0.581	0.000	0.228	0.191
1	0.543	0.024	0.247	0.186	0.513	0.023	0.249	0.214
2	0.503	0.046	0.257	0.194	0.455	0.043	0.268	0.234
3	0.468	0.064	0.265	0.202	0.406	0.059	0.285	0.250
4	0.437	0.081	0.273	0.209	0.365	0.072	0.298	0.265
5	0.409	0.096	0.280	0.215	0.329	0.083	0.310	0.278
6	0.383	0.109	0.286	0.221	0.298	0.092	0.321	0.289
7	0.360	0.121	0.292	0.227	0.270	0.100	0.331	0.300
8	0.338	0.132	0.298	0.232	0.244	0.107	0.340	0.310
9	0.319	0.142	0.303	0.237	0.221	0.113	0.348	0.319
10	0.301	0.151	0.307	0.241	0.201	0.117	0.355	0.327
15	0.235	0.182	0.325	0.258	0.146	0.126	0.375	0.353
20	0.192	0.201	0.336	0.271	0.125	0.125	0.383	0.368
25	0.162	0.213	0.344	0.281	0.115	0.121	0.386	0.378
30	0.140	0.221	0.351	0.289	0.108	0.118	0.388	0.386
35	0.122	0.226	0.356	0.297	0.102	0.116	0.390	0.393
40	0.107	0.230	0.360	0.303	0.096	0.114	0.391	0.399
45	0.095	0.234	0.363	0.308	0.092	0.114	0.391	0.404
50	0.085	0.237	0.365	0.313	0.087	0.113	0.391	0.409
55	0.077	0.239	0.367	0.317	0.083	0.113	0.391	0.413
60	0.069	0.241	0.369	0.321	0.079	0.113	0.391	0.416
65	0.063	0.243	0.370	0.325	0.076	0.114	0.391	0.419
70	0.057	0.244	0.371	0.328	0.072	0.115	0.391	0.422
75	0.052	0.246	0.371	0.331	0.069	0.115	0.391	0.424
80	0.048	0.247	0.372	0.334	0.066	0.116	0.391	0.427
85	0.044	0.248	0.372	0.336	0.064	0.117	0.391	0.428
90	0.040	0.249	0.372	0.338	0.061	0.118	0.391	0.430
95	0.037	0.250	0.372	0.341	0.059	0.119	0.391	0.432
100	0.034	0.251	0.372	0.342	0.056	0.120	0.391	0.433

Continued

Table 6.—continued

Year after production	West, Hardwood			
	All			
	In use	Landfill	Energy	Emitted without energy
0	0.568	0.000	0.256	0.177
1	0.529	0.018	0.267	0.186
2	0.494	0.034	0.277	0.195
3	0.464	0.048	0.286	0.202
4	0.437	0.061	0.294	0.208
5	0.412	0.073	0.301	0.214
6	0.390	0.083	0.308	0.220
7	0.369	0.092	0.314	0.225
8	0.350	0.101	0.319	0.230
9	0.332	0.109	0.325	0.234
10	0.316	0.116	0.330	0.239
15	0.256	0.143	0.347	0.255
20	0.217	0.159	0.358	0.266
25	0.188	0.171	0.367	0.275
30	0.165	0.179	0.373	0.283
35	0.146	0.186	0.379	0.289
40	0.130	0.192	0.383	0.295
45	0.116	0.196	0.387	0.300
50	0.105	0.200	0.390	0.305
55	0.095	0.203	0.393	0.309
60	0.087	0.205	0.395	0.313
65	0.079	0.208	0.396	0.316
70	0.073	0.210	0.398	0.319
75	0.067	0.212	0.399	0.322
80	0.062	0.213	0.400	0.325
85	0.058	0.215	0.400	0.327
90	0.053	0.216	0.401	0.330
95	0.050	0.218	0.401	0.332
100	0.046	0.219	0.401	0.334

Table 7.—Factors to convert primary wood products to carbon mass from the units characteristic of each product

Solidwood product or paper	Unit	Factor to convert units to tons (2000 lb) carbon	Factor to convert units to tonnes carbon
Softwood lumber/laminated veneer lumber/glulam lumber/ I-joists	thousand board feet	0.488	0.443
Hardwood lumber	thousand board feet	0.844	0.765
Softwood plywood	thousand square feet, 3/8-inch basis	0.260	0.236
Oriented strandboard	thousand square feet, 3/8-inch basis	0.303	0.275
Non structural panels (average)	thousand square feet, 3/8-inch basis	0.319	0.289
Hardwood veneer/plywood	thousand square feet, 3/8-inch basis	0.315	0.286
Particleboard/medium density fiberboard	thousand square feet, 3/4-inch basis	0.647	0.587
Hardboard	thousand square feet,1/8-inch basis	0.152	0.138
Insulation board	thousand square feet, 1/2-inch basis	0.242	0.220
Other industrial products	thousand cubic feet	8.250	7.484
Paper	tons, air dry	0.450	0.496

Table 8.—Fraction of carbon in primary wood products remaining in end uses up to 100 years after production (year 0 indicates fraction at time of production, with fraction for year 1 the allocation after 1 year)

Year after production	Softwood lumber	Hardwood lumber	Softwood plywood	Oriented strandboard	Non-structural panels	Miscel-laneous products	Paper
0	1	1	1	1	1	1	1
1	0.973	0.938	0.976	0.983	0.969	0.944	0.845
2	0.947	0.882	0.952	0.967	0.939	0.891	0.713
3	0.922	0.831	0.930	0.952	0.911	0.841	0.603
4	0.898	0.784	0.909	0.937	0.883	0.794	0.509
5	0.875	0.741	0.888	0.922	0.857	0.749	0.430
6	0.854	0.701	0.869	0.908	0.832	0.707	0.360
7	0.833	0.665	0.850	0.895	0.808	0.667	0.299
8	0.813	0.631	0.832	0.881	0.785	0.630	0.243
9	0.795	0.600	0.815	0.869	0.763	0.595	0.192
10	0.777	0.571	0.798	0.856	0.741	0.561	0.149
11	0.760	0.545	0.782	0.844	0.721	0.530	0.115
12	0.743	0.520	0.767	0.832	0.701	0.500	0.088
13	0.728	0.497	0.752	0.821	0.683	0.472	0.068
14	0.712	0.476	0.738	0.810	0.665	0.445	0.052
15	0.698	0.456	0.724	0.799	0.647	0.420	0.040
16	0.684	0.438	0.711	0.789	0.630	0.397	0.030
17	0.671	0.421	0.698	0.778	0.614	0.375	0.023
18	0.658	0.405	0.685	0.768	0.599	0.354	0.018
19	0.645	0.389	0.673	0.759	0.584	0.334	0.013
20	0.633	0.375	0.662	0.749	0.569	0.315	0.009
21	0.622	0.362	0.650	0.740	0.555	0.297	0.006
22	0.611	0.349	0.639	0.731	0.542	0.281	0.005
23	0.600	0.337	0.629	0.722	0.529	0.265	0.004
24	0.589	0.326	0.619	0.713	0.517	0.250	0.003
25	0.579	0.316	0.609	0.705	0.505	0.236	0.002
26	0.569	0.306	0.599	0.697	0.493	0.223	0.002
27	0.560	0.296	0.589	0.689	0.482	0.210	0.001
28	0.551	0.287	0.580	0.681	0.471	0.198	0.001
29	0.542	0.278	0.571	0.673	0.460	0.187	0.001
30	0.533	0.270	0.563	0.666	0.450	0.177	0.001
31	0.525	0.263	0.554	0.658	0.440	0.167	0.000
32	0.517	0.255	0.546	0.651	0.431	0.157	0.000
33	0.509	0.248	0.538	0.644	0.421	0.149	0.000
34	0.501	0.241	0.530	0.637	0.412	0.140	0.000
35	0.494	0.235	0.522	0.630	0.404	0.132	0.000
36	0.487	0.229	0.515	0.623	0.395	0.125	0.000
37	0.480	0.223	0.508	0.617	0.387	0.118	0.000
38	0.473	0.217	0.500	0.610	0.379	0.111	0.000
39	0.466	0.211	0.493	0.604	0.372	0.105	0.000
40	0.459	0.206	0.487	0.598	0.364	0.099	0.000

Continued

Table 8.—continued

Year after production	Softwood lumber	Hardwood lumber	Softwood plywood	Oriented strandboard	Non-structural panels	Miscel-laneous products	Paper
41	0.453	0.201	0.480	0.592	0.357	0.094	0.000
42	0.447	0.196	0.474	0.586	0.350	0.088	0.000
43	0.441	0.191	0.467	0.580	0.343	0.083	0.000
44	0.435	0.187	0.461	0.574	0.337	0.079	0.000
45	0.429	0.183	0.455	0.568	0.330	0.074	0.000
46	0.423	0.178	0.449	0.563	0.324	0.070	0.000
47	0.418	0.174	0.443	0.557	0.318	0.066	0.000
48	0.413	0.170	0.437	0.552	0.312	0.063	0.000
49	0.407	0.166	0.432	0.546	0.306	0.059	0.000
50	0.402	0.163	0.426	0.541	0.301	0.056	0.000
55	0.378	0.146	0.401	0.516	0.275	0.042	0.000
60	0.356	0.131	0.377	0.493	0.252	0.031	0.000
65	0.336	0.119	0.356	0.471	0.232	0.023	0.000
70	0.318	0.108	0.336	0.450	0.214	0.018	0.000
75	0.301	0.098	0.318	0.431	0.198	0.013	0.000
80	0.286	0.090	0.301	0.413	0.183	0.010	0.000
85	0.271	0.082	0.286	0.395	0.170	0.007	0.000
90	0.258	0.075	0.271	0.379	0.159	0.006	0.000
95	0.246	0.069	0.258	0.364	0.148	0.004	0.000
100	0.234	0.064	0.245	0.349	0.138	0.003	0.000

Table 9.—Fraction of carbon in primary wood products remaining in landfills up to 100 years after production (year 0 indicates fraction at time of production, with fraction for year 1 the allocation after 1 year)

Year after production	Softwood lumber	Hardwood lumber	Softwood plywood	Oriented strandboard	Non-structural panels	Miscel-laneous products	Paper
0	0	0	0	0	0	0	0
1	0.018	0.041	0.016	0.011	0.021	0.037	0.051
2	0.035	0.078	0.032	0.021	0.040	0.072	0.093
3	0.051	0.111	0.046	0.032	0.059	0.104	0.128
4	0.067	0.141	0.060	0.041	0.076	0.134	0.155
5	0.081	0.168	0.073	0.050	0.093	0.163	0.178
6	0.094	0.193	0.085	0.059	0.108	0.189	0.196
7	0.107	0.215	0.096	0.068	0.123	0.213	0.211
8	0.119	0.235	0.107	0.076	0.137	0.236	0.225
9	0.130	0.254	0.118	0.084	0.151	0.257	0.236
10	0.141	0.270	0.128	0.091	0.163	0.277	0.245
11	0.151	0.285	0.137	0.098	0.176	0.296	0.251
12	0.161	0.299	0.146	0.105	0.187	0.313	0.254
13	0.170	0.312	0.155	0.112	0.198	0.329	0.255
14	0.178	0.323	0.163	0.118	0.208	0.344	0.255
15	0.187	0.334	0.171	0.124	0.218	0.357	0.253
16	0.194	0.344	0.178	0.130	0.227	0.370	0.251
17	0.202	0.352	0.185	0.136	0.236	0.382	0.248
18	0.209	0.361	0.192	0.142	0.245	0.393	0.245
19	0.215	0.368	0.199	0.147	0.253	0.403	0.242
20	0.222	0.375	0.205	0.152	0.261	0.413	0.239
21	0.228	0.381	0.211	0.157	0.268	0.422	0.235
22	0.234	0.387	0.217	0.162	0.275	0.430	0.232
23	0.239	0.392	0.222	0.167	0.282	0.438	0.228
24	0.245	0.397	0.227	0.171	0.288	0.445	0.224
25	0.250	0.402	0.233	0.176	0.294	0.451	0.221
26	0.255	0.406	0.238	0.180	0.300	0.457	0.218
27	0.259	0.410	0.242	0.184	0.306	0.463	0.214
28	0.264	0.414	0.247	0.188	0.311	0.468	0.211
29	0.268	0.417	0.251	0.192	0.316	0.473	0.209
30	0.272	0.421	0.256	0.196	0.321	0.477	0.206
31	0.276	0.424	0.260	0.200	0.326	0.481	0.203
32	0.280	0.426	0.264	0.204	0.330	0.485	0.200
33	0.284	0.429	0.268	0.207	0.335	0.488	0.198
34	0.287	0.432	0.272	0.211	0.339	0.491	0.196
35	0.291	0.434	0.275	0.214	0.343	0.494	0.194
36	0.294	0.436	0.279	0.217	0.347	0.497	0.191
37	0.298	0.438	0.282	0.221	0.350	0.499	0.189
38	0.301	0.440	0.286	0.224	0.354	0.502	0.187
39	0.304	0.442	0.289	0.227	0.357	0.504	0.186
40	0.307	0.444	0.292	0.230	0.361	0.506	0.184

Continued

Table 9.—continued

Year after production	Softwood lumber	Hardwood lumber	Softwood plywood	Oriented strandboard	Non-structural panels	Miscel-laneous products	Paper
41	0.310	0.446	0.295	0.233	0.364	0.507	0.182
42	0.312	0.447	0.298	0.236	0.367	0.509	0.181
43	0.315	0.449	0.301	0.239	0.370	0.510	0.179
44	0.318	0.450	0.304	0.241	0.373	0.512	0.178
45	0.320	0.452	0.307	0.244	0.376	0.513	0.176
46	0.323	0.453	0.309	0.247	0.378	0.514	0.175
47	0.325	0.454	0.312	0.249	0.381	0.515	0.174
48	0.328	0.456	0.315	0.252	0.384	0.516	0.173
49	0.330	0.457	0.317	0.255	0.386	0.516	0.172
50	0.332	0.458	0.320	0.257	0.388	0.517	0.171
55	0.343	0.463	0.331	0.269	0.399	0.520	0.166
60	0.352	0.468	0.342	0.280	0.408	0.521	0.162
65	0.361	0.472	0.351	0.290	0.417	0.521	0.160
70	0.369	0.475	0.360	0.300	0.424	0.521	0.157
75	0.376	0.478	0.368	0.309	0.430	0.521	0.156
80	0.382	0.481	0.375	0.317	0.436	0.521	0.154
85	0.389	0.483	0.382	0.325	0.441	0.520	0.153
90	0.395	0.486	0.388	0.333	0.446	0.519	0.152
95	0.400	0.488	0.394	0.340	0.450	0.519	0.152
100	0.405	0.490	0.400	0.347	0.454	0.518	0.151

Table 10.—Confidence intervals for the estimates of carbon density for live and standing dead trees at the 50th and 99th percentiles of volume. The percentiles reflect the distribution of stand-level volume in survey data for the conterminous United States.[a] The 95-percent intervals about the expected carbon density are represented as the percentage of the carbon density; thus, the interval is ± the percentage.

Forest type-region[b]	Volume at the 50th percentile					Volume at the 99th percentile				
	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval
	m³/ha	*t C/ha*	*± percent*	*t C/ha*	*± percent*	*m³/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*
Aspen-birch, Northeast	52	47	3.3	7	7.7	279	140	3.0	17	11.0
Maple-beech-birch, Northeast	118	87	1.0	13	4.3	361	194	1.4	18	7.6
Oak-hickory, Northeast	120	90	1.0	8	5.7	392	226	1.3	10	10.6
Oak-pine, Northeast	124	85	3.1	8	15.8	430	216	3.5	11	29.5
Spruce-balsam fir, Northeast	82	60	2.0	14	6.4	374	170	2.5	18	11.3
White-red-jack pine, Northeast	182	103	2.0	11	12.6	572	241	3.2	14	25.5
Aspen-birch, Northern Lake States	54	44	1.2	10	5.6	311	153	1.2	20	7.7
Elm-ash-cottonwood, Northern Lake States	60	54	2.3	11	9.2	514	270	2.2	18	16.3
Maple-beech-birch, Northern Lake States	108	84	0.8	10	4.8	348	207	1.0	12	9.1
Oak-hickory, Northern Lake States	84	80	1.0	8	5.4	343	230	1.3	12	10.4
Spruce-balsam fir, Northern Lake States	54	44	1.8	9	8.5	329	163	1.7	20	9.8
White-red-jack pine, Northern Lake States	101	61	2.4	10	12.0	725	267	2.6	16	24.2
Elm-ash-cottonwood, Northern Prairie States	76	66	3.7	9	17.5	514	271	2.2	18	16.3
Maple-beech-birch, Northern Prairie States	93	75	1.1	12	4.8	348	194	1.4	18	7.6
Oak-hickory, Northern Prairie States	77	76	1.0	8	5.5	343	202	1.1	10	9.7
Oak-pine, Northern Prairie States	59	52	3.4	7	15.3	355	159	2.8	10	22.6

Continued

Table 10.—Continued

Forest type-region[b]	Volume at the 50th percentile					Volume at the 99th percentile				
	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval
	m^3/ha	*t C/ha*	*± percent*	*t C/ha*	*± percent*	*m^3/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*
Douglas-fir, Pacific Northwest, East	138	84	1.5	18	8.8	627	264	1.9	29	16.1
Fir-spruce-mountain hemlock, Pacific Northwest, East	216	98	1.5	31	6.3	746	268	1.4	48	11.1
Lodgepole pine, Pacific Northwest, East	65	36	4.1	10	22.6	528	123	2.3	23	15.9
Ponderosa pine, Pacific Northwest, East	100	51	1.9	8	13.8	508	187	1.7	17	18.7
Alder-maple, Pacific Northwest, West	190	88	4.4	25	25.5	1,005	352	4.2	55	38.3
Douglas-fir, Pacific Northwest, West	308	150	1.3	30	17.1	1,876	727	1.7	84	18.5
Douglas-fir, high productivity and high management intensity, Pacific Northwest, West	147	79	3.4	18	24.3	822	319	2.2	21	38.4
Fir-spruce-mountain hemlock, Pacific Northwest, West	360	179	3.1	49	12.6	1,342	527	3.2	84	20.4
Hemlock-Sitka spruce, Pacific Northwest, West	503	203	2.7	51	17.2	1,795	602	3.2	104	27.4
Hemlock-Sitka spruce, high productivity, Pacific Northwest, West	420	174	2.6	46	20.1	1,795	602	3.2	104	27.4
California mixed conifer, Pacific Southwest	241	121	1.9	28	7.5	983	397	1.8	66	9.4

Continued

Table 10.—Continued

Forest type-region[b]	Volume at the 50th percentile					Volume at the 99th percentile				
	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval
	m^3/ha	*t C/ha*	*± percent*	*t C/ha*	*± percent*	*m^3/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*
Fir-spruce-mountain hemlock, Pacific Southwest	352	175	3.1	48	12.7	1,342	475	2.7	80	18.8
Western oak, Pacific Southwest	66	61	3.9	9	21.8	570	310	3.5	18	33.5
Douglas-fir, Rocky Mountain, North	128	79	1.6	18	9.1	627	264	1.9	29	16.1
Fir-spruce-mountain hemlock, Rocky Mountain, North	170	81	1.5	29	6.9	746	271	1.4	49	11.2
Lodgepole pine, Rocky Mountain, North	135	58	2.4	14	12.9	528	152	3.2	27	20.1
Ponderosa pine, Rocky Mountain, North	51	30	3.7	6	11.8	508	183	1.7	17	18.6
Aspen-birch, Rocky Mountain, South	89	61	2.9	17	10.1	498	202	3.2	32	16.2
Douglas-fir, Rocky Mountain, South	115	83	2.9	20	13.2	546	270	3.6	40	21.0
Fir-spruce-mountain hemlock, Rocky Mountain, South	188	96	1.7	32	7.0	736	265	2.3	48	13.4
Lodgepole pine, Rocky Mountain, South	150	63	2.5	20	10.6	521	153	3.2	20	10.6
Ponderosa pine, Rocky Mountain, South	83	53	1.7	7	13.7	353	141	2.3	11	26.9
Loblolly-shortleaf pine, Southeast	75	47	2.1	4	10.5	636	210	1.6	8	15.7

Continued

Table 10.—Continued

Forest type-region[b]	Volume at the 50th percentile					Volume at the 99th percentile				
	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval
	m^3/ha	*t C/ha*	*± percent*	*t C/ha*	*± percent*	*m^3/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*
Loblolly-shortleaf pine, high productivity and management intensity, Southeast	91	53	1.8	3	13.8	385	144	1.8	5	18.3
Longleaf-slash pine, Southeast	46	25	3.6	2	13.7	429	145	2.0	3	21.7
Longleaf-slash pine, high productivity and management intensity, Southeast	82	44	1.5	2	16.4	249	91	2.3	2	20.5
Oak-gum-cypress, Southeast	98	75	2.1	8	10.2	527	237	2.0	14	14.8
Oak-hickory, Southeast	104	81	1.3	7	7.5	536	263	1.4	11	13.1
Oak- pine, Southeast	61	48	2.5	4	9.3	462	201	2.0	9	13.9
Elm-ash-cottonwood, South Central	69	64	3.4	8	17.2	461	245	3.8	14	32.5
Loblolly-shortleaf pine, South Central	71	47	2.3	4	16.0	506	167	2.2	6	24.5
Loblolly-shortleaf pine, high productivity and management intensity, South Central	61	42	1.8	2	17.4	309	116	2.3	2	24.2
Oak-gum-cypress, South Central	100	81	2.0	7	10.9	534	244	2.5	9	21.4
Oak-hickory, South Central	79	69	1.0	5	6.5	390	206	1.2	7	11.9
Oak-pine, South Central	64	53	2.2	5	11.6	436	190	2.5	9	19.2

[a] Data from USDA Forest Service, Forest Inventory and Analysis Program's database of forest surveys (FIADB; USDA For. Serv. 2005).
[b] These correspond to the table identifiers in Appendix A, B, and C.

Acknowledgments

We thank Susan McGrane for considerable help with the data and formatting. Coeli Hoover, Reid Miner, Brian Murray, and R. Neil Sampson provided helpful comments on drafts of this manuscript.

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APPENDIX A

Forest Ecosystem Yield Tables for Reforestation[1]

Carbon Stocks on Forest Land After Clearcut Harvest

[1] Note carbon mass is in metric tons (tonnes) in all tables.

A1.— Regional estimates of timber volume and carbon stocks for aspen-birch stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	18.7	10.2	87.4	31.0
5	0.0	6.6	0.6	2.2	12.9	7.5	87.4	29.8
15	12.9	21.3	1.8	2.1	7.1	6.0	87.4	38.4
25	33.8	36.0	2.9	2.1	5.2	6.5	87.4	52.7
35	58.4	50.1	3.8	2.1	4.9	7.5	87.4	68.4
45	84.7	62.7	4.6	2.1	5.3	8.5	87.4	83.1
55	112.4	75.1	5.3	2.0	6.0	9.3	87.4	97.8
65	141.7	87.5	5.9	2.0	6.9	10.1	87.4	112.4
75	172.6	100.0	6.5	2.0	7.8	10.7	87.4	127.1
85	205.0	112.7	7.1	2.0	8.8	11.3	87.4	141.9
95	238.9	125.5	7.7	2.0	9.8	11.8	87.4	156.7
105	274.4	138.5	8.2	2.0	10.8	12.2	87.4	171.7
115	311.4	151.7	8.8	2.0	11.8	12.5	87.4	186.8
125	349.9	165.0	9.3	2.0	12.8	12.9	87.4	202.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	7.6	4.1	35.4	12.5
5	0	2.7	0.2	0.9	5.2	3.0	35.4	12.1
15	184	8.6	0.7	0.9	2.9	2.4	35.4	15.5
25	483	14.6	1.2	0.8	2.1	2.6	35.4	21.3
35	835	20.3	1.5	0.8	2.0	3.0	35.4	27.7
45	1,210	25.4	1.9	0.8	2.2	3.4	35.4	33.6
55	1,607	30.4	2.1	0.8	2.4	3.8	35.4	39.6
65	2,025	35.4	2.4	0.8	2.8	4.1	35.4	45.5
75	2,466	40.5	2.6	0.8	3.2	4.3	35.4	51.4
85	2,929	45.6	2.9	0.8	3.6	4.6	35.4	57.4
95	3,414	50.8	3.1	0.8	4.0	4.8	35.4	63.4
105	3,921	56.0	3.3	0.8	4.4	4.9	35.4	69.5
115	4,450	61.4	3.5	0.8	4.8	5.1	35.4	75.6
125	5,001	66.8	3.8	0.8	5.2	5.2	35.4	81.8

A2.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands on forest land after clearcut harvest in the Northeast

Age	Mean Volume	Mean carbon density						
		Live Tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	32.0	27.7	69.6	61.8
5	0.0	7.4	0.7	2.1	21.7	20.3	69.6	52.2
15	28.0	31.8	3.2	1.9	11.5	16.3	69.6	64.7
25	58.1	53.2	5.3	1.8	7.8	17.6	69.6	85.7
35	89.6	72.8	6.0	1.7	6.9	20.3	69.6	107.8
45	119.1	87.8	6.6	1.7	7.0	23.0	69.6	126.0
55	146.6	101.1	7.0	1.7	7.5	25.3	69.6	142.7
65	172.1	113.1	7.4	1.7	8.2	27.4	69.6	157.7
75	195.6	123.8	7.7	1.7	8.8	29.2	69.6	171.2
85	217.1	133.5	7.9	1.7	9.5	30.7	69.6	183.2
95	236.6	142.1	8.1	1.7	10.1	32.0	69.6	193.9
105	254.1	149.7	8.3	1.6	10.6	33.1	69.6	203.4
115	269.7	156.3	8.5	1.6	11.1	34.2	69.6	211.7
125	283.2	162.1	8.6	1.6	11.5	35.1	69.6	218.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	13.0	11.2	28.1	25.0
5	0	3.0	0.3	0.8	8.8	8.2	28.1	21.1
15	400	12.9	1.3	0.8	4.7	6.6	28.1	26.2
25	830	21.5	2.1	0.7	3.2	7.1	28.1	34.7
35	1,280	29.5	2.4	0.7	2.8	8.2	28.1	43.6
45	1,702	35.5	2.7	0.7	2.8	9.3	28.1	51.0
55	2,095	40.9	2.8	0.7	3.0	10.3	28.1	57.7
65	2,460	45.8	3.0	0.7	3.3	11.1	28.1	63.8
75	2,796	50.1	3.1	0.7	3.6	11.8	28.1	69.3
85	3,103	54.0	3.2	0.7	3.8	12.4	28.1	74.1
95	3,382	57.5	3.3	0.7	4.1	12.9	28.1	78.5
105	3,632	60.6	3.4	0.7	4.3	13.4	28.1	82.3
115	3,854	63.3	3.4	0.7	4.5	13.8	28.1	85.7
125	4,047	65.6	3.5	0.7	4.6	14.2	28.1	88.6

A3.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	46.7	8.2	53.1	56.9
5	0.0	6.9	0.7	2.1	31.4	5.7	53.1	46.7
15	54.5	43.0	3.6	1.9	16.5	4.1	53.1	69.1
25	95.7	71.9	4.0	1.9	10.8	4.5	53.1	93.0
35	135.3	96.2	4.2	1.8	9.2	5.3	53.1	116.8
45	173.3	118.2	4.5	1.8	9.2	6.3	53.1	139.9
55	209.6	136.8	4.6	1.8	9.9	7.3	53.1	160.3
65	244.3	154.3	4.8	1.8	10.8	8.1	53.1	179.7
75	277.4	170.6	4.9	1.8	11.8	8.9	53.1	198.0
85	308.9	186.0	5.0	1.8	12.8	9.7	53.1	215.2
95	338.8	200.4	5.1	1.8	13.7	10.3	53.1	231.3
105	367.1	213.9	5.1	1.7	14.6	10.9	53.1	246.4
115	393.7	226.5	5.2	1.7	15.5	11.5	53.1	260.5
125	418.6	238.2	5.3	1.7	16.3	12.0	53.1	273.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	18.9	3.3	21.5	23.0
5	0	2.8	0.3	0.8	12.7	2.3	21.5	18.9
15	779	17.4	1.4	0.8	6.7	1.7	21.5	28.0
25	1,368	29.1	1.6	0.7	4.4	1.8	21.5	37.7
35	1,934	38.9	1.7	0.7	3.7	2.2	21.5	47.3
45	2,477	47.8	1.8	0.7	3.7	2.6	21.5	56.6
55	2,996	55.4	1.9	0.7	4.0	2.9	21.5	64.9
65	3,492	62.4	1.9	0.7	4.4	3.3	21.5	72.7
75	3,965	69.1	2.0	0.7	4.8	3.6	21.5	80.1
85	4,415	75.3	2.0	0.7	5.2	3.9	21.5	87.1
95	4,842	81.1	2.0	0.7	5.6	4.2	21.5	93.6
105	5,246	86.6	2.1	0.7	5.9	4.4	21.5	99.7
115	5,626	91.7	2.1	0.7	6.3	4.7	21.5	105.4
125	5,983	96.4	2.1	0.7	6.6	4.9	21.5	110.7

A4.— Regional estimates of timber volume and carbon stocks for oak-pine stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	30.0	29.7	66.9	63.9
5	0.0	6.2	0.6	4.2	23.0	20.2	66.9	54.3
15	36.5	27.0	2.6	3.3	14.6	15.3	66.9	62.9
25	70.9	48.6	3.2	2.9	10.4	17.1	66.9	82.2
35	103.1	67.9	3.7	2.6	8.4	20.3	66.9	102.9
45	133.1	84.7	4.0	2.5	7.6	23.6	66.9	122.3
55	160.9	99.1	4.2	2.4	7.4	26.6	66.9	139.8
65	186.7	113.0	4.4	2.3	7.7	29.3	66.9	156.6
75	210.2	123.6	4.6	2.3	8.0	31.6	66.9	170.0
85	231.5	133.1	4.7	2.3	8.4	33.6	66.9	182.1
95	250.8	141.7	4.8	2.2	8.8	35.4	66.9	192.9
105	267.9	149.2	4.9	2.2	9.2	37.0	66.9	202.5
115	282.7	155.7	5.0	2.2	9.6	38.4	66.9	210.9
125	295.4	161.3	5.1	2.2	9.9	39.7	66.9	218.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	12.1	12.0	27.1	25.9
5	0	2.5	0.3	1.7	9.3	8.2	27.1	22.0
15	522	10.9	1.1	1.3	5.9	6.2	27.1	25.4
25	1,013	19.7	1.3	1.2	4.2	6.9	27.1	33.3
35	1,473	27.5	1.5	1.1	3.4	8.2	27.1	41.7
45	1,902	34.3	1.6	1.0	3.1	9.6	27.1	49.5
55	2,300	40.1	1.7	1.0	3.0	10.8	27.1	56.6
65	2,668	45.7	1.8	0.9	3.1	11.8	27.1	63.4
75	3,004	50.0	1.8	0.9	3.2	12.8	27.1	68.8
85	3,309	53.9	1.9	0.9	3.4	13.6	27.1	73.7
95	3,584	57.3	1.9	0.9	3.6	14.3	27.1	78.1
105	3,828	60.4	2.0	0.9	3.7	15.0	27.1	82.0
115	4,040	63.0	2.0	0.9	3.9	15.6	27.1	85.4
125	4,222	65.3	2.1	0.9	4.0	16.1	27.1	88.3

A5.— Regional estimates of timber volume and carbon stocks for spruce-balsam fir stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	---------- *tonnes carbon/hectare* ----------						
0	0.0	0.0	0.0	2.1	20.3	33.7	98.0	56.2
5	0.0	7.0	0.7	1.8	16.0	23.6	98.0	49.1
15	11.5	20.1	2.0	1.6	10.6	18.6	98.0	53.0
25	29.1	32.5	3.3	1.5	8.0	20.7	98.0	66.0
35	51.6	45.7	4.6	1.4	7.1	24.2	98.0	83.1
45	76.9	57.4	5.7	1.4	6.9	27.7	98.0	99.2
55	102.6	68.7	6.9	1.4	7.3	30.7	98.0	114.9
65	126.4	78.6	7.4	1.3	7.8	33.3	98.0	128.5
75	149.3	87.9	7.6	1.3	8.4	35.5	98.0	140.8
85	170.9	96.5	7.8	1.3	9.1	37.4	98.0	152.2
95	191.6	104.5	8.0	1.3	9.7	39.1	98.0	162.6
105	211.1	111.9	8.2	1.3	10.4	40.6	98.0	172.3
115	229.6	118.8	8.3	1.3	11.0	41.9	98.0	181.2
125	247.1	125.3	8.4	1.3	11.6	43.0	98.0	189.6
years	*ft³/acre*	---------- *tonnes carbon/acre* ----------						
0	0	0.0	0.0	0.9	8.2	13.6	39.7	22.7
5	0	2.8	0.3	0.7	6.5	9.5	39.7	19.9
15	164	8.1	0.8	0.6	4.3	7.5	39.7	21.4
25	416	13.2	1.3	0.6	3.2	8.4	39.7	26.7
35	738	18.5	1.9	0.6	2.9	9.8	39.7	33.6
45	1,099	23.2	2.3	0.6	2.8	11.2	39.7	40.1
55	1,466	27.8	2.8	0.6	2.9	12.4	39.7	46.5
65	1,807	31.8	3.0	0.5	3.2	13.5	39.7	52.0
75	2,133	35.6	3.1	0.5	3.4	14.4	39.7	57.0
85	2,443	39.0	3.2	0.5	3.7	15.2	39.7	61.6
95	2,738	42.3	3.2	0.5	3.9	15.8	39.7	65.8
105	3,017	45.3	3.3	0.5	4.2	16.4	39.7	69.7
115	3,281	48.1	3.4	0.5	4.4	16.9	39.7	73.3
125	3,532	50.7	3.4	0.5	4.7	17.4	39.7	76.7

A6.— Regional estimates of timber volume and carbon stocks for white-red-jack pine stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	20.4	13.8	78.1	36.3
5	0.0	7.3	0.7	2.2	15.8	10.7	78.1	36.8
15	30.0	28.6	2.9	1.8	10.4	9.4	78.1	53.1
25	54.4	44.7	3.9	1.8	7.5	10.1	78.1	68.1
35	77.9	57.7	4.3	1.7	6.1	11.2	78.1	81.0
45	100.6	69.4	4.6	1.7	5.5	12.2	78.1	93.4
55	122.5	78.7	4.8	1.6	5.3	13.1	78.1	103.4
65	142.3	86.8	5.0	1.6	5.3	13.7	78.1	112.5
75	160.9	94.3	5.2	1.6	5.5	14.2	78.1	120.8
85	178.4	101.2	5.3	1.6	5.8	14.7	78.1	128.6
95	194.7	107.6	5.4	1.6	6.0	15.0	78.1	135.7
105	210.0	113.5	5.5	1.6	6.3	15.4	78.1	142.3
115	224.1	118.9	5.6	1.6	6.6	15.6	78.1	148.3
125	237.1	123.8	5.7	1.6	6.8	15.9	78.1	153.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	8.3	5.6	31.6	14.7
5	0	3.0	0.3	0.9	6.4	4.3	31.6	14.9
15	429	11.6	1.2	0.7	4.2	3.8	31.6	21.5
25	777	18.1	1.6	0.7	3.0	4.1	31.6	27.5
35	1,113	23.3	1.7	0.7	2.5	4.6	31.6	32.8
45	1,438	28.1	1.9	0.7	2.2	5.0	31.6	37.8
55	1,751	31.8	2.0	0.7	2.1	5.3	31.6	41.9
65	2,034	35.1	2.0	0.7	2.2	5.5	31.6	45.5
75	2,300	38.2	2.1	0.7	2.2	5.8	31.6	48.9
85	2,550	41.0	2.1	0.6	2.3	5.9	31.6	52.0
95	2,783	43.5	2.2	0.6	2.4	6.1	31.6	54.9
105	3,001	45.9	2.2	0.6	2.6	6.2	31.6	57.6
115	3,202	48.1	2.3	0.6	2.7	6.3	31.6	60.0
125	3,389	50.1	2.3	0.6	2.8	6.4	31.6	62.2

A7.— Regional estimates of timber volume and carbon stocks for aspen-birch stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	13.4	10.2	146.1	25.6
5	0.0	7.3	0.5	2.1	9.5	7.5	146.1	26.8
15	2.9	13.9	1.4	2.1	5.0	6.0	146.1	28.4
25	21.5	26.8	2.7	2.1	3.9	6.5	146.1	42.0
35	47.2	40.8	4.1	2.0	4.0	7.5	146.1	58.4
45	72.8	53.5	5.3	2.0	4.6	8.5	146.1	74.0
55	97.1	64.9	6.1	2.0	5.4	9.3	146.1	87.7
65	119.5	75.0	6.7	2.0	6.1	10.1	146.1	99.8
75	139.7	83.8	7.1	2.0	6.8	10.7	146.1	110.4
85	157.5	91.5	7.4	2.0	7.4	11.3	146.1	119.6
95	173.0	98.0	7.7	2.0	7.9	11.8	146.1	127.4
105	186.0	103.4	7.9	2.0	8.4	12.2	146.1	133.9
115	196.4	107.7	8.1	2.0	8.7	12.5	146.1	139.1
125	204.3	110.9	8.3	2.0	9.0	12.9	146.1	143.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	5.4	4.1	59.1	10.4
5	0	3.0	0.2	0.8	3.8	3.0	59.1	10.9
15	42	5.6	0.6	0.8	2.0	2.4	59.1	11.5
25	307	10.9	1.1	0.8	1.6	2.6	59.1	17.0
35	674	16.5	1.6	0.8	1.6	3.0	59.1	23.6
45	1,041	21.6	2.2	0.8	1.9	3.4	59.1	29.9
55	1,388	26.2	2.5	0.8	2.2	3.8	59.1	35.5
65	1,708	30.3	2.7	0.8	2.5	4.1	59.1	40.4
75	1,996	33.9	2.9	0.8	2.8	4.3	59.1	44.7
85	2,251	37.0	3.0	0.8	3.0	4.6	59.1	48.4
95	2,472	39.7	3.1	0.8	3.2	4.8	59.1	51.6
105	2,658	41.8	3.2	0.8	3.4	4.9	59.1	54.2
115	2,807	43.6	3.3	0.8	3.5	5.1	59.1	56.3
125	2,920	44.9	3.3	0.8	3.6	5.2	59.1	57.9

A8.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	9.4	27.7	179.9	39.2
5	0.0	3.9	0.4	1.9	6.5	20.3	179.9	33.0
15	2.4	10.3	1.0	1.9	3.4	16.3	179.9	32.9
25	13.2	20.1	2.0	1.9	2.4	17.6	179.9	44.1
35	25.2	29.8	3.0	1.9	2.4	20.3	179.9	57.3
45	37.4	38.7	3.9	1.9	2.6	23.0	179.9	70.1
55	49.8	47.1	4.7	1.9	3.0	25.3	179.9	82.1
65	62.3	55.6	5.3	1.9	3.5	27.4	179.9	93.8
75	74.9	62.8	5.6	1.9	3.9	29.2	179.9	103.4
85	87.5	69.9	5.8	1.9	4.3	30.7	179.9	112.6
95	100.1	76.8	6.0	1.9	4.7	32.0	179.9	121.4
105	112.9	83.6	6.2	1.9	5.1	33.1	179.9	130.0
115	125.8	90.4	6.4	1.9	5.6	34.2	179.9	138.5
125	139.2	97.4	6.5	1.9	6.0	35.1	179.9	147.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	3.8	11.2	72.8	15.8
5	0	1.6	0.2	0.8	2.6	8.2	72.8	13.3
15	35	4.2	0.4	0.8	1.4	6.6	72.8	13.3
25	189	8.1	0.8	0.8	1.0	7.1	72.8	17.8
35	360	12.0	1.2	0.8	1.0	8.2	72.8	23.2
45	535	15.7	1.6	0.8	1.1	9.3	72.8	28.4
55	712	19.1	1.9	0.8	1.2	10.3	72.8	33.2
65	890	22.5	2.2	0.8	1.4	11.1	72.8	38.0
75	1,070	25.4	2.3	0.8	1.6	11.8	72.8	41.8
85	1,250	28.3	2.4	0.8	1.7	12.4	72.8	45.6
95	1,431	31.1	2.4	0.8	1.9	12.9	72.8	49.1
105	1,613	33.8	2.5	0.8	2.1	13.4	72.8	52.6
115	1,798	36.6	2.6	0.8	2.2	13.8	72.8	56.0
125	1,990	39.4	2.7	0.8	2.4	14.2	72.8	59.5

A9.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	-------------------			*tonnes carbon/hectare*			-------------------
0	0.0	0.0	0.0	2.1	19.5	27.7	134.3	49.4
5	0.0	5.1	0.5	2.0	13.3	20.3	134.3	41.2
15	4.3	13.4	1.3	1.7	6.7	16.3	134.3	39.4
25	24.6	30.3	3.0	1.6	4.8	17.6	134.3	57.3
35	48.1	47.7	4.0	1.5	4.7	20.3	134.3	78.2
45	72.5	62.9	4.4	1.4	5.2	23.0	134.3	96.9
55	96.9	77.3	4.7	1.4	6.1	25.3	134.3	114.8
65	121.3	91.1	4.9	1.4	7.0	27.4	134.3	131.8
75	145.3	104.4	5.1	1.4	8.0	29.2	134.3	148.0
85	168.9	117.1	5.3	1.3	8.9	30.7	134.3	163.3
95	191.9	129.3	5.4	1.3	9.8	32.0	134.3	177.8
105	214.4	140.9	5.6	1.3	10.7	33.1	134.3	191.6
115	236.0	151.9	5.7	1.3	11.5	34.2	134.3	204.6
125	256.9	162.4	5.8	1.3	12.3	35.1	134.3	216.9
years	*ft^3/acre*	-------------------			*tonnes carbon/acre*			-------------------
0	0	0.0	0.0	0.9	7.9	11.2	54.3	20.0
5	0	2.1	0.2	0.8	5.4	8.2	54.3	16.7
15	62	5.4	0.5	0.7	2.7	6.6	54.3	16.0
25	351	12.2	1.2	0.6	1.9	7.1	54.3	23.2
35	688	19.3	1.6	0.6	1.9	8.2	54.3	31.7
45	1,036	25.4	1.8	0.6	2.1	9.3	54.3	39.2
55	1,385	31.3	1.9	0.6	2.5	10.3	54.3	46.5
65	1,733	36.9	2.0	0.6	2.8	11.1	54.3	53.4
75	2,076	42.2	2.1	0.6	3.2	11.8	54.3	59.9
85	2,414	47.4	2.1	0.5	3.6	12.4	54.3	66.1
95	2,743	52.3	2.2	0.5	4.0	12.9	54.3	72.0
105	3,064	57.0	2.3	0.5	4.3	13.4	54.3	77.5
115	3,373	61.5	2.3	0.5	4.7	13.8	54.3	82.8
125	3,671	65.7	2.3	0.5	5.0	14.2	54.3	87.8

A10.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	20.5	8.2	97.1	30.8
5	0.0	6.7	0.7	2.2	14.1	5.7	97.1	29.3
15	4.1	17.0	1.7	2.0	7.3	4.1	97.1	32.1
25	21.9	33.6	3.1	1.9	5.2	4.5	97.1	48.2
35	42.5	50.3	3.6	1.8	5.0	5.3	97.1	66.1
45	64.9	66.7	3.9	1.8	5.7	6.3	97.1	84.4
55	88.7	83.6	4.2	1.8	6.7	7.3	97.1	103.5
65	113.4	99.1	4.5	1.7	7.8	8.1	97.1	121.2
75	139.0	114.7	4.7	1.7	8.9	8.9	97.1	139.0
85	165.2	130.3	4.9	1.7	10.1	9.7	97.1	156.7
95	192.1	146.0	5.1	1.7	11.3	10.3	97.1	174.4
105	219.2	161.6	5.3	1.7	12.5	10.9	97.1	192.0
115	246.4	177.0	5.4	1.6	13.7	11.5	97.1	209.2
125	272.5	191.6	5.5	1.6	14.8	12.0	97.1	225.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	8.3	3.3	39.3	12.5
5	0	2.7	0.3	0.9	5.7	2.3	39.3	11.9
15	58	6.9	0.7	0.8	2.9	1.7	39.3	13.0
25	313	13.6	1.2	0.8	2.1	1.8	39.3	19.5
35	608	20.4	1.4	0.7	2.0	2.2	39.3	26.7
45	928	27.0	1.6	0.7	2.3	2.6	39.3	34.2
55	1,267	33.8	1.7	0.7	2.7	2.9	39.3	41.9
65	1,620	40.1	1.8	0.7	3.1	3.3	39.3	49.0
75	1,986	46.4	1.9	0.7	3.6	3.6	39.3	56.2
85	2,361	52.7	2.0	0.7	4.1	3.9	39.3	63.4
95	2,745	59.1	2.1	0.7	4.6	4.2	39.3	70.6
105	3,133	65.4	2.1	0.7	5.1	4.4	39.3	77.7
115	3,521	71.6	2.2	0.7	5.5	4.7	39.3	84.7
125	3,895	77.5	2.2	0.7	6.0	4.9	39.3	91.3

A11.— Regional estimates of timber volume and carbon stocks for spruce-balsam fir stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	16.0	33.7	261.8	51.9
5	0.0	3.4	0.3	2.1	12.4	23.6	261.8	41.8
15	3.0	9.3	0.9	2.6	7.7	18.6	261.8	39.1
25	23.2	24.3	2.4	1.9	6.1	20.7	261.8	55.3
35	51.1	41.2	4.1	1.6	5.8	24.2	261.8	77.0
45	77.2	56.0	5.1	1.5	6.1	27.7	261.8	96.4
55	100.7	67.4	5.8	1.4	6.6	30.7	261.8	111.9
65	121.6	77.2	6.4	1.3	7.1	33.3	261.8	125.2
75	140.2	85.5	6.8	1.3	7.6	35.5	261.8	136.8
85	156.5	92.8	7.2	1.2	8.2	37.4	261.8	146.8
95	170.9	99.0	7.5	1.2	8.6	39.1	261.8	155.4
105	183.5	104.3	7.7	1.2	9.1	40.6	261.8	162.9
115	194.4	109.0	7.9	1.2	9.5	41.9	261.8	169.4
125	203.8	112.9	8.1	1.2	9.8	43.0	261.8	174.9
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	6.5	13.6	105.9	21.0
5	0	1.4	0.1	0.9	5.0	9.5	105.9	16.9
15	43	3.7	0.4	1.0	3.1	7.5	105.9	15.8
25	332	9.8	1.0	0.8	2.5	8.4	105.9	22.4
35	730	16.7	1.7	0.7	2.4	9.8	105.9	31.2
45	1,103	22.7	2.1	0.6	2.5	11.2	105.9	39.0
55	1,439	27.3	2.4	0.6	2.7	12.4	105.9	45.3
65	1,738	31.2	2.6	0.5	2.9	13.5	105.9	50.7
75	2,003	34.6	2.7	0.5	3.1	14.4	105.9	55.4
85	2,237	37.5	2.9	0.5	3.3	15.2	105.9	59.4
95	2,442	40.1	3.0	0.5	3.5	15.8	105.9	62.9
105	2,622	42.2	3.1	0.5	3.7	16.4	105.9	65.9
115	2,778	44.1	3.2	0.5	3.8	16.9	105.9	68.5
125	2,912	45.7	3.3	0.5	4.0	17.4	105.9	70.8

A12.— Regional estimates of timber volume and carbon stocks for white-red-jack pine stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	25.5	13.8	120.8	41.3
5	0.0	0.4	0.0	2.0	19.3	10.7	120.8	32.5
15	6.6	8.0	0.8	2.0	11.6	9.4	120.8	31.8
25	48.1	35.4	3.5	2.0	8.8	10.1	120.8	59.9
35	104.7	62.9	4.9	2.0	8.1	11.2	120.8	89.1
45	158.9	85.8	5.5	2.0	8.2	12.2	120.8	113.7
55	209.1	105.3	5.9	2.0	8.8	13.1	120.8	135.0
65	255.1	122.2	6.2	2.0	9.5	13.7	120.8	153.6
75	297.4	137.1	6.5	2.0	10.3	14.2	120.8	170.0
85	336.1	150.3	6.7	2.0	11.0	14.7	120.8	184.6
95	371.7	162.0	6.9	2.0	11.8	15.0	120.8	197.7
105	404.2	172.5	7.0	2.0	12.5	15.4	120.8	209.3
115	434.0	182.0	7.2	2.0	13.1	15.6	120.8	219.8
125	461.3	190.5	7.3	1.9	13.7	15.9	120.8	229.3
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	10.3	5.6	48.9	16.7
5	0	0.2	0.0	0.8	7.8	4.3	48.9	13.2
15	94	3.3	0.3	0.8	4.7	3.8	48.9	12.9
25	688	14.3	1.4	0.8	3.6	4.1	48.9	24.2
35	1,496	25.5	2.0	0.8	3.3	4.6	48.9	36.1
45	2,271	34.7	2.2	0.8	3.3	5.0	48.9	46.0
55	2,988	42.6	2.4	0.8	3.5	5.3	48.9	54.6
65	3,646	49.5	2.5	0.8	3.8	5.5	48.9	62.2
75	4,250	55.5	2.6	0.8	4.1	5.8	48.9	68.8
85	4,804	60.8	2.7	0.8	4.5	5.9	48.9	74.7
95	5,312	65.6	2.8	0.8	4.8	6.1	48.9	80.0
105	5,777	69.8	2.8	0.8	5.1	6.2	48.9	84.7
115	6,203	73.6	2.9	0.8	5.3	6.3	48.9	89.0
125	6,593	77.1	2.9	0.8	5.6	6.4	48.9	92.8

A13.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands on forest land after clearcut harvest in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	11.3	27.7	84.8	41.0
5	0.0	3.9	0.4	2.1	7.7	20.3	84.8	34.4
15	0.0	8.7	0.9	2.7	3.9	16.3	84.8	32.4
25	5.8	15.5	1.6	2.4	2.5	17.6	84.8	39.7
35	21.8	27.7	2.8	2.2	2.5	20.3	84.8	55.5
45	45.1	43.2	4.3	2.0	3.3	23.0	84.8	75.7
55	73.0	60.2	5.6	1.9	4.3	25.3	84.8	97.2
65	104.1	78.9	6.1	1.8	5.5	27.4	84.8	119.7
75	137.4	96.5	6.5	1.8	6.7	29.2	84.8	140.6
85	171.9	114.0	6.9	1.7	7.9	30.7	84.8	161.2
95	206.8	131.3	7.2	1.7	9.1	32.0	84.8	181.3
105	241.7	148.2	7.5	1.6	10.3	33.1	84.8	200.7
115	275.8	164.3	7.8	1.6	11.4	34.2	84.8	219.2
125	308.6	179.6	8.0	1.6	12.4	35.1	84.8	236.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	4.6	11.2	34.3	16.6
5	0	1.6	0.2	0.8	3.1	8.2	34.3	13.9
15	0	3.5	0.4	1.1	1.6	6.6	34.3	13.1
25	83	6.3	0.6	1.0	1.0	7.1	34.3	16.1
35	312	11.2	1.1	0.9	1.0	8.2	34.3	22.5
45	644	17.5	1.7	0.8	1.3	9.3	34.3	30.6
55	1,043	24.3	2.3	0.8	1.7	10.3	34.3	39.4
65	1,488	31.9	2.5	0.7	2.2	11.1	34.3	48.5
75	1,964	39.0	2.6	0.7	2.7	11.8	34.3	56.9
85	2,456	46.1	2.8	0.7	3.2	12.4	34.3	65.2
95	2,956	53.1	2.9	0.7	3.7	12.9	34.3	73.4
105	3,454	60.0	3.0	0.7	4.2	13.4	34.3	81.2
115	3,941	66.5	3.2	0.6	4.6	13.8	34.3	88.7
125	4,410	72.7	3.2	0.6	5.0	14.2	34.3	95.8

A14.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands on forest land after clearcut harvest in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	12.8	27.7	64.9	42.6
5	0.0	5.1	0.5	2.2	8.8	20.3	64.9	37.0
15	0.9	10.5	1.1	1.9	4.4	16.3	64.9	34.2
25	8.2	18.5	1.8	1.7	2.8	17.6	64.9	42.5
35	21.4	29.7	3.0	1.6	2.6	20.3	64.9	57.1
45	38.2	41.3	3.8	1.5	2.9	23.0	64.9	72.4
55	57.4	53.6	4.2	1.4	3.5	25.3	64.9	88.1
65	78.6	66.5	4.5	1.3	4.3	27.4	64.9	104.0
75	101.0	79.6	4.7	1.3	5.1	29.2	64.9	119.9
85	124.4	92.9	4.9	1.2	5.9	30.7	64.9	135.7
95	148.6	106.2	5.1	1.2	6.7	32.0	64.9	151.3
105	173.1	119.4	5.3	1.2	7.6	33.1	64.9	166.6
115	197.4	132.1	5.5	1.2	8.4	34.2	64.9	181.3
125	220.5	144.0	5.6	1.1	9.1	35.1	64.9	195.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	5.2	11.2	26.2	17.3
5	0	2.1	0.2	0.9	3.6	8.2	26.2	15.0
15	13	4.3	0.4	0.8	1.8	6.6	26.2	13.8
25	117	7.5	0.7	0.7	1.1	7.1	26.2	17.2
35	306	12.0	1.2	0.6	1.0	8.2	26.2	23.1
45	546	16.7	1.5	0.6	1.2	9.3	26.2	29.3
55	821	21.7	1.7	0.6	1.4	10.3	26.2	35.6
65	1,123	26.9	1.8	0.5	1.7	11.1	26.2	42.1
75	1,443	32.2	1.9	0.5	2.1	11.8	26.2	48.5
85	1,778	37.6	2.0	0.5	2.4	12.4	26.2	54.9
95	2,123	43.0	2.1	0.5	2.7	12.9	26.2	61.2
105	2,474	48.3	2.2	0.5	3.1	13.4	26.2	67.4
115	2,821	53.5	2.2	0.5	3.4	13.8	26.2	73.4
125	3,151	58.3	2.3	0.5	3.7	14.2	26.2	78.9

A15.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	14.1	8.2	45.9	24.4
5	0.0	6.7	0.6	2.4	9.8	5.7	45.9	25.1
15	2.1	15.6	1.6	2.1	5.2	4.1	45.9	28.6
25	13.0	27.5	2.7	2.0	3.7	4.5	45.9	40.3
35	27.4	40.0	3.2	1.9	3.5	5.3	45.9	53.9
45	43.0	52.2	3.6	1.8	3.9	6.3	45.9	67.8
55	59.1	64.3	3.9	1.8	4.5	7.3	45.9	81.7
65	74.9	74.7	4.1	1.7	5.1	8.1	45.9	93.8
75	90.2	84.6	4.3	1.7	5.7	8.9	45.9	105.2
85	104.7	93.7	4.4	1.7	6.3	9.7	45.9	115.8
95	118.3	102.1	4.5	1.6	6.9	10.3	45.9	125.6
105	130.8	109.7	4.7	1.6	7.4	10.9	45.9	134.4
115	142.0	116.5	4.7	1.6	7.9	11.5	45.9	142.3
125	151.9	122.5	4.8	1.6	8.3	12.0	45.9	149.2
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	5.7	3.3	18.6	9.9
5	0	2.7	0.2	1.0	4.0	2.3	18.6	10.2
15	30	6.3	0.6	0.9	2.1	1.7	18.6	11.6
25	186	11.1	1.1	0.8	1.5	1.8	18.6	16.3
35	391	16.2	1.3	0.8	1.4	2.2	18.6	21.8
45	615	21.1	1.4	0.7	1.6	2.6	18.6	27.4
55	844	26.0	1.6	0.7	1.8	2.9	18.6	33.0
65	1,070	30.2	1.7	0.7	2.1	3.3	18.6	37.9
75	1,289	34.2	1.7	0.7	2.3	3.6	18.6	42.6
85	1,497	37.9	1.8	0.7	2.6	3.9	18.6	46.9
95	1,691	41.3	1.8	0.7	2.8	4.2	18.6	50.8
105	1,869	44.4	1.9	0.7	3.0	4.4	18.6	54.4
115	2,030	47.2	1.9	0.7	3.2	4.7	18.6	57.6
125	2,171	49.6	2.0	0.7	3.3	4.9	18.6	60.4

A16.— Regional estimates of timber volume and carbon stocks for oak-pine stands on forest land after clearcut harvest in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	17.8	29.7	36.2	51.7
5	0.0	5.1	0.4	4.2	13.8	20.2	36.2	43.8
15	4.5	13.8	1.2	4.3	8.7	15.3	36.2	43.2
25	28.4	29.8	2.6	3.6	6.5	17.1	36.2	59.5
35	57.9	47.4	3.4	3.3	5.8	20.3	36.2	80.2
45	86.7	63.3	4.0	3.1	5.8	23.6	36.2	99.8
55	113.2	77.0	4.4	2.9	6.2	26.6	36.2	117.1
65	137.1	89.4	4.7	2.9	6.7	29.3	36.2	132.9
75	158.1	98.9	5.0	2.8	7.1	31.6	36.2	145.4
85	176.0	106.8	5.2	2.7	7.5	33.6	36.2	155.9
95	190.8	113.3	5.4	2.7	7.9	35.4	36.2	164.7
105	202.4	118.3	5.5	2.7	8.2	37.0	36.2	171.7
115	210.9	121.9	5.6	2.7	8.5	38.4	36.2	177.1
125	216.1	124.1	5.7	2.7	8.6	39.7	36.2	180.8
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	7.2	12.0	14.6	20.9
5	0	2.1	0.2	1.7	5.6	8.2	14.6	17.7
15	65	5.6	0.5	1.7	3.5	6.2	14.6	17.5
25	406	12.1	1.0	1.5	2.6	6.9	14.6	24.1
35	828	19.2	1.4	1.3	2.3	8.2	14.6	32.5
45	1,239	25.6	1.6	1.2	2.4	9.6	14.6	40.4
55	1,618	31.2	1.8	1.2	2.5	10.8	14.6	47.4
65	1,959	36.2	1.9	1.2	2.7	11.8	14.6	53.8
75	2,259	40.0	2.0	1.1	2.9	12.8	14.6	58.8
85	2,515	43.2	2.1	1.1	3.1	13.6	14.6	63.1
95	2,727	45.8	2.2	1.1	3.2	14.3	14.6	66.6
105	2,893	47.9	2.2	1.1	3.3	15.0	14.6	69.5
115	3,014	49.3	2.3	1.1	3.4	15.6	14.6	71.7
125	3,088	50.2	2.3	1.1	3.5	16.1	14.6	73.2

A17.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m*^{3}*/hectare*	------- *tonnes carbon/hectare* -------						
0	0.0	0.0	0.0	4.6	26.0	37.2	94.8	67.8
5	0.0	2.7	0.3	4.4	22.5	35.4	94.8	65.2
15	3.8	8.7	0.9	4.1	17.2	32.9	94.8	63.7
25	47.7	38.3	3.8	3.7	15.9	31.8	94.8	93.5
35	119.0	75.1	7.5	3.6	16.5	31.6	94.8	134.2
45	184.7	104.0	10.0	3.5	17.1	32.0	94.8	166.5
55	241.8	127.3	10.9	3.4	17.8	32.7	94.8	192.1
65	290.9	146.4	11.5	3.4	18.5	33.6	94.8	213.5
75	332.7	162.2	12.0	3.4	19.2	34.6	94.8	231.4
85	368.3	175.3	12.4	3.4	19.8	35.6	94.8	246.5
95	398.6	186.2	12.7	3.4	20.5	36.6	94.8	259.3
105	424.4	195.4	13.0	3.3	21.0	37.5	94.8	270.2
115	446.4	203.1	13.2	3.3	21.6	38.4	94.8	279.5
125	465.2	209.6	13.3	3.3	22.0	39.2	94.8	287.5
years	*ft*^{3}*/acre*	------- *tonnes carbon/acre* -------						
0	0	0.0	0.0	1.9	10.5	15.1	38.3	27.4
5	0	1.1	0.1	1.8	9.1	14.3	38.3	26.4
15	54	3.5	0.4	1.7	7.0	13.3	38.3	25.8
25	682	15.5	1.5	1.5	6.4	12.9	38.3	37.8
35	1,701	30.4	3.0	1.4	6.7	12.8	38.3	54.3
45	2,639	42.1	4.1	1.4	6.9	12.9	38.3	67.4
55	3,456	51.5	4.4	1.4	7.2	13.2	38.3	77.8
65	4,157	59.3	4.7	1.4	7.5	13.6	38.3	86.4
75	4,755	65.6	4.9	1.4	7.8	14.0	38.3	93.6
85	5,264	70.9	5.0	1.4	8.0	14.4	38.3	99.8
95	5,697	75.4	5.1	1.4	8.3	14.8	38.3	104.9
105	6,065	79.1	5.2	1.4	8.5	15.2	38.3	109.4
115	6,379	82.2	5.3	1.4	8.7	15.5	38.3	113.1
125	6,648	84.8	5.4	1.3	8.9	15.8	38.3	116.3

A18.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	------- *tonnes carbon/hectare* -------						
0	0.0	0.0	0.0	4.8	16.6	37.2	62.1	58.6
5	0.0	3.1	0.3	4.1	14.5	35.4	62.1	57.4
15	0.0	5.8	0.6	3.7	11.0	32.9	62.1	54.0
25	15.2	15.5	1.6	3.2	9.3	31.8	62.1	61.3
35	52.1	33.9	3.4	2.8	9.2	31.6	62.1	80.9
45	97.4	53.0	5.3	2.6	9.7	32.0	62.1	102.6
55	144.4	71.3	7.1	2.5	10.6	32.7	62.1	124.3
65	189.7	88.3	8.8	2.4	11.6	33.6	62.1	144.7
75	231.5	103.3	10.3	2.4	12.6	34.6	62.1	163.2
85	268.7	116.4	11.6	2.3	13.6	35.6	62.1	179.6
95	301.0	127.6	12.8	2.3	14.4	36.6	62.1	193.6
105	328.2	136.9	13.7	2.3	15.2	37.5	62.1	205.5
115	350.6	144.4	14.4	2.2	15.8	38.4	62.1	215.2
125	368.3	150.3	15.0	2.2	16.3	39.2	62.1	223.0
years	*ft³/acre*	------- *tonnes carbon/acre* -------						
0	0	0.0	0.0	1.9	6.7	15.1	25.1	23.7
5	0	1.3	0.1	1.7	5.9	14.3	25.1	23.2
15	0	2.3	0.2	1.5	4.5	13.3	25.1	21.9
25	217	6.3	0.6	1.3	3.8	12.9	25.1	24.8
35	745	13.7	1.4	1.1	3.7	12.8	25.1	32.8
45	1,392	21.4	2.1	1.1	3.9	12.9	25.1	41.5
55	2,063	28.9	2.9	1.0	4.3	13.2	25.1	50.3
65	2,711	35.7	3.6	1.0	4.7	13.6	25.1	58.6
75	3,308	41.8	4.2	1.0	5.1	14.0	25.1	66.1
85	3,840	47.1	4.7	0.9	5.5	14.4	25.1	72.7
95	4,302	51.6	5.2	0.9	5.8	14.8	25.1	78.4
105	4,691	55.4	5.5	0.9	6.1	15.2	25.1	83.2
115	5,010	58.4	5.8	0.9	6.4	15.5	25.1	87.1
125	5,264	60.8	6.1	0.9	6.6	15.8	25.1	90.3

A19.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands on forest land after clearcut harvest in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	13.1	24.1	52.0	42.0
5	0.0	1.9	0.2	4.8	11.4	22.0	52.0	40.2
15	6.6	8.1	0.8	3.5	9.0	19.4	52.0	40.7
25	40.8	24.3	2.4	2.6	8.3	18.3	52.0	56.0
35	81.7	40.1	4.0	2.3	8.2	18.2	52.0	72.8
45	120.5	54.0	5.4	2.2	8.3	18.7	52.0	88.5
55	156.3	64.5	6.4	2.1	8.4	19.4	52.0	100.8
65	189.3	73.6	7.4	2.0	8.6	20.4	52.0	111.9
75	219.9	81.7	8.2	1.9	8.9	21.4	52.0	122.0
85	248.0	88.9	8.9	1.9	9.2	22.4	52.0	131.2
95	274.0	95.4	9.5	1.9	9.6	23.3	52.0	139.7
105	298.2	101.2	10.1	1.8	9.9	24.3	52.0	147.4
115	320.5	106.5	10.6	1.8	10.3	25.2	52.0	154.4
125	341.2	111.4	10.9	1.8	10.6	26.0	52.0	160.7
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	5.3	9.8	21.1	17.0
5	0	0.8	0.1	2.0	4.6	8.9	21.1	16.3
15	95	3.3	0.3	1.4	3.6	7.8	21.1	16.5
25	583	9.8	1.0	1.1	3.4	7.4	21.1	22.7
35	1,168	16.2	1.6	0.9	3.3	7.4	21.1	29.5
45	1,722	21.8	2.2	0.9	3.3	7.6	21.1	35.8
55	2,234	26.1	2.6	0.8	3.4	7.9	21.1	40.8
65	2,706	29.8	3.0	0.8	3.5	8.2	21.1	45.3
75	3,142	33.1	3.3	0.8	3.6	8.6	21.1	49.4
85	3,544	36.0	3.6	0.8	3.7	9.1	21.1	53.1
95	3,916	38.6	3.9	0.8	3.9	9.4	21.1	56.5
105	4,261	41.0	4.1	0.7	4.0	9.8	21.1	59.6
115	4,580	43.1	4.3	0.7	4.2	10.2	21.1	62.5
125	4,876	45.1	4.4	0.7	4.3	10.5	21.1	65.0

A20.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands on forest land after clearcut harvest in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	9.6	24.1	50.7	38.5
5	0.0	3.3	0.3	4.6	8.5	22.0	50.7	38.6
15	4.1	7.9	0.8	3.8	6.8	19.4	50.7	38.7
25	21.6	17.3	1.7	3.2	6.2	18.3	50.7	46.7
35	40.8	26.2	2.6	2.9	5.9	18.2	50.7	55.9
45	61.4	34.9	3.3	2.8	6.0	18.7	50.7	65.5
55	83.3	43.6	3.7	2.6	6.3	19.4	50.7	75.7
65	106.0	52.5	4.2	2.5	6.7	20.4	50.7	86.2
75	129.3	61.3	4.6	2.4	7.3	21.4	50.7	96.9
85	153.0	70.0	4.9	2.4	7.9	22.4	50.7	107.6
95	176.8	78.6	5.3	2.3	8.6	23.3	50.7	118.1
105	200.4	87.0	5.6	2.3	9.4	24.3	50.7	128.4
115	223.6	95.1	5.9	2.2	10.1	25.2	50.7	138.4
125	246.0	102.8	6.1	2.2	10.8	26.0	50.7	147.9
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	3.9	9.8	20.5	15.6
5	0	1.3	0.1	1.8	3.5	8.9	20.5	15.6
15	59	3.2	0.3	1.5	2.8	7.8	20.5	15.6
25	309	7.0	0.7	1.3	2.5	7.4	20.5	18.9
35	583	10.6	1.1	1.2	2.4	7.4	20.5	22.6
45	878	14.1	1.3	1.1	2.4	7.6	20.5	26.5
55	1,190	17.7	1.5	1.1	2.5	7.9	20.5	30.6
65	1,515	21.2	1.7	1.0	2.7	8.2	20.5	34.9
75	1,848	24.8	1.8	1.0	2.9	8.6	20.5	39.2
85	2,187	28.3	2.0	1.0	3.2	9.1	20.5	43.5
95	2,527	31.8	2.1	0.9	3.5	9.4	20.5	47.8
105	2,864	35.2	2.3	0.9	3.8	9.8	20.5	52.0
115	3,195	38.5	2.4	0.9	4.1	10.2	20.5	56.0
125	3,515	41.6	2.5	0.9	4.4	10.5	20.5	59.8

A21.— Regional estimates of timber volume and carbon stocks for alder-maple stands on forest land after clearcut harvest in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	32.2	9.3	115.2	46.2
5	0.0	8.0	0.8	4.7	22.0	3.9	115.2	39.5
15	49.5	31.0	3.1	3.7	12.3	4.5	115.2	54.6
25	229.7	99.4	9.9	2.8	13.5	6.2	115.2	131.9
35	380.8	153.8	15.4	2.5	16.4	7.6	115.2	195.7
45	513.7	200.8	20.1	2.4	19.8	8.6	115.2	251.7
55	633.3	242.5	22.2	2.3	23.3	9.4	115.2	299.7
65	742.1	280.1	23.9	2.2	26.7	10.1	115.2	343.0
75	842.1	314.4	25.3	2.2	29.9	10.7	115.2	382.4
85	934.5	346.0	26.6	2.1	32.8	11.1	115.2	418.6
95	1,020.3	375.2	27.7	2.1	35.6	11.5	115.2	452.0
105	1,100.3	402.2	28.7	2.0	38.1	11.9	115.2	483.0
115	1,175.0	427.4	29.6	2.1	40.5	12.2	115.2	511.8
125	1,244.9	450.9	30.4	2.3	42.7	12.4	115.2	538.7
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	13.0	3.8	46.6	18.7
5	0	3.2	0.3	1.9	8.9	1.6	46.6	16.0
15	708	12.6	1.3	1.5	5.0	1.8	46.6	22.1
25	3,282	40.2	4.0	1.1	5.5	2.5	46.6	53.4
35	5,442	62.3	6.2	1.0	6.6	3.1	46.6	79.2
45	7,342	81.3	8.1	1.0	8.0	3.5	46.6	101.9
55	9,050	98.1	9.0	0.9	9.4	3.8	46.6	121.3
65	10,605	113.3	9.7	0.9	10.8	4.1	46.6	138.8
75	12,034	127.2	10.3	0.9	12.1	4.3	46.6	154.8
85	13,355	140.0	10.8	0.9	13.3	4.5	46.6	169.4
95	14,582	151.8	11.2	0.8	14.4	4.7	46.6	182.9
105	15,725	162.8	11.6	0.8	15.4	4.8	46.6	195.4
115	16,792	173.0	12.0	0.9	16.4	4.9	46.6	207.1
125	17,791	182.5	12.3	0.9	17.3	5.0	46.6	218.0

A22.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	50.3	27.5	94.8	82.4
5	0.0	8.4	0.8	4.5	43.9	23.7	94.8	81.3
15	37.4	30.3	3.0	3.9	34.6	20.7	94.8	92.6
25	208.9	107.1	10.7	3.4	33.9	21.2	94.8	176.3
35	391.8	181.6	17.4	3.2	35.2	23.3	94.8	260.7
45	554.7	246.1	21.2	3.1	37.1	26.0	94.8	333.5
55	698.4	302.2	24.1	3.0	39.4	28.9	94.8	397.6
65	826.0	351.4	26.4	3.0	41.8	31.8	94.8	454.4
75	939.9	394.9	28.4	2.9	44.4	34.5	94.8	505.1
85	1,042.1	433.7	30.1	2.9	47.0	37.0	94.8	550.7
95	1,134.5	468.6	31.6	2.9	49.5	39.3	94.8	591.9
105	1,218.3	500.1	32.9	2.9	51.9	41.5	94.8	629.2
115	1,294.7	528.7	34.0	2.9	54.3	43.4	94.8	663.3
125	1,364.7	554.8	35.0	2.8	56.5	45.3	94.8	694.4
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	20.3	11.1	38.3	33.3
5	0	3.4	0.3	1.8	17.8	9.6	38.3	32.9
15	535	12.3	1.2	1.6	14.0	8.4	38.3	37.5
25	2,985	43.3	4.3	1.4	13.7	8.6	38.3	71.3
35	5,600	73.5	7.1	1.3	14.2	9.4	38.3	105.5
45	7,927	99.6	8.6	1.3	15.0	10.5	38.3	135.0
55	9,981	122.3	9.7	1.2	15.9	11.7	38.3	160.9
65	11,804	142.2	10.7	1.2	16.9	12.9	38.3	183.9
75	13,432	159.8	11.5	1.2	18.0	14.0	38.3	204.4
85	14,893	175.5	12.2	1.2	19.0	15.0	38.3	222.9
95	16,213	189.6	12.8	1.2	20.0	15.9	38.3	239.5
105	17,411	202.4	13.3	1.2	21.0	16.8	38.3	254.6
115	18,503	213.9	13.8	1.2	22.0	17.6	38.3	268.4
125	19,503	224.5	14.2	1.1	22.9	18.3	38.3	281.0

A23.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Pacific Northwest, West; volumes are for high-productivity sites (growth rate greater than 165 cubic feet wood per acre per year) with high-intensity management (replanting with genetically improved stock, fertilization, and precommercial thinning)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	---- *tonnes carbon/hectare* ----						
0	0.0	0.0	0.0	4.6	49.3	27.5	94.8	81.4
5	0.0	9.5	0.9	4.4	43.1	23.7	94.8	81.7
15	19.8	23.4	2.3	4.0	33.3	20.7	94.8	83.8
25	169.7	84.6	8.5	3.5	31.2	21.2	94.8	148.9
35	445.7	187.4	10.0	3.2	35.4	23.3	94.8	259.3
45	718.8	286.2	10.6	3.0	40.8	26.0	94.8	366.7
55	924.1	359.4	10.9	3.0	44.9	28.9	94.8	447.0
65	1,086.5	416.7	11.1	2.9	48.2	31.8	94.8	510.7
75	1,225.8	465.6	11.2	2.9	51.4	34.5	94.8	565.5
85	1,346.8	507.8	11.3	2.9	54.3	37.0	94.8	613.4
95	1,452.4	544.6	11.4	2.8	57.0	39.3	94.8	655.2
105	1,544.4	576.5	11.5	2.9	59.6	41.5	94.8	691.9
115	1,544.4	576.5	11.5	2.9	59.0	43.4	94.8	693.4
125	1,544.4	576.5	11.5	2.9	58.7	45.3	94.8	694.8
years	*ft³/acre*	---- *tonnes carbon/acre* ----						
0	0	0.0	0.0	1.9	19.9	11.1	38.3	32.9
5	0	3.8	0.4	1.8	17.5	9.6	38.3	33.0
15	283	9.5	0.9	1.6	13.5	8.4	38.3	33.9
25	2,425	34.2	3.4	1.4	12.6	8.6	38.3	60.3
35	6,370	75.9	4.1	1.3	14.3	9.4	38.3	104.9
45	10,272	115.8	4.3	1.2	16.5	10.5	38.3	148.4
55	13,207	145.4	4.4	1.2	18.2	11.7	38.3	180.9
65	15,527	168.6	4.5	1.2	19.5	12.9	38.3	206.7
75	17,518	188.4	4.5	1.2	20.8	14.0	38.3	228.9
85	19,248	205.5	4.6	1.2	22.0	15.0	38.3	248.2
95	20,756	220.4	4.6	1.2	23.1	15.9	38.3	265.2
105	22,072	233.3	4.7	1.2	24.1	16.8	38.3	280.0
115	22,072	233.3	4.7	1.2	23.9	17.6	38.3	280.6
125	22,072	233.3	4.7	1.2	23.7	18.3	38.3	281.2

A24.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	23.8	29.5	62.1	58.1
5	0.0	3.2	0.3	4.8	20.7	27.0	62.1	56.0
15	8.2	11.6	1.2	3.9	16.0	25.2	62.1	57.9
25	62.3	42.5	4.3	3.2	14.8	25.6	62.1	90.3
35	145.5	84.3	8.4	2.8	15.6	27.1	62.1	138.2
45	238.7	128.7	12.9	2.6	17.4	28.9	62.1	190.6
55	333.9	168.2	16.8	2.5	19.4	30.8	62.1	237.8
65	427.0	205.1	20.5	2.5	21.6	32.6	62.1	282.2
75	515.8	239.2	23.9	2.4	23.8	34.2	62.1	323.4
85	599.0	270.3	27.0	2.3	25.9	35.6	62.1	361.2
95	676.0	298.5	29.8	2.3	28.0	36.8	62.1	395.5
105	746.6	323.9	32.4	2.3	29.9	37.9	62.1	426.5
115	810.8	346.7	34.1	2.3	31.7	38.9	62.1	453.7
125	869.1	367.2	35.1	2.2	33.4	39.8	62.1	477.7
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	9.6	11.9	25.1	23.5
5	0	1.3	0.1	1.9	8.4	10.9	25.1	22.7
15	117	4.7	0.5	1.6	6.5	10.2	25.1	23.4
25	890	17.2	1.7	1.3	6.0	10.4	25.1	36.6
35	2,080	34.1	3.4	1.1	6.3	11.0	25.1	55.9
45	3,412	52.1	5.2	1.1	7.1	11.7	25.1	77.1
55	4,772	68.1	6.8	1.0	7.9	12.5	25.1	96.2
65	6,103	83.0	8.3	1.0	8.7	13.2	25.1	114.2
75	7,371	96.8	9.7	1.0	9.6	13.8	25.1	130.9
85	8,560	109.4	10.9	0.9	10.5	14.4	25.1	146.2
95	9,661	120.8	12.1	0.9	11.3	14.9	25.1	160.0
105	10,670	131.1	13.1	0.9	12.1	15.4	25.1	172.6
115	11,588	140.3	13.8	0.9	12.8	15.8	25.1	183.6
125	12,421	148.6	14.2	0.9	13.5	16.1	25.1	193.3

A25.— Regional estimates of timber volume and carbon stocks for hemlock-Sitka spruce stands on forest land after clearcut harvest in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	43.2	27.5	116.3	75.4
5	0.0	5.9	0.6	4.7	37.6	23.7	116.3	72.5
15	33.7	22.5	2.2	4.1	29.4	20.7	116.3	78.9
25	184.1	78.0	7.8	3.1	27.6	21.2	116.3	137.7
35	350.8	139.8	14.0	2.7	28.4	23.3	116.3	208.2
45	516.7	201.6	20.2	2.5	30.6	26.0	116.3	280.9
55	678.7	256.6	25.7	2.4	33.2	28.9	116.3	346.8
65	835.1	309.1	30.9	2.3	36.2	31.8	116.3	410.4
75	985.6	359.2	35.9	2.2	39.6	34.5	116.3	471.5
85	1,129.8	406.7	40.1	2.2	43.2	37.0	116.3	529.2
95	1,267.4	451.8	42.8	2.3	46.8	39.3	116.3	583.0
105	1,398.3	494.4	45.2	2.5	50.4	41.5	116.3	634.0
115	1,522.4	534.7	47.4	2.7	53.9	43.4	116.3	682.2
125	1,639.6	572.6	49.4	2.9	57.3	45.3	116.3	727.5
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	17.5	11.1	47.1	30.5
5	0	2.4	0.2	1.9	15.2	9.6	47.1	29.3
15	482	9.1	0.9	1.6	11.9	8.4	47.1	31.9
25	2,631	31.6	3.2	1.3	11.2	8.6	47.1	55.7
35	5,013	56.6	5.7	1.1	11.5	9.4	47.1	84.2
45	7,385	81.6	8.2	1.0	12.4	10.5	47.1	113.7
55	9,699	103.9	10.4	1.0	13.4	11.7	47.1	140.3
65	11,935	125.1	12.5	0.9	14.7	12.9	47.1	166.1
75	14,086	145.4	14.5	0.9	16.0	14.0	47.1	190.8
85	16,146	164.6	16.2	0.9	17.5	15.0	47.1	214.2
95	18,113	182.8	17.3	0.9	18.9	15.9	47.1	235.9
105	19,983	200.1	18.3	1.0	20.4	16.8	47.1	256.6
115	21,757	216.4	19.2	1.1	21.8	17.6	47.1	276.1
125	23,432	231.7	20.0	1.2	23.2	18.3	47.1	294.4

A26.— Regional estimates of timber volume and carbon stocks for hemlock-Sitka spruce stands on forest land after clearcut harvest in the Pacific Northwest, West; volumes are for high-productivity sites (growth rate greater than 225 cubic feet wood/acre/year)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	42.7	27.5	116.3	74.9
5	0.0	5.9	0.6	4.7	37.1	23.7	116.3	72.0
15	80.3	36.4	3.6	3.7	30.4	20.7	116.3	94.8
25	221.7	90.4	9.0	3.0	28.6	21.2	116.3	152.3
35	413.7	161.0	16.1	2.7	30.3	23.3	116.3	233.3
45	669.6	253.6	25.4	2.4	35.6	26.0	116.3	342.9
55	903.9	332.1	33.2	2.3	40.5	28.9	116.3	437.0
65	1,119.3	403.3	39.9	2.2	45.5	31.8	116.3	522.6
75	1,318.1	468.3	43.7	2.3	50.4	34.5	116.3	599.3
85	1,502.0	528.1	47.1	2.6	55.1	37.0	116.3	669.9
95	1,672.1	583.0	50.0	2.9	59.7	39.3	116.3	735.0
105	1,829.1	633.5	52.6	3.2	64.1	41.5	116.3	794.8
115	1,973.0	679.5	54.9	3.4	68.2	43.4	116.3	849.4
125	2,103.3	721.0	56.9	3.6	72.0	45.3	116.3	898.7
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	17.3	11.1	47.1	30.3
5	0	2.4	0.2	1.9	15.0	9.6	47.1	29.1
15	1,148	14.7	1.5	1.5	12.3	8.4	47.1	38.4
25	3,169	36.6	3.7	1.2	11.6	8.6	47.1	61.6
35	5,912	65.1	6.5	1.1	12.3	9.4	47.1	94.4
45	9,570	102.6	10.3	1.0	14.4	10.5	47.1	138.8
55	12,918	134.4	13.4	0.9	16.4	11.7	47.1	176.8
65	15,996	163.2	16.1	0.9	18.4	12.9	47.1	211.5
75	18,837	189.5	17.7	0.9	20.4	14.0	47.1	242.5
85	21,465	213.7	19.0	1.1	22.3	15.0	47.1	271.1
95	23,896	235.9	20.2	1.2	24.2	15.9	47.1	297.4
105	26,140	256.4	21.3	1.3	25.9	16.8	47.1	321.6
115	28,197	275.0	22.2	1.4	27.6	17.6	47.1	343.7
125	30,059	291.8	23.0	1.5	29.1	18.3	47.1	363.7

A27.— Regional estimates of timber volume and carbon stocks for mixed conifer stands on forest land after clearcut harvest in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	12.0	37.2	49.8	54.0
5	0.0	4.2	0.3	4.8	10.7	35.4	49.8	55.4
15	2.0	8.1	0.8	4.8	8.4	32.9	49.8	54.9
25	11.1	14.6	1.5	6.9	7.0	31.8	49.8	61.7
35	24.4	22.3	2.2	4.9	6.3	31.6	49.8	67.3
45	44.5	32.9	3.3	3.6	6.3	32.0	49.8	78.1
55	71.9	46.5	4.7	2.8	6.9	32.7	49.8	93.5
65	106.6	62.8	6.3	2.2	7.9	33.6	49.8	112.8
75	147.9	81.4	8.1	1.8	9.3	34.6	49.8	135.3
85	195.4	102.0	10.2	1.5	11.1	35.6	49.8	160.4
95	248.3	124.2	12.4	1.3	13.1	36.6	49.8	187.5
105	305.6	147.5	14.8	1.1	15.3	37.5	49.8	216.2
115	366.7	171.8	17.2	1.0	17.6	38.4	49.8	245.9
125	430.5	196.6	19.7	1.0	20.0	39.2	49.8	276.4
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	4.9	15.1	20.2	21.9
5	0	1.7	0.1	1.9	4.3	14.3	20.2	22.4
15	29	3.3	0.3	1.9	3.4	13.3	20.2	22.2
25	159	5.9	0.6	2.8	2.8	12.9	20.2	25.0
35	349	9.0	0.9	2.0	2.6	12.8	20.2	27.2
45	636	13.3	1.3	1.5	2.5	12.9	20.2	31.6
55	1,028	18.8	1.9	1.1	2.8	13.2	20.2	37.9
65	1,523	25.4	2.5	0.9	3.2	13.6	20.2	45.7
75	2,114	33.0	3.3	0.7	3.8	14.0	20.2	54.8
85	2,793	41.3	4.1	0.6	4.5	14.4	20.2	64.9
95	3,548	50.2	5.0	0.5	5.3	14.8	20.2	75.9
105	4,368	59.7	6.0	0.5	6.2	15.2	20.2	87.5
115	5,240	69.5	7.0	0.4	7.1	15.5	20.2	99.5
125	6,152	79.6	8.0	0.4	8.1	15.8	20.2	111.9

A28.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	16.0	37.2	51.9	58.0
5	0.0	3.2	0.3	4.8	14.0	35.4	51.9	57.7
15	2.0	7.9	0.8	4.2	10.9	32.9	51.9	56.8
25	13.7	17.3	1.7	3.4	9.3	31.8	51.9	63.5
35	32.4	29.5	3.0	2.9	8.6	31.6	51.9	75.6
45	58.8	45.2	4.5	2.6	8.9	32.0	51.9	93.2
55	94.0	63.1	6.3	2.4	9.8	32.7	51.9	114.3
65	136.7	83.5	8.4	2.2	11.2	33.6	51.9	138.9
75	185.6	105.7	10.6	2.1	13.1	34.6	51.9	166.0
85	239.2	128.9	12.9	2.0	15.2	35.6	51.9	194.6
95	296.6	153.0	15.3	1.9	17.5	36.6	51.9	224.2
105	356.8	177.4	17.7	1.8	19.9	37.5	51.9	254.4
115	419.1	202.0	20.2	1.8	22.4	38.4	51.9	284.8
125	482.7	226.6	22.7	1.7	25.0	39.2	51.9	315.1
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	6.5	15.1	21.0	23.5
5	0	1.3	0.1	1.9	5.7	14.3	21.0	23.4
15	28	3.2	0.3	1.7	4.4	13.3	21.0	23.0
25	196	7.0	0.7	1.4	3.7	12.9	21.0	25.7
35	463	11.9	1.2	1.2	3.5	12.8	21.0	30.6
45	840	18.3	1.8	1.1	3.6	12.9	21.0	37.7
55	1,343	25.5	2.6	1.0	4.0	13.2	21.0	46.3
65	1,954	33.8	3.4	0.9	4.5	13.6	21.0	56.2
75	2,652	42.8	4.3	0.8	5.3	14.0	21.0	67.2
85	3,419	52.2	5.2	0.8	6.1	14.4	21.0	78.8
95	4,239	61.9	6.2	0.8	7.1	14.8	21.0	90.7
105	5,099	71.8	7.2	0.7	8.1	15.2	21.0	102.9
115	5,989	81.8	8.2	0.7	9.1	15.5	21.0	115.2
125	6,899	91.7	9.2	0.7	10.1	15.8	21.0	127.5

A29.— Regional estimates of timber volume and carbon stocks for western oak stands on forest land after clearcut harvest in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	13.3	31.7	27.6	49.7
5	0.0	2.6	0.2	4.6	8.9	28.4	27.6	44.8
15	0.0	5.7	0.6	4.5	4.1	24.6	27.6	39.5
25	1.0	8.8	0.9	4.4	2.1	23.4	27.6	39.5
35	25.9	30.6	3.1	4.2	2.0	23.5	27.6	63.4
45	76.3	65.1	4.5	4.1	3.0	24.3	27.6	101.1
55	127.8	98.3	5.4	4.0	4.2	25.5	27.6	137.5
65	174.4	124.0	6.0	4.0	5.2	26.8	27.6	166.1
75	215.0	145.3	6.5	4.0	6.1	28.1	27.6	189.9
85	249.4	162.7	6.8	4.0	6.8	29.4	27.6	209.7
95	278.4	177.1	7.1	4.0	7.4	30.6	27.6	226.1
105	302.8	189.0	7.3	3.9	7.9	31.7	27.6	239.7
115	323.3	198.8	7.4	3.9	8.3	32.6	27.6	251.1
125	340.6	207.0	7.6	3.9	8.6	33.5	27.6	260.7
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	5.4	12.8	11.2	20.1
5	0	1.1	0.1	1.9	3.6	11.5	11.2	18.1
15	0	2.3	0.2	1.8	1.7	10.0	11.2	16.0
25	15	3.6	0.4	1.8	0.8	9.5	11.2	16.0
35	370	12.4	1.2	1.7	0.8	9.5	11.2	25.7
45	1,090	26.3	1.8	1.7	1.2	9.8	11.2	40.9
55	1,826	39.8	2.2	1.6	1.7	10.3	11.2	55.6
65	2,493	50.2	2.4	1.6	2.1	10.9	11.2	67.2
75	3,072	58.8	2.6	1.6	2.5	11.4	11.2	76.9
85	3,564	65.9	2.8	1.6	2.7	11.9	11.2	84.9
95	3,979	71.7	2.9	1.6	3.0	12.4	11.2	91.5
105	4,328	76.5	2.9	1.6	3.2	12.8	11.2	97.0
115	4,620	80.5	3.0	1.6	3.3	13.2	11.2	101.6
125	4,868	83.8	3.1	1.6	3.5	13.6	11.2	105.5

A30.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	22.4	37.2	38.8	64.4
5	0.0	2.7	0.3	4.7	20.2	35.4	38.8	63.2
15	1.1	6.1	0.6	4.7	16.3	32.9	38.8	60.6
25	19.7	21.5	2.2	3.4	14.0	31.8	38.8	72.8
35	57.1	44.3	4.4	2.7	12.8	31.6	38.8	95.8
45	100.9	66.5	6.7	2.3	12.1	32.0	38.8	119.5
55	145.9	87.2	8.7	2.1	11.8	32.7	38.8	142.5
65	189.3	105.9	10.1	1.9	11.6	33.6	38.8	163.1
75	229.7	122.5	10.7	1.8	11.6	34.6	38.8	181.3
85	266.3	137.0	11.2	1.8	11.7	35.6	38.8	197.3
95	298.6	149.4	11.6	1.7	11.8	36.6	38.8	211.1
105	326.6	159.9	12.0	1.7	12.0	37.5	38.8	223.0
115	350.1	168.6	12.2	1.6	12.1	38.4	38.8	232.9
125	369.5	175.7	12.4	1.6	12.2	39.2	38.8	241.1
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	9.1	15.1	15.7	26.0
5	0	1.1	0.1	1.9	8.2	14.3	15.7	25.6
15	16	2.5	0.2	1.9	6.6	13.3	15.7	24.5
25	281	8.7	0.9	1.4	5.6	12.9	15.7	29.5
35	816	17.9	1.8	1.1	5.2	12.8	15.7	38.8
45	1,442	26.9	2.7	0.9	4.9	12.9	15.7	48.4
55	2,085	35.3	3.5	0.8	4.8	13.2	15.7	57.7
65	2,705	42.9	4.1	0.8	4.7	13.6	15.7	66.0
75	3,283	49.6	4.3	0.7	4.7	14.0	15.7	73.4
85	3,806	55.4	4.5	0.7	4.7	14.4	15.7	79.8
95	4,268	60.5	4.7	0.7	4.8	14.8	15.7	85.4
105	4,667	64.7	4.8	0.7	4.8	15.2	15.7	90.2
115	5,003	68.2	4.9	0.7	4.9	15.5	15.7	94.3
125	5,280	71.1	5.0	0.7	4.9	15.8	15.7	97.6

A31.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	------------------------------------- *tonnes carbon/hectare* -------------------------------------						
0	0.0	0.0	0.0	4.7	25.7	37.2	44.1	67.7
5	0.0	3.1	0.3	4.7	23.2	35.4	44.1	66.8
15	0.0	5.8	0.6	4.7	18.8	32.9	44.1	62.8
25	18.2	17.0	1.7	3.4	16.2	31.8	44.1	70.1
35	61.6	38.1	3.8	2.7	15.3	31.6	44.1	91.4
45	113.8	59.5	5.9	2.3	15.1	32.0	44.1	114.8
55	167.2	80.0	8.0	2.1	15.3	32.7	44.1	138.1
65	218.2	98.6	9.9	2.0	15.7	33.6	44.1	159.7
75	264.6	115.0	11.5	1.9	16.1	34.6	44.1	179.1
85	305.4	129.1	12.9	1.8	16.6	35.6	44.1	196.0
95	340.2	140.9	14.1	1.8	17.0	36.6	44.1	210.4
105	368.8	150.5	15.0	1.7	17.4	37.5	44.1	222.2
115	391.6	158.0	15.8	1.7	17.7	38.4	44.1	231.6
125	408.8	163.7	16.4	1.7	17.9	39.2	44.1	238.8
years	*ft³/acre*	------------------------------------- *tonnes carbon/acre* -------------------------------------						
0	0	0.0	0.0	1.9	10.4	15.1	17.9	27.4
5	0	1.3	0.1	1.9	9.4	14.3	17.9	27.0
15	0	2.3	0.2	1.9	7.6	13.3	17.9	25.4
25	260	6.9	0.7	1.4	6.5	12.9	17.9	28.4
35	880	15.4	1.5	1.1	6.2	12.8	17.9	37.0
45	1,626	24.1	2.4	0.9	6.1	12.9	17.9	46.5
55	2,390	32.4	3.2	0.9	6.2	13.2	17.9	55.9
65	3,118	39.9	4.0	0.8	6.3	13.6	17.9	64.6
75	3,782	46.5	4.7	0.8	6.5	14.0	17.9	72.5
85	4,365	52.2	5.2	0.7	6.7	14.4	17.9	79.3
95	4,862	57.0	5.7	0.7	6.9	14.8	17.9	85.1
105	5,271	60.9	6.1	0.7	7.0	15.2	17.9	89.9
115	5,596	63.9	6.4	0.7	7.2	15.5	17.9	93.7
125	5,842	66.2	6.6	0.7	7.2	15.8	17.9	96.6

A32.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands on forest land after clearcut harvest in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	17.7	24.1	37.2	46.5
5	0.0	1.9	0.1	4.8	15.9	22.0	37.2	44.6
15	0.2	4.1	0.3	4.8	12.8	19.4	37.2	41.3
25	15.9	14.3	1.4	3.5	10.8	18.3	37.2	48.3
35	51.6	29.9	3.0	2.4	9.6	18.2	37.2	63.1
45	94.3	45.8	4.6	1.9	8.9	18.7	37.2	79.9
55	138.8	59.4	5.9	1.7	8.4	19.4	37.2	94.9
65	182.1	71.6	7.2	1.5	8.1	20.4	37.2	108.8
75	223.1	82.5	8.3	1.4	7.9	21.4	37.2	121.5
85	261.0	92.1	9.2	1.4	7.8	22.4	37.2	132.9
95	295.3	100.5	10.1	1.3	7.8	23.3	37.2	143.1
105	325.9	107.8	10.7	1.3	7.8	24.3	37.2	151.9
115	353.2	114.2	11.1	1.2	7.9	25.2	37.2	159.6
125	377.3	119.7	11.5	1.2	7.9	26.0	37.2	166.3
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	7.2	9.8	15.0	18.8
5	0	0.8	0.0	1.9	6.4	8.9	15.0	18.0
15	3	1.7	0.1	1.9	5.2	7.8	15.0	16.7
25	227	5.8	0.6	1.4	4.4	7.4	15.0	19.6
35	737	12.1	1.2	1.0	3.9	7.4	15.0	25.5
45	1,348	18.5	1.9	0.8	3.6	7.6	15.0	32.3
55	1,983	24.0	2.4	0.7	3.4	7.9	15.0	38.4
65	2,603	29.0	2.9	0.6	3.3	8.2	15.0	44.0
75	3,189	33.4	3.3	0.6	3.2	8.6	15.0	49.2
85	3,730	37.3	3.7	0.6	3.2	9.1	15.0	53.8
95	4,220	40.7	4.1	0.5	3.2	9.4	15.0	57.9
105	4,658	43.6	4.3	0.5	3.2	9.8	15.0	61.5
115	5,048	46.2	4.5	0.5	3.2	10.2	15.0	64.6
125	5,392	48.4	4.6	0.5	3.2	10.5	15.0	67.3

A33.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands on forest land after clearcut harvest in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	18.8	24.1	34.3	47.7
5	0.0	3.3	0.2	4.8	17.0	22.0	34.3	47.2
15	1.3	6.3	0.6	4.3	13.9	19.4	34.3	44.5
25	18.6	15.9	1.6	3.2	12.0	18.3	34.3	50.9
35	51.8	30.9	3.0	2.5	11.1	18.2	34.3	65.7
45	89.4	46.1	3.9	2.2	10.7	18.7	34.3	81.5
55	127.1	60.4	4.5	2.0	10.6	19.4	34.3	96.9
65	162.2	73.3	5.1	1.9	10.6	20.4	34.3	111.2
75	193.8	84.6	5.5	1.8	10.7	21.4	34.3	124.0
85	221.0	94.2	5.8	1.7	10.9	22.4	34.3	135.0
95	243.7	102.0	6.1	1.7	11.0	23.3	34.3	144.1
105	261.8	108.2	6.3	1.6	11.1	24.3	34.3	151.6
115	275.6	112.9	6.4	1.6	11.2	25.2	34.3	157.3
125	285.1	116.1	6.5	1.6	11.2	26.0	34.3	161.4
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	7.6	9.8	13.9	19.3
5	0	1.3	0.1	1.9	6.9	8.9	13.9	19.1
15	19	2.6	0.2	1.8	5.6	7.8	13.9	18.0
25	266	6.4	0.6	1.3	4.8	7.4	13.9	20.6
35	740	12.5	1.2	1.0	4.5	7.4	13.9	26.6
45	1,278	18.6	1.6	0.9	4.3	7.6	13.9	33.0
55	1,816	24.5	1.8	0.8	4.3	7.9	13.9	39.2
65	2,318	29.7	2.0	0.8	4.3	8.2	13.9	45.0
75	2,769	34.2	2.2	0.7	4.3	8.6	13.9	50.2
85	3,159	38.1	2.4	0.7	4.4	9.1	13.9	54.6
95	3,483	41.3	2.5	0.7	4.5	9.4	13.9	58.3
105	3,742	43.8	2.5	0.7	4.5	9.8	13.9	61.3
115	3,938	45.7	2.6	0.6	4.5	10.2	13.9	63.6
125	4,075	47.0	2.6	0.6	4.5	10.5	13.9	65.3

A34.— Regional estimates of timber volume and carbon stocks for aspen-birch stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	11.6	31.7	58.8	48.1
5	0.0	3.1	0.3	4.7	9.0	28.4	58.8	45.5
15	0.0	6.4	0.6	4.7	5.5	24.6	58.8	41.9
25	6.3	13.9	1.4	4.8	3.8	23.4	58.8	47.2
35	22.7	25.7	2.6	4.5	3.3	23.5	58.8	59.6
45	45.0	38.8	3.9	4.3	3.5	24.3	58.8	74.7
55	70.7	52.3	5.2	4.2	3.9	25.5	58.8	91.1
65	98.1	64.7	6.5	4.1	4.5	26.8	58.8	106.5
75	126.5	76.6	7.7	4.0	5.1	28.1	58.8	121.5
85	155.0	88.0	8.8	3.9	5.8	29.4	58.8	135.9
95	183.1	98.8	9.9	3.9	6.4	30.6	58.8	149.5
105	210.5	108.8	10.9	3.8	7.0	31.7	58.8	162.2
115	236.8	118.3	11.8	3.8	7.6	32.6	58.8	174.1
125	261.8	127.0	12.4	3.8	8.2	33.5	58.8	184.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	4.7	12.8	23.8	19.5
5	0	1.2	0.1	1.9	3.6	11.5	23.8	18.4
15	0	2.6	0.3	1.9	2.2	10.0	23.8	17.0
25	90	5.6	0.6	1.9	1.5	9.5	23.8	19.1
35	324	10.4	1.0	1.8	1.4	9.5	23.8	24.1
45	643	15.7	1.6	1.7	1.4	9.8	23.8	30.2
55	1,010	21.2	2.1	1.7	1.6	10.3	23.8	36.9
65	1,402	26.2	2.6	1.6	1.8	10.9	23.8	43.1
75	1,808	31.0	3.1	1.6	2.1	11.4	23.8	49.2
85	2,215	35.6	3.6	1.6	2.3	11.9	23.8	55.0
95	2,617	40.0	4.0	1.6	2.6	12.4	23.8	60.5
105	3,008	44.0	4.4	1.6	2.8	12.8	23.8	65.7
115	3,384	47.9	4.8	1.5	3.1	13.2	23.8	70.5
125	3,741	51.4	5.0	1.5	3.3	13.6	23.8	74.8

A35.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	17.0	37.2	30.9	59.0
5	0.0	2.6	0.3	4.8	15.3	35.4	30.9	58.4
15	1.6	7.2	0.7	4.8	12.6	32.9	30.9	58.3
25	15.3	19.8	2.0	4.4	11.1	31.8	30.9	68.9
35	39.1	37.2	3.7	2.0	10.4	31.6	30.9	84.9
45	66.2	54.6	5.5	1.2	10.2	32.0	30.9	103.5
55	93.9	71.6	7.2	0.9	10.3	32.7	30.9	122.7
65	120.8	85.9	8.6	0.7	10.4	33.6	30.9	139.2
75	146.1	98.8	9.9	0.6	10.6	34.6	30.9	154.5
85	169.5	110.3	11.0	0.6	10.9	35.6	30.9	168.4
95	190.7	120.6	12.1	0.6	11.1	36.6	30.9	180.9
105	209.8	129.5	12.9	0.6	11.4	37.5	30.9	192.0
115	227.0	137.5	13.3	0.7	11.7	38.4	30.9	201.6
125	242.3	144.4	13.8	0.7	12.0	39.2	30.9	210.1
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	6.9	15.1	12.5	23.9
5	0	1.1	0.1	2.0	6.2	14.3	12.5	23.6
15	23	2.9	0.3	2.0	5.1	13.3	12.5	23.6
25	219	8.0	0.8	1.8	4.5	12.9	12.5	27.9
35	559	15.0	1.5	0.8	4.2	12.8	12.5	34.4
45	946	22.1	2.2	0.5	4.1	12.9	12.5	41.9
55	1,342	29.0	2.9	0.4	4.2	13.2	12.5	49.6
65	1,726	34.8	3.5	0.3	4.2	13.6	12.5	56.3
75	2,088	40.0	4.0	0.2	4.3	14.0	12.5	62.5
85	2,422	44.7	4.5	0.2	4.4	14.4	12.5	68.1
95	2,726	48.8	4.9	0.2	4.5	14.8	12.5	73.2
105	2,999	52.4	5.2	0.3	4.6	15.2	12.5	77.7
115	3,244	55.6	5.4	0.3	4.7	15.5	12.5	81.6
125	3,463	58.5	5.6	0.3	4.9	15.8	12.5	85.0

A36.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	11.3	37.2	31.5	53.3
5	0.0	1.8	0.2	4.8	10.2	35.4	31.5	52.4
15	0.0	4.0	0.4	4.8	8.3	32.9	31.5	50.4
25	8.5	12.0	1.2	4.3	7.3	31.8	31.5	56.5
35	27.7	24.4	2.4	2.8	7.0	31.6	31.5	68.3
45	49.5	36.7	3.7	2.3	6.9	32.0	31.5	81.5
55	71.9	48.7	4.9	1.9	7.0	32.7	31.5	95.2
65	94.1	58.6	5.9	1.7	7.1	33.6	31.5	107.0
75	115.7	67.8	6.8	1.6	7.3	34.6	31.5	118.1
85	136.5	76.2	7.6	1.5	7.6	35.6	31.5	128.5
95	156.4	84.0	8.4	1.4	7.9	36.6	31.5	138.2
105	175.2	91.2	9.1	1.3	8.2	37.5	31.5	147.3
115	193.0	97.8	9.8	1.3	8.5	38.4	31.5	155.7
125	209.6	103.8	10.4	1.2	8.8	39.2	31.5	163.4
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	4.6	15.1	12.7	21.6
5	0	0.7	0.1	2.0	4.1	14.3	12.7	21.2
15	0	1.6	0.2	2.0	3.4	13.3	12.7	20.4
25	122	4.8	0.5	1.7	3.0	12.9	12.7	22.9
35	396	9.9	1.0	1.1	2.8	12.8	12.7	27.6
45	708	14.8	1.5	0.9	2.8	12.9	12.7	33.0
55	1,028	19.7	2.0	0.8	2.8	13.2	12.7	38.5
65	1,345	23.7	2.4	0.7	2.9	13.6	12.7	43.3
75	1,654	27.4	2.7	0.6	3.0	14.0	12.7	47.8
85	1,951	30.8	3.1	0.6	3.1	14.4	12.7	52.0
95	2,235	34.0	3.4	0.6	3.2	14.8	12.7	55.9
105	2,504	36.9	3.7	0.5	3.3	15.2	12.7	59.6
115	2,758	39.6	4.0	0.5	3.4	15.5	12.7	63.0
125	2,995	42.0	4.2	0.5	3.6	15.8	12.7	66.1

A37.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	10.8	24.1	27.0	39.7
5	0.0	2.1	0.2	4.8	9.8	22.0	27.0	38.9
15	0.0	4.3	0.4	4.8	8.1	19.4	27.0	37.0
25	5.0	9.2	0.9	4.8	7.0	18.3	27.0	40.1
35	18.3	16.9	1.7	3.4	6.5	18.2	27.0	46.6
45	37.0	25.9	2.6	2.5	6.4	18.7	27.0	56.0
55	58.5	34.1	3.4	2.0	6.4	19.4	27.0	65.4
65	81.2	42.0	4.2	1.7	6.6	20.4	27.0	74.9
75	104.1	49.5	4.9	1.5	6.8	21.4	27.0	84.1
85	126.7	56.4	5.6	1.4	7.1	22.4	27.0	92.9
95	148.3	62.8	6.3	1.3	7.4	23.3	27.0	101.1
105	168.6	68.6	6.9	1.2	7.7	24.3	27.0	108.6
115	187.3	73.8	7.4	1.1	8.0	25.2	27.0	115.5
125	204.1	78.3	7.8	1.1	8.3	26.0	27.0	121.5
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	4.4	9.8	10.9	16.1
5	0	0.9	0.1	1.9	4.0	8.9	10.9	15.7
15	0	1.7	0.2	1.9	3.3	7.8	10.9	15.0
25	71	3.7	0.4	1.9	2.8	7.4	10.9	16.2
35	262	6.8	0.7	1.4	2.6	7.4	10.9	18.9
45	529	10.5	1.0	1.0	2.6	7.6	10.9	22.7
55	836	13.8	1.4	0.8	2.6	7.9	10.9	26.5
65	1,160	17.0	1.7	0.7	2.7	8.2	10.9	30.3
75	1,488	20.0	2.0	0.6	2.7	8.6	10.9	34.0
85	1,810	22.8	2.3	0.6	2.9	9.1	10.9	37.6
95	2,120	25.4	2.5	0.5	3.0	9.4	10.9	40.9
105	2,410	27.8	2.8	0.5	3.1	9.8	10.9	44.0
115	2,677	29.8	3.0	0.5	3.2	10.2	10.9	46.7
125	2,917	31.7	3.2	0.4	3.4	10.5	10.9	49.2

A38.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	9.7	24.1	24.1	38.6
5	0.0	1.8	0.2	4.8	8.8	22.0	24.1	37.6
15	0.0	3.7	0.4	4.8	7.1	19.4	24.1	35.4
25	4.4	9.4	0.9	4.8	6.2	18.3	24.1	39.7
35	16.2	18.6	1.9	2.9	5.8	18.2	24.1	47.4
45	32.2	28.8	2.7	2.1	5.8	18.7	24.1	58.1
55	50.3	38.2	3.0	1.7	5.9	19.4	24.1	68.3
65	69.3	47.1	3.3	1.5	6.0	20.4	24.1	78.3
75	88.4	55.5	3.6	1.3	6.3	21.4	24.1	88.0
85	107.2	63.2	3.8	1.2	6.6	22.4	24.1	97.1
95	125.5	70.4	4.0	1.1	6.9	23.3	24.1	105.7
105	143.0	77.1	4.1	1.0	7.2	24.3	24.1	113.7
115	159.5	83.2	4.3	1.0	7.5	25.2	24.1	121.1
125	175.1	88.8	4.4	0.9	7.8	26.0	24.1	127.9
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	3.9	9.8	9.8	15.6
5	0	0.7	0.1	2.0	3.5	8.9	9.8	15.2
15	0	1.5	0.1	2.0	2.9	7.8	9.8	14.3
25	63	3.8	0.4	2.0	2.5	7.4	9.8	16.1
35	231	7.5	0.8	1.2	2.4	7.4	9.8	19.2
45	460	11.7	1.1	0.9	2.3	7.6	9.8	23.5
55	719	15.5	1.2	0.7	2.4	7.9	9.8	27.6
65	990	19.1	1.4	0.6	2.4	8.2	9.8	31.7
75	1,263	22.4	1.5	0.5	2.5	8.6	9.8	35.6
85	1,532	25.6	1.5	0.5	2.7	9.1	9.8	39.3
95	1,793	28.5	1.6	0.4	2.8	9.4	9.8	42.8
105	2,043	31.2	1.7	0.4	2.9	9.8	9.8	46.0
115	2,280	33.7	1.7	0.4	3.0	10.2	9.8	49.0
125	2,503	35.9	1.8	0.4	3.2	10.5	9.8	51.8

A39.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	9.9	12.2	72.9	26.3
5	0.0	11.1	0.7	4.0	8.4	6.5	72.9	30.6
10	19.1	22.6	1.3	3.6	7.5	6.4	72.9	41.4
15	36.7	31.3	1.6	3.4	6.8	7.5	72.9	50.7
20	60.4	40.8	1.9	3.2	6.6	8.7	72.9	61.2
25	85.5	50.3	2.1	3.1	6.5	9.8	72.9	71.9
30	108.7	58.2	2.3	3.1	6.6	10.7	72.9	80.8
35	131.2	65.6	2.4	3.0	6.7	11.5	72.9	89.3
40	152.3	72.5	2.5	3.0	6.9	12.2	72.9	97.1
45	172.3	78.9	2.7	2.9	7.2	12.7	72.9	104.4
50	191.4	85.0	2.7	2.9	7.5	13.2	72.9	111.3
55	208.4	90.3	2.8	2.9	7.8	13.7	72.9	117.4
60	223.9	95.1	2.9	2.8	8.1	14.1	72.9	122.9
65	238.4	99.6	2.9	2.8	8.3	14.4	72.9	128.1
70	252.9	104.0	3.0	2.8	8.6	14.7	72.9	133.2
75	264.6	107.6	3.0	2.8	8.9	15.0	72.9	137.3
80	277.1	111.4	3.1	2.8	9.1	15.2	72.9	141.6
85	289.5	115.1	3.1	2.8	9.4	15.5	72.9	145.9
90	299.6	118.2	3.2	2.7	9.6	15.7	72.9	149.4
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	4.0	4.9	29.5	10.7
5	0	4.5	0.3	1.6	3.4	2.6	29.5	12.4
10	273	9.2	0.5	1.4	3.0	2.6	29.5	16.8
15	525	12.7	0.7	1.4	2.8	3.0	29.5	20.5
20	863	16.5	0.8	1.3	2.7	3.5	29.5	24.8
25	1,222	20.4	0.9	1.3	2.6	4.0	29.5	29.1
30	1,554	23.5	0.9	1.2	2.7	4.3	29.5	32.7
35	1,875	26.6	1.0	1.2	2.7	4.7	29.5	36.1
40	2,177	29.3	1.0	1.2	2.8	4.9	29.5	39.3
45	2,462	31.9	1.1	1.2	2.9	5.2	29.5	42.3
50	2,736	34.4	1.1	1.2	3.0	5.4	29.5	45.1
55	2,978	36.5	1.1	1.2	3.1	5.5	29.5	47.5
60	3,200	38.5	1.2	1.1	3.3	5.7	29.5	49.8
65	3,407	40.3	1.2	1.1	3.4	5.8	29.5	51.8
70	3,614	42.1	1.2	1.1	3.5	6.0	29.5	53.9
75	3,782	43.5	1.2	1.1	3.6	6.1	29.5	55.6
80	3,960	45.1	1.3	1.1	3.7	6.2	29.5	57.3
85	4,138	46.6	1.3	1.1	3.8	6.3	29.5	59.1
90	4,281	47.8	1.3	1.1	3.9	6.3	29.5	60.5

A40.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the Southeast; volumes are for high-productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	20.4	12.2	72.9	36.8
5	0.0	11.0	0.7	4.0	15.9	6.5	72.9	38.0
10	47.7	31.9	1.4	3.8	12.9	6.4	72.9	56.3
15	146.5	67.4	1.9	3.7	11.4	7.5	72.9	91.9
20	244.8	102.3	2.1	3.7	10.5	8.7	72.9	127.3
25	315.2	124.2	2.3	3.7	9.7	9.8	72.9	149.7
30	347.3	134.1	2.4	3.7	8.8	10.7	72.9	159.7
35	351.5	135.4	2.4	3.7	8.0	11.5	72.9	160.9
40	355.0	136.5	2.4	3.7	7.3	12.2	72.9	161.9
45	358.5	137.5	2.4	3.6	6.8	12.7	72.9	163.1
50	362.0	138.6	2.4	3.6	6.4	13.2	72.9	164.3
55	362.0	138.6	2.4	3.6	6.1	13.7	72.9	164.4
60	362.0	138.6	2.4	3.6	5.9	14.1	72.9	164.6
65	362.0	138.6	2.4	3.6	5.7	14.4	72.9	164.8
70	362.0	138.6	2.4	3.6	5.6	14.7	72.9	164.9
75	362.0	138.6	2.4	3.6	5.5	15.0	72.9	165.1
80	362.0	138.6	2.4	3.6	5.4	15.2	72.9	165.3
85	362.0	138.6	2.4	3.6	5.4	15.5	72.9	165.5
90	362.0	138.6	2.4	3.6	5.3	15.7	72.9	165.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	8.3	4.9	29.5	14.9
5	0	4.5	0.3	1.6	6.4	2.6	29.5	15.4
10	682	12.9	0.6	1.6	5.2	2.6	29.5	22.8
15	2,094	27.3	0.8	1.5	4.6	3.0	29.5	37.2
20	3,498	41.4	0.9	1.5	4.3	3.5	29.5	51.5
25	4,504	50.3	0.9	1.5	3.9	4.0	29.5	60.6
30	4,963	54.3	1.0	1.5	3.6	4.3	29.5	64.6
35	5,024	54.8	1.0	1.5	3.2	4.7	29.5	65.1
40	5,074	55.2	1.0	1.5	3.0	4.9	29.5	65.5
45	5,124	55.7	1.0	1.5	2.8	5.2	29.5	66.0
50	5,174	56.1	1.0	1.5	2.6	5.4	29.5	66.5
55	5,174	56.1	1.0	1.5	2.5	5.5	29.5	66.5
60	5,174	56.1	1.0	1.5	2.4	5.7	29.5	66.6
65	5,174	56.1	1.0	1.5	2.3	5.8	29.5	66.7
70	5,174	56.1	1.0	1.5	2.3	6.0	29.5	66.8
75	5,174	56.1	1.0	1.5	2.2	6.1	29.5	66.8
80	5,174	56.1	1.0	1.5	2.2	6.2	29.5	66.9
85	5,174	56.1	1.0	1.5	2.2	6.3	29.5	67.0
90	5,174	56.1	1.0	1.5	2.2	6.3	29.5	67.0

A41.— Regional estimates of timber volume and carbon stocks for longleaf-slash pine stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	9.7	12.2	110.0	26.1
5	0.0	5.3	0.4	4.2	7.8	6.5	110.0	24.1
10	19.1	14.1	0.9	3.8	6.7	6.4	110.0	31.8
15	36.7	21.4	1.0	3.6	5.9	7.5	110.0	39.4
20	60.4	30.4	1.1	3.4	5.6	8.7	110.0	49.2
25	85.5	39.2	1.1	3.3	5.6	9.8	110.0	59.0
30	108.7	47.2	1.2	3.2	5.6	10.7	110.0	67.9
35	131.2	54.8	1.2	3.1	5.8	11.5	110.0	76.4
40	152.3	61.9	1.3	3.0	6.0	12.2	110.0	84.4
45	172.3	68.5	1.3	3.0	6.3	12.7	110.0	91.9
50	191.4	74.8	1.3	2.9	6.7	13.2	110.0	99.0
55	208.4	80.4	1.3	2.9	7.0	13.7	110.0	105.2
60	223.9	85.4	1.3	2.9	7.3	14.1	110.0	111.0
65	238.4	90.1	1.4	2.9	7.6	14.4	110.0	116.3
70	252.9	94.8	1.4	2.8	7.9	14.7	110.0	121.6
75	264.6	98.6	1.4	2.8	8.1	15.0	110.0	125.9
80	277.1	102.6	1.4	2.8	8.4	15.2	110.0	130.5
85	289.5	106.6	1.4	2.8	8.7	15.5	110.0	135.0
90	299.6	109.8	1.4	2.8	9.0	15.7	110.0	138.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	3.9	4.9	44.5	10.5
5	0	2.2	0.2	1.7	3.1	2.6	44.5	9.8
10	273	5.7	0.3	1.5	2.7	2.6	44.5	12.9
15	525	8.7	0.4	1.4	2.4	3.0	44.5	15.9
20	863	12.3	0.4	1.4	2.3	3.5	44.5	19.9
25	1,222	15.9	0.5	1.3	2.3	4.0	44.5	23.9
30	1,554	19.1	0.5	1.3	2.3	4.3	44.5	27.5
35	1,875	22.2	0.5	1.3	2.4	4.7	44.5	30.9
40	2,177	25.0	0.5	1.2	2.4	4.9	44.5	34.2
45	2,462	27.7	0.5	1.2	2.6	5.2	44.5	37.2
50	2,736	30.3	0.5	1.2	2.7	5.4	44.5	40.1
55	2,978	32.5	0.5	1.2	2.8	5.5	44.5	42.6
60	3,200	34.6	0.5	1.2	2.9	5.7	44.5	44.9
65	3,407	36.5	0.6	1.2	3.1	5.8	44.5	47.1
70	3,614	38.4	0.6	1.1	3.2	6.0	44.5	49.2
75	3,782	39.9	0.6	1.1	3.3	6.1	44.5	51.0
80	3,960	41.5	0.6	1.1	3.4	6.2	44.5	52.8
85	4,138	43.1	0.6	1.1	3.5	6.3	44.5	54.6
90	4,281	44.4	0.6	1.1	3.6	6.3	44.5	56.1

A42.— Regional estimates of timber volume and carbon stocks for longleaf-slash pine stands on forest land after clearcut harvest in the Southeast; volumes are for high-productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	21.1	12.2	110.0	37.4
5	0.0	8.8	0.4	4.0	16.3	6.5	110.0	36.0
10	47.7	27.2	0.8	3.9	13.1	6.4	110.0	51.3
15	146.5	60.1	0.8	3.8	11.4	7.5	110.0	83.5
20	244.8	91.2	0.9	3.7	10.3	8.7	110.0	114.8
25	315.2	113.5	0.9	3.7	9.5	9.8	110.0	137.3
30	347.3	122.8	0.9	3.7	8.5	10.7	110.0	146.6
35	351.5	124.0	0.9	3.7	7.6	11.5	110.0	147.7
40	355.0	125.0	0.9	3.7	6.9	12.2	110.0	148.7
45	358.5	126.0	0.9	3.7	6.4	12.7	110.0	149.8
50	362.0	127.0	0.9	3.7	6.0	13.2	110.0	150.9
55	362.0	127.0	0.9	3.7	5.7	13.7	110.0	151.0
60	362.0	127.0	0.9	3.7	5.5	14.1	110.0	151.2
65	362.0	127.0	0.9	3.7	5.3	14.4	110.0	151.3
70	362.0	127.0	0.9	3.7	5.2	14.7	110.0	151.5
75	362.0	127.0	0.9	3.7	5.1	15.0	110.0	151.7
80	362.0	127.0	0.9	3.7	5.0	15.2	110.0	151.9
85	362.0	127.0	0.9	3.7	4.9	15.5	110.0	152.0
90	362.0	127.0	0.9	3.7	4.9	15.7	110.0	152.2
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	8.5	4.9	44.5	15.2
5	0	3.6	0.2	1.6	6.6	2.6	44.5	14.6
10	682	11.0	0.3	1.6	5.3	2.6	44.5	20.8
15	2,094	24.3	0.3	1.5	4.6	3.0	44.5	33.8
20	3,498	36.9	0.4	1.5	4.2	3.5	44.5	46.5
25	4,504	45.9	0.4	1.5	3.8	4.0	44.5	55.6
30	4,963	49.7	0.4	1.5	3.5	4.3	44.5	59.3
35	5,024	50.2	0.4	1.5	3.1	4.7	44.5	59.8
40	5,074	50.6	0.4	1.5	2.8	4.9	44.5	60.2
45	5,124	51.0	0.4	1.5	2.6	5.2	44.5	60.6
50	5,174	51.4	0.4	1.5	2.4	5.4	44.5	61.1
55	5,174	51.4	0.4	1.5	2.3	5.5	44.5	61.1
60	5,174	51.4	0.4	1.5	2.2	5.7	44.5	61.2
65	5,174	51.4	0.4	1.5	2.2	5.8	44.5	61.2
70	5,174	51.4	0.4	1.5	2.1	6.0	44.5	61.3
75	5,174	51.4	0.4	1.5	2.1	6.1	44.5	61.4
80	5,174	51.4	0.4	1.5	2.0	6.2	44.5	61.5
85	5,174	51.4	0.4	1.5	2.0	6.3	44.5	61.5
90	5,174	51.4	0.4	1.5	2.0	6.3	44.5	61.6

A43.— Regional estimates of timber volume and carbon stocks for oak-gum-cypress stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	1.8	10.2	6.0	158.0	18.1
5	0.0	6.7	0.7	1.9	6.2	2.4	158.0	17.9
10	9.8	18.8	1.9	1.8	4.5	2.4	158.0	29.3
15	19.9	28.3	2.4	1.7	3.7	3.0	158.0	39.1
20	32.7	38.0	2.8	1.7	3.5	3.8	158.0	49.7
25	45.4	46.8	3.1	1.6	3.6	4.4	158.0	59.5
30	58.1	54.0	3.4	1.6	3.8	5.0	158.0	67.8
35	73.4	62.3	3.6	1.6	4.2	5.5	158.0	77.2
40	92.2	71.9	3.9	1.6	4.7	6.0	158.0	88.1
45	110.7	80.9	4.2	1.6	5.2	6.4	158.0	98.3
50	128.1	89.0	4.4	1.5	5.7	6.8	158.0	107.5
55	146.3	97.3	4.6	1.5	6.2	7.2	158.0	116.7
60	166.1	105.9	4.7	1.5	6.7	7.5	158.0	126.5
65	186.4	114.5	4.9	1.5	7.3	7.8	158.0	136.1
70	205.7	122.5	5.1	1.5	7.8	8.1	158.0	145.0
75	222.5	129.3	5.2	1.5	8.2	8.4	158.0	152.6
80	237.9	135.4	5.3	1.5	8.6	8.6	158.0	159.4
85	257.3	142.9	5.5	1.5	9.1	8.9	158.0	167.8
90	278.9	151.2	5.6	1.5	9.6	9.1	158.0	177.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.7	4.1	2.4	63.9	7.3
5	0	2.7	0.3	0.8	2.5	1.0	63.9	7.3
10	140	7.6	0.8	0.7	1.8	1.0	63.9	11.9
15	284	11.5	1.0	0.7	1.5	1.2	63.9	15.8
20	467	15.4	1.1	0.7	1.4	1.5	63.9	20.1
25	649	18.9	1.3	0.7	1.5	1.8	63.9	24.1
30	830	21.9	1.4	0.7	1.5	2.0	63.9	27.4
35	1,049	25.2	1.5	0.6	1.7	2.2	63.9	31.3
40	1,318	29.1	1.6	0.6	1.9	2.4	63.9	35.7
45	1,582	32.7	1.7	0.6	2.1	2.6	63.9	39.8
50	1,830	36.0	1.8	0.6	2.3	2.8	63.9	43.5
55	2,091	39.4	1.8	0.6	2.5	2.9	63.9	47.2
60	2,374	42.9	1.9	0.6	2.7	3.1	63.9	51.2
65	2,664	46.3	2.0	0.6	2.9	3.2	63.9	55.1
70	2,940	49.6	2.1	0.6	3.2	3.3	63.9	58.7
75	3,180	52.3	2.1	0.6	3.3	3.4	63.9	61.8
80	3,400	54.8	2.2	0.6	3.5	3.5	63.9	64.5
85	3,677	57.8	2.2	0.6	3.7	3.6	63.9	67.9
90	3,986	61.2	2.3	0.6	3.9	3.7	63.9	71.6

A44.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	10.8	6.0	45.3	21.0
5	0.0	8.1	0.8	4.2	6.7	2.4	45.3	22.1
10	11.7	21.0	2.1	3.8	4.8	2.4	45.3	34.0
15	21.2	30.3	2.5	3.5	3.8	3.0	45.3	43.1
20	33.8	40.0	2.8	3.3	3.5	3.8	45.3	53.4
25	46.6	49.5	3.0	3.2	3.6	4.4	45.3	63.8
30	60.2	57.5	3.2	3.1	3.8	5.0	45.3	72.6
35	76.3	66.6	3.4	3.0	4.2	5.5	45.3	82.7
40	94.3	76.2	3.6	2.9	4.6	6.0	45.3	93.5
45	114.1	86.4	3.8	2.9	5.2	6.4	45.3	104.7
50	133.0	95.8	4.0	2.8	5.7	6.8	45.3	115.2
55	151.4	104.8	4.1	2.8	6.2	7.2	45.3	125.1
60	168.9	113.0	4.2	2.7	6.7	7.5	45.3	134.2
65	185.6	120.8	4.3	2.7	7.2	7.8	45.3	142.8
70	201.5	128.0	4.4	2.7	7.6	8.1	45.3	150.8
75	215.7	134.4	4.5	2.6	8.0	8.4	45.3	157.9
80	229.4	140.5	4.6	2.6	8.3	8.6	45.3	164.6
85	242.5	146.2	4.6	2.6	8.7	8.9	45.3	171.0
90	254.1	151.3	4.7	2.6	9.0	9.1	45.3	176.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	4.4	2.4	18.3	8.5
5	0	3.3	0.3	1.7	2.7	1.0	18.3	9.0
10	167	8.5	0.8	1.5	1.9	1.0	18.3	13.8
15	303	12.3	1.0	1.4	1.5	1.2	18.3	17.4
20	483	16.2	1.1	1.3	1.4	1.5	18.3	21.6
25	666	20.1	1.2	1.3	1.5	1.8	18.3	25.8
30	860	23.3	1.3	1.3	1.5	2.0	18.3	29.4
35	1,091	26.9	1.4	1.2	1.7	2.2	18.3	33.5
40	1,348	30.8	1.5	1.2	1.9	2.4	18.3	37.8
45	1,630	35.0	1.5	1.2	2.1	2.6	18.3	42.4
50	1,901	38.8	1.6	1.1	2.3	2.8	18.3	46.6
55	2,164	42.4	1.7	1.1	2.5	2.9	18.3	50.6
60	2,414	45.7	1.7	1.1	2.7	3.1	18.3	54.3
65	2,652	48.9	1.7	1.1	2.9	3.2	18.3	57.8
70	2,880	51.8	1.8	1.1	3.1	3.3	18.3	61.0
75	3,082	54.4	1.8	1.1	3.2	3.4	18.3	63.9
80	3,278	56.8	1.8	1.1	3.4	3.5	18.3	66.6
85	3,465	59.2	1.9	1.0	3.5	3.6	18.3	69.2
90	3,632	61.2	1.9	1.0	3.6	3.7	18.3	71.5

A45.— Regional estimates of timber volume and carbon stocks for oak-pine stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	11.3	10.3	61.4	25.8
5	0.0	7.4	0.6	4.1	9.0	5.8	61.4	26.9
10	13.6	19.6	1.2	3.6	7.7	5.9	61.4	38.0
15	27.8	29.3	1.6	3.5	6.7	6.8	61.4	47.9
20	43.9	39.0	1.9	3.4	6.2	7.7	61.4	58.2
25	59.3	46.8	2.1	3.3	5.8	8.6	61.4	66.5
30	77.2	55.4	2.3	3.2	5.6	9.2	61.4	75.8
35	96.8	64.4	2.5	3.2	5.7	9.8	61.4	85.5
40	117.2	73.4	2.7	3.1	5.9	10.2	61.4	95.3
45	136.4	81.6	2.8	3.1	6.1	10.6	61.4	104.2
50	154.1	88.9	2.9	3.1	6.3	11.0	61.4	112.2
55	171.4	96.0	3.0	3.0	6.6	11.3	61.4	119.9
60	189.6	103.2	3.1	3.0	6.9	11.5	61.4	127.8
65	204.5	109.1	3.2	3.0	7.2	11.8	61.4	134.3
70	218.8	114.6	3.3	3.0	7.5	12.0	61.4	140.3
75	234.5	120.6	3.4	2.9	7.8	12.1	61.4	146.9
80	247.6	125.5	3.5	2.9	8.1	12.3	61.4	152.3
85	259.4	129.9	3.5	2.9	8.3	12.5	61.4	157.2
90	272.3	134.7	3.6	2.9	8.6	12.6	61.4	162.4
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	4.6	4.2	24.9	10.4
5	0	3.0	0.3	1.7	3.6	2.4	24.9	10.9
10	195	7.9	0.5	1.5	3.1	2.4	24.9	15.4
15	397	11.9	0.6	1.4	2.7	2.7	24.9	19.4
20	628	15.8	0.8	1.4	2.5	3.1	24.9	23.5
25	848	19.0	0.8	1.3	2.3	3.5	24.9	26.9
30	1,104	22.4	0.9	1.3	2.3	3.7	24.9	30.7
35	1,384	26.1	1.0	1.3	2.3	4.0	24.9	34.6
40	1,675	29.7	1.1	1.3	2.4	4.1	24.9	38.5
45	1,950	33.0	1.1	1.2	2.5	4.3	24.9	42.2
50	2,202	36.0	1.2	1.2	2.6	4.4	24.9	45.4
55	2,450	38.8	1.2	1.2	2.7	4.6	24.9	48.5
60	2,710	41.8	1.3	1.2	2.8	4.7	24.9	51.7
65	2,923	44.1	1.3	1.2	2.9	4.8	24.9	54.3
70	3,127	46.4	1.3	1.2	3.0	4.8	24.9	56.8
75	3,352	48.8	1.4	1.2	3.2	4.9	24.9	59.5
80	3,539	50.8	1.4	1.2	3.3	5.0	24.9	61.6
85	3,707	52.6	1.4	1.2	3.4	5.0	24.9	63.6
90	3,891	54.5	1.4	1.2	3.5	5.1	24.9	65.7

A46.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	11.2	6.0	49.9	21.4
5	0.0	8.6	0.9	4.9	7.0	2.4	49.9	23.7
10	11.7	18.3	1.8	4.1	4.9	2.4	49.9	31.5
15	21.2	27.0	2.7	3.7	3.9	3.0	49.9	40.3
20	33.8	36.3	3.3	3.5	3.6	3.8	49.9	50.3
25	46.6	45.1	3.6	3.3	3.7	4.4	49.9	60.0
30	60.2	53.8	3.8	3.2	4.0	5.0	49.9	69.7
35	76.3	63.3	4.1	3.1	4.4	5.5	49.9	80.4
40	94.3	73.3	4.4	2.9	5.0	6.0	49.9	91.6
45	114.1	83.8	4.6	2.9	5.6	6.4	49.9	103.4
50	133.0	95.1	4.8	2.8	6.4	6.8	49.9	115.9
55	151.4	104.2	5.0	2.7	7.0	7.2	49.9	126.0
60	168.9	112.7	5.1	2.7	7.5	7.5	49.9	135.5
65	185.6	120.7	5.3	2.6	8.0	7.8	49.9	144.5
70	201.5	128.4	5.4	2.6	8.5	8.1	49.9	153.0
75	215.7	135.1	5.5	2.6	9.0	8.4	49.9	160.6
80	229.4	141.6	5.6	2.5	9.4	8.6	49.9	167.8
85	242.5	147.8	5.7	2.5	9.8	8.9	49.9	174.7
90	254.1	153.4	5.8	2.5	10.2	9.1	49.9	180.9
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	4.5	2.4	20.2	8.7
5	0	3.5	0.3	2.0	2.8	1.0	20.2	9.6
10	167	7.4	0.7	1.7	2.0	1.0	20.2	12.7
15	303	10.9	1.1	1.5	1.6	1.2	20.2	16.3
20	483	14.7	1.3	1.4	1.5	1.5	20.2	20.4
25	666	18.3	1.4	1.3	1.5	1.8	20.2	24.3
30	860	21.8	1.6	1.3	1.6	2.0	20.2	28.2
35	1,091	25.6	1.7	1.2	1.8	2.2	20.2	32.5
40	1,348	29.7	1.8	1.2	2.0	2.4	20.2	37.1
45	1,630	33.9	1.9	1.2	2.3	2.6	20.2	41.8
50	1,901	38.5	1.9	1.1	2.6	2.8	20.2	46.9
55	2,164	42.2	2.0	1.1	2.8	2.9	20.2	51.0
60	2,414	45.6	2.1	1.1	3.0	3.1	20.2	54.8
65	2,652	48.9	2.1	1.1	3.3	3.2	20.2	58.5
70	2,880	52.0	2.2	1.0	3.5	3.3	20.2	61.9
75	3,082	54.7	2.2	1.0	3.6	3.4	20.2	65.0
80	3,278	57.3	2.3	1.0	3.8	3.5	20.2	67.9
85	3,465	59.8	2.3	1.0	4.0	3.6	20.2	70.7
90	3,632	62.1	2.3	1.0	4.1	3.7	20.2	73.2

A47.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	9.2	12.2	41.9	25.6
5	0.0	10.8	0.7	4.7	7.7	6.5	41.9	30.3
10	19.1	23.1	1.3	3.9	6.8	6.4	41.9	41.5
15	36.7	32.4	1.6	3.5	6.2	7.5	41.9	51.2
20	60.4	42.2	1.8	3.3	5.9	8.7	41.9	61.9
25	85.5	52.0	2.0	3.1	5.8	9.8	41.9	72.8
30	108.7	59.6	2.1	3.0	5.8	10.7	41.9	81.2
35	131.2	66.6	2.3	2.9	5.9	11.5	41.9	89.1
40	152.3	73.1	2.3	2.9	6.0	12.2	41.9	96.4
45	172.3	79.0	2.4	2.8	6.1	12.7	41.9	103.1
50	191.4	84.7	2.5	2.8	6.4	13.2	41.9	109.5
55	208.4	89.6	2.6	2.7	6.5	13.7	41.9	115.1
60	223.9	94.0	2.6	2.7	6.7	14.1	41.9	120.1
65	238.4	98.1	2.7	2.6	7.0	14.4	41.9	124.8
70	252.9	102.2	2.7	2.6	7.2	14.7	41.9	129.4
75	264.6	105.5	2.7	2.6	7.3	15.0	41.9	133.1
80	277.1	108.9	2.8	2.6	7.6	15.2	41.9	137.0
85	289.5	112.3	2.8	2.6	7.8	15.5	41.9	140.9
90	299.6	115.1	2.8	2.5	7.9	15.7	41.9	144.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	3.7	4.9	17.0	10.4
5	0	4.4	0.3	1.9	3.1	2.6	17.0	12.3
10	273	9.4	0.5	1.6	2.8	2.6	17.0	16.8
15	525	13.1	0.6	1.4	2.5	3.0	17.0	20.7
20	863	17.1	0.7	1.3	2.4	3.5	17.0	25.1
25	1,222	21.1	0.8	1.3	2.4	4.0	17.0	29.5
30	1,554	24.1	0.9	1.2	2.3	4.3	17.0	32.9
35	1,875	27.0	0.9	1.2	2.4	4.7	17.0	36.1
40	2,177	29.6	0.9	1.2	2.4	4.9	17.0	39.0
45	2,462	32.0	1.0	1.1	2.5	5.2	17.0	41.7
50	2,736	34.3	1.0	1.1	2.6	5.4	17.0	44.3
55	2,978	36.3	1.0	1.1	2.7	5.5	17.0	46.6
60	3,200	38.1	1.1	1.1	2.7	5.7	17.0	48.6
65	3,407	39.7	1.1	1.1	2.8	5.8	17.0	50.5
70	3,614	41.4	1.1	1.1	2.9	6.0	17.0	52.4
75	3,782	42.7	1.1	1.1	3.0	6.1	17.0	53.9
80	3,960	44.1	1.1	1.0	3.1	6.2	17.0	55.5
85	4,138	45.5	1.1	1.0	3.1	6.3	17.0	57.0
90	4,281	46.6	1.1	1.0	3.2	6.3	17.0	58.3

A48.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the South Central; volumes are for high-productivity sites (growth rate greater than 120 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	20.4	12.2	41.9	36.7
5	0.0	10.8	0.4	4.1	15.8	6.5	41.9	37.6
10	47.7	34.2	0.9	3.9	13.0	6.4	41.9	58.3
15	146.5	68.7	1.0	3.8	11.5	7.5	41.9	92.5
20	244.8	99.2	1.1	3.7	10.5	8.7	41.9	123.2
25	315.2	118.3	1.1	3.7	9.6	9.8	41.9	142.6
30	347.3	126.8	1.1	3.7	8.7	10.7	41.9	151.1
35	351.5	127.9	1.1	3.7	7.8	11.5	41.9	152.1
40	355.0	128.8	1.1	3.7	7.2	12.2	41.9	153.0
45	358.5	129.8	1.1	3.7	6.7	12.7	41.9	154.0
50	362.0	130.7	1.1	3.7	6.3	13.2	41.9	155.0
55	362.0	130.7	1.1	3.7	6.0	13.7	41.9	155.2
60	362.0	130.7	1.1	3.7	5.8	14.1	41.9	155.3
65	362.0	130.7	1.1	3.7	5.6	14.4	41.9	155.5
70	362.0	130.7	1.1	3.7	5.5	14.7	41.9	155.7
75	362.0	130.7	1.1	3.7	5.4	15.0	41.9	155.9
80	362.0	130.7	1.1	3.7	5.3	15.2	41.9	156.0
85	362.0	130.7	1.1	3.7	5.2	15.5	41.9	156.2
90	362.0	130.7	1.1	3.7	5.2	15.7	41.9	156.4
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	8.2	4.9	17.0	14.9
5	0	4.4	0.2	1.6	6.4	2.6	17.0	15.2
10	682	13.8	0.3	1.6	5.2	2.6	17.0	23.6
15	2,094	27.8	0.4	1.5	4.6	3.0	17.0	37.4
20	3,498	40.1	0.4	1.5	4.2	3.5	17.0	49.9
25	4,504	47.9	0.4	1.5	3.9	4.0	17.0	57.7
30	4,963	51.3	0.5	1.5	3.5	4.3	17.0	61.1
35	5,024	51.8	0.5	1.5	3.2	4.7	17.0	61.6
40	5,074	52.1	0.5	1.5	2.9	4.9	17.0	61.9
45	5,124	52.5	0.5	1.5	2.7	5.2	17.0	62.3
50	5,174	52.9	0.5	1.5	2.6	5.4	17.0	62.7
55	5,174	52.9	0.5	1.5	2.4	5.5	17.0	62.8
60	5,174	52.9	0.5	1.5	2.3	5.7	17.0	62.9
65	5,174	52.9	0.5	1.5	2.3	5.8	17.0	62.9
70	5,174	52.9	0.5	1.5	2.2	6.0	17.0	63.0
75	5,174	52.9	0.5	1.5	2.2	6.1	17.0	63.1
80	5,174	52.9	0.5	1.5	2.1	6.2	17.0	63.1
85	5,174	52.9	0.5	1.5	2.1	6.3	17.0	63.2
90	5,174	52.9	0.5	1.5	2.1	6.3	17.0	63.3

A49.— Regional estimates of timber volume and carbon stocks for oak-gum-cypress stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	1.8	10.8	6.0	52.8	18.6
5	0.0	5.4	0.5	2.1	6.5	2.4	52.8	16.9
10	9.8	17.8	1.8	1.8	4.6	2.4	52.8	28.4
15	19.9	28.4	2.8	1.7	3.8	3.0	52.8	39.8
20	32.7	39.3	3.2	1.7	3.6	3.8	52.8	51.6
25	45.4	48.8	3.4	1.6	3.7	4.4	52.8	61.9
30	58.1	57.2	3.5	1.6	4.0	5.0	52.8	71.2
35	73.4	66.9	3.6	1.6	4.4	5.5	52.8	82.1
40	92.2	76.9	3.7	1.6	5.0	6.0	52.8	93.1
45	110.7	86.1	3.7	1.5	5.5	6.4	52.8	103.4
50	128.1	94.4	3.8	1.5	6.0	6.8	52.8	112.6
55	146.3	102.8	3.9	1.5	6.5	7.2	52.8	121.9
60	166.1	111.6	3.9	1.5	7.1	7.5	52.8	131.6
65	186.4	120.3	4.0	1.5	7.6	7.8	52.8	141.2
70	205.7	128.3	4.0	1.5	8.1	8.1	52.8	150.1
75	222.5	135.1	4.1	1.5	8.5	8.4	52.8	157.6
80	237.9	141.2	4.1	1.5	8.9	8.6	52.8	164.4
85	257.3	148.8	4.1	1.5	9.4	8.9	52.8	172.6
90	278.9	157.0	4.2	1.4	9.9	9.1	52.8	181.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.7	4.4	2.4	21.4	7.5
5	0	2.2	0.2	0.8	2.6	1.0	21.4	6.9
10	140	7.2	0.7	0.7	1.9	1.0	21.4	11.5
15	284	11.5	1.1	0.7	1.5	1.2	21.4	16.1
20	467	15.9	1.3	0.7	1.5	1.5	21.4	20.9
25	649	19.7	1.4	0.7	1.5	1.8	21.4	25.1
30	830	23.1	1.4	0.7	1.6	2.0	21.4	28.8
35	1,049	27.1	1.4	0.6	1.8	2.2	21.4	33.2
40	1,318	31.1	1.5	0.6	2.0	2.4	21.4	37.7
45	1,582	34.9	1.5	0.6	2.2	2.6	21.4	41.8
50	1,830	38.2	1.5	0.6	2.4	2.8	21.4	45.6
55	2,091	41.6	1.6	0.6	2.6	2.9	21.4	49.3
60	2,374	45.2	1.6	0.6	2.9	3.1	21.4	53.3
65	2,664	48.7	1.6	0.6	3.1	3.2	21.4	57.1
70	2,940	51.9	1.6	0.6	3.3	3.3	21.4	60.7
75	3,180	54.7	1.6	0.6	3.5	3.4	21.4	63.8
80	3,400	57.2	1.7	0.6	3.6	3.5	21.4	66.5
85	3,677	60.2	1.7	0.6	3.8	3.6	21.4	69.9
90	3,986	63.5	1.7	0.6	4.0	3.7	21.4	73.5

A50.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	11.7	6.0	38.6	21.8
5	0.0	9.7	0.9	4.7	7.3	2.4	38.6	25.0
10	11.7	20.9	1.9	4.0	5.2	2.4	38.6	34.3
15	21.2	30.1	2.1	3.6	4.2	3.0	38.6	43.0
20	33.8	39.5	2.3	3.4	3.9	3.8	38.6	52.9
25	46.6	48.2	2.4	3.3	3.9	4.4	38.6	62.2
30	60.2	56.6	2.6	3.1	4.2	5.0	38.6	71.4
35	76.3	65.6	2.7	3.0	4.6	5.5	38.6	81.4
40	94.3	76.2	2.8	2.9	5.2	6.0	38.6	93.1
45	114.1	85.7	2.9	2.8	5.8	6.4	38.6	103.7
50	133.0	94.7	3.0	2.8	6.3	6.8	38.6	113.6
55	151.4	103.3	3.0	2.7	6.9	7.2	38.6	123.1
60	168.9	111.3	3.1	2.7	7.4	7.5	38.6	132.0
65	185.6	118.8	3.2	2.6	7.9	7.8	38.6	140.4
70	201.5	126.0	3.2	2.6	8.4	8.1	38.6	148.3
75	215.7	132.3	3.2	2.6	8.8	8.4	38.6	155.3
80	229.4	138.3	3.3	2.5	9.2	8.6	38.6	162.0
85	242.5	144.0	3.3	2.5	9.6	8.9	38.6	168.3
90	254.1	149.1	3.3	2.5	9.9	9.1	38.6	174.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	4.7	2.4	15.6	8.8
5	0	3.9	0.4	1.9	2.9	1.0	15.6	10.1
10	167	8.5	0.8	1.6	2.1	1.0	15.6	13.9
15	303	12.2	0.9	1.5	1.7	1.2	15.6	17.4
20	483	16.0	0.9	1.4	1.6	1.5	15.6	21.4
25	666	19.5	1.0	1.3	1.6	1.8	15.6	25.2
30	860	22.9	1.0	1.3	1.7	2.0	15.6	28.9
35	1,091	26.6	1.1	1.2	1.9	2.2	15.6	33.0
40	1,348	30.8	1.1	1.2	2.1	2.4	15.6	37.7
45	1,630	34.7	1.2	1.2	2.3	2.6	15.6	41.9
50	1,901	38.3	1.2	1.1	2.6	2.8	15.6	46.0
55	2,164	41.8	1.2	1.1	2.8	2.9	15.6	49.8
60	2,414	45.0	1.3	1.1	3.0	3.1	15.6	53.4
65	2,652	48.1	1.3	1.1	3.2	3.2	15.6	56.8
70	2,880	51.0	1.3	1.1	3.4	3.3	15.6	60.0
75	3,082	53.5	1.3	1.0	3.6	3.4	15.6	62.8
80	3,278	56.0	1.3	1.0	3.7	3.5	15.6	65.6
85	3,465	58.3	1.3	1.0	3.9	3.6	15.6	68.1
90	3,632	60.3	1.4	1.0	4.0	3.7	15.6	70.4

A51.— Regional estimates of timber volume and carbon stocks for oak-pine stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	12.4	10.3	41.7	26.9
5	0.0	8.7	0.7	4.4	10.0	5.8	41.7	29.6
10	13.6	21.4	1.4	3.7	8.6	5.9	41.7	41.0
15	27.8	31.9	1.7	3.5	7.7	6.8	41.7	51.5
20	43.9	41.8	2.0	3.3	7.1	7.7	41.7	61.9
25	59.3	50.9	2.2	3.2	6.7	8.6	41.7	71.6
30	77.2	59.2	2.5	3.1	6.6	9.2	41.7	80.6
35	96.8	67.9	2.6	3.0	6.7	9.8	41.7	90.0
40	117.2	76.5	2.8	2.9	6.9	10.2	41.7	99.4
45	136.4	84.4	3.0	2.9	7.1	10.6	41.7	108.0
50	154.1	91.4	3.1	2.8	7.4	11.0	41.7	115.7
55	171.4	98.2	3.2	2.8	7.7	11.3	41.7	123.2
60	189.6	105.2	3.3	2.8	8.0	11.5	41.7	130.8
65	204.5	110.7	3.4	2.7	8.3	11.8	41.7	137.0
70	218.8	116.0	3.5	2.7	8.6	12.0	41.7	142.8
75	234.5	121.8	3.6	2.7	9.0	12.1	41.7	149.2
80	247.6	126.5	3.6	2.7	9.3	12.3	41.7	154.4
85	259.4	130.7	3.7	2.7	9.6	12.5	41.7	159.0
90	272.3	135.2	3.8	2.6	9.9	12.6	41.7	164.1
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	5.0	4.2	16.9	10.9
5	0	3.5	0.3	1.8	4.0	2.4	16.9	12.0
10	195	8.6	0.6	1.5	3.5	2.4	16.9	16.6
15	397	12.9	0.7	1.4	3.1	2.7	16.9	20.9
20	628	16.9	0.8	1.3	2.9	3.1	16.9	25.0
25	848	20.6	0.9	1.3	2.7	3.5	16.9	29.0
30	1,104	24.0	1.0	1.2	2.7	3.7	16.9	32.6
35	1,384	27.5	1.1	1.2	2.7	4.0	16.9	36.4
40	1,675	31.0	1.1	1.2	2.8	4.1	16.9	40.2
45	1,950	34.2	1.2	1.2	2.9	4.3	16.9	43.7
50	2,202	37.0	1.3	1.2	3.0	4.4	16.9	46.8
55	2,450	39.7	1.3	1.1	3.1	4.6	16.9	49.9
60	2,710	42.6	1.3	1.1	3.3	4.7	16.9	52.9
65	2,923	44.8	1.4	1.1	3.4	4.8	16.9	55.4
70	3,127	47.0	1.4	1.1	3.5	4.8	16.9	57.8
75	3,352	49.3	1.4	1.1	3.6	4.9	16.9	60.4
80	3,539	51.2	1.5	1.1	3.8	5.0	16.9	62.5
85	3,707	52.9	1.5	1.1	3.9	5.0	16.9	64.4
90	3,891	54.7	1.5	1.1	4.0	5.1	16.9	66.4

APPENDIX B

Forest Ecosystem Yield Tables for Afforestation (Establishment on Nonforest Land)[2]

Carbon Stocks with Afforestation of Land

[2] Note carbon mass is in metric tons (tonnes) in all tables.

B1.— Regional estimates of timber volume and carbon stocks for aspen-birch stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	0.0	0.0	65.6	2.0
5	0.0	6.6	0.6	2.2	0.5	1.6	65.8	11.5
15	12.9	21.3	1.8	2.1	1.7	4.0	67.4	30.9
25	33.8	36.0	2.9	2.1	2.8	5.8	70.4	49.6
35	58.4	50.1	3.8	2.1	3.9	7.3	74.0	67.1
45	84.7	62.7	4.6	2.1	4.9	8.4	77.7	82.6
55	112.4	75.1	5.3	2.0	5.8	9.3	80.9	97.6
65	141.7	87.5	5.9	2.0	6.8	10.1	83.4	112.3
75	172.6	100.0	6.5	2.0	7.8	10.7	85.1	127.1
85	205.0	112.7	7.1	2.0	8.8	11.3	86.2	141.9
95	238.9	125.5	7.7	2.0	9.8	11.8	86.8	156.7
105	274.4	138.5	8.2	2.0	10.8	12.2	87.1	171.7
115	311.4	151.7	8.8	2.0	11.8	12.5	87.3	186.8
125	349.9	165.0	9.3	2.0	12.8	12.9	87.4	202.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	26.5	0.8
5	0	2.7	0.2	0.9	0.2	0.6	26.6	4.7
15	184	8.6	0.7	0.9	0.7	1.6	27.3	12.5
25	483	14.6	1.2	0.8	1.1	2.4	28.5	20.1
35	835	20.3	1.5	0.8	1.6	2.9	30.0	27.2
45	1,210	25.4	1.9	0.8	2.0	3.4	31.4	33.4
55	1,607	30.4	2.1	0.8	2.4	3.8	32.7	39.5
65	2,025	35.4	2.4	0.8	2.8	4.1	33.7	45.5
75	2,466	40.5	2.6	0.8	3.1	4.3	34.4	51.4
85	2,929	45.6	2.9	0.8	3.5	4.6	34.9	57.4
95	3,414	50.8	3.1	0.8	3.9	4.8	35.1	63.4
105	3,921	56.0	3.3	0.8	4.4	4.9	35.3	69.5
115	4,450	61.4	3.5	0.8	4.8	5.1	35.3	75.6
125	5,001	66.8	3.8	0.8	5.2	5.2	35.4	81.8

B2.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	52.2	2.1
5	0.0	7.4	0.7	2.1	0.5	4.2	52.3	15.0
15	28.0	31.8	3.2	1.9	2.3	10.8	53.7	50.0
25	58.1	53.2	5.3	1.8	3.8	15.8	56.0	79.8
35	89.6	72.8	6.0	1.7	5.2	19.7	58.9	105.4
45	119.1	87.8	6.6	1.7	6.2	22.7	61.8	125.0
55	146.6	101.1	7.0	1.7	7.2	25.3	64.4	142.3
65	172.1	113.1	7.4	1.7	8.0	27.4	66.3	157.5
75	195.6	123.8	7.7	1.7	8.8	29.1	67.7	171.1
85	217.1	133.5	7.9	1.7	9.5	30.7	68.6	183.2
95	236.6	142.1	8.1	1.7	10.1	32.0	69.1	193.9
105	254.1	149.7	8.3	1.6	10.6	33.1	69.3	203.4
115	269.7	156.3	8.5	1.6	11.1	34.2	69.5	211.7
125	283.2	162.1	8.6	1.6	11.5	35.1	69.5	218.8
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	21.1	0.8
5	0	3.0	0.3	0.8	0.2	1.7	21.2	6.1
15	400	12.9	1.3	0.8	0.9	4.4	21.7	20.2
25	830	21.5	2.1	0.7	1.5	6.4	22.7	32.3
35	1,280	29.5	2.4	0.7	2.1	8.0	23.8	42.7
45	1,702	35.5	2.7	0.7	2.5	9.2	25.0	50.6
55	2,095	40.9	2.8	0.7	2.9	10.2	26.0	57.6
65	2,460	45.8	3.0	0.7	3.2	11.1	26.8	63.7
75	2,796	50.1	3.1	0.7	3.5	11.8	27.4	69.2
85	3,103	54.0	3.2	0.7	3.8	12.4	27.8	74.1
95	3,382	57.5	3.3	0.7	4.1	12.9	28.0	78.5
105	3,632	60.6	3.4	0.7	4.3	13.4	28.1	82.3
115	3,854	63.3	3.4	0.7	4.5	13.8	28.1	85.7
125	4,047	65.6	3.5	0.7	4.6	14.2	28.1	88.6

B3.— Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	------- *tonnes carbon/hectare* -------						
0	0.0	0.0	0.0	2.1	0.0	0.0	39.8	2.1
5	0.0	6.9	0.7	2.1	0.5	0.9	39.9	11.0
15	54.5	43.0	3.6	1.9	2.9	2.5	40.9	54.0
25	95.7	71.9	4.0	1.9	4.9	3.9	42.7	86.6
35	135.3	96.2	4.2	1.8	6.6	5.2	44.9	114.0
45	173.3	118.2	4.5	1.8	8.1	6.3	47.2	138.8
55	209.6	136.8	4.6	1.8	9.4	7.2	49.1	159.8
65	244.3	154.3	4.8	1.8	10.6	8.1	50.6	179.5
75	277.4	170.6	4.9	1.8	11.7	8.9	51.7	197.9
85	308.9	186.0	5.0	1.8	12.7	9.7	52.3	215.1
95	338.8	200.4	5.1	1.8	13.7	10.3	52.7	231.3
105	367.1	213.9	5.1	1.7	14.6	10.9	52.9	246.4
115	393.7	226.5	5.2	1.7	15.5	11.5	53.0	260.5
125	418.6	238.2	5.3	1.7	16.3	12.0	53.1	273.6
years	*ft³/acre*	------- *tonnes carbon/acre* -------						
0	0	0.0	0.0	0.8	0.0	0.0	16.1	0.8
5	0	2.8	0.3	0.8	0.2	0.4	16.2	4.5
15	779	17.4	1.4	0.8	1.2	1.0	16.6	21.8
25	1,904	29.1	1.6	0.7	2.0	1.6	17.3	35.0
35	1,934	38.9	1.7	0.7	2.7	2.1	18.2	46.1
45	2,477	47.8	1.8	0.7	3.3	2.5	19.1	56.2
55	2,996	55.4	1.9	0.7	3.8	2.9	19.9	64.7
65	3,492	62.4	1.9	0.7	4.3	3.3	20.5	72.6
75	3,965	69.1	2.0	0.7	4.7	3.6	20.9	80.1
85	4,415	75.3	2.0	0.7	5.1	3.9	21.2	87.1
95	4,842	81.1	2.0	0.7	5.5	4.2	21.3	93.6
105	5,246	86.6	2.1	0.7	5.9	4.4	21.4	99.7
115	5,626	91.7	2.1	0.7	6.3	4.7	21.5	105.4
125	5,983	96.4	2.1	0.7	6.6	4.9	21.5	110.7

B4.— Regional estimates of timber volume and carbon stocks for oak-pine stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	50.2	4.2
5	0.0	6.2	0.6	4.2	0.4	3.8	50.3	15.2
15	36.5	27.0	2.6	3.3	1.7	10.3	51.6	44.9
25	70.9	48.6	3.2	2.9	3.0	15.6	53.9	73.3
35	103.1	67.9	3.7	2.6	4.2	19.9	56.6	98.3
45	133.1	84.7	4.0	2.5	5.2	23.5	59.5	119.8
55	160.9	99.1	4.2	2.4	6.1	26.6	61.9	138.4
65	186.7	113.0	4.4	2.3	6.9	29.2	63.8	155.8
75	210.2	123.6	4.6	2.3	7.6	31.6	65.1	169.5
85	231.5	133.1	4.7	2.3	8.1	33.6	66.0	181.8
95	250.8	141.7	4.8	2.2	8.7	35.4	66.4	192.8
105	267.9	149.2	4.9	2.2	9.1	37.0	66.7	202.4
115	282.7	155.7	5.0	2.2	9.5	38.4	66.8	210.9
125	295.4	161.3	5.1	2.2	9.9	39.7	66.9	218.1
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	20.3	1.7
5	0	2.5	0.3	1.7	0.2	1.6	20.4	6.2
15	522	10.9	1.1	1.3	0.7	4.2	20.9	18.2
25	1,013	19.7	1.3	1.2	1.2	6.3	21.8	29.6
35	1,473	27.5	1.5	1.1	1.7	8.0	22.9	39.8
45	1,902	34.3	1.6	1.0	2.1	9.5	24.1	48.5
55	2,300	40.1	1.7	1.0	2.5	10.8	25.1	56.0
65	2,668	45.7	1.8	0.9	2.8	11.8	25.8	63.1
75	3,004	50.0	1.8	0.9	3.1	12.8	26.4	68.6
85	3,309	53.9	1.9	0.9	3.3	13.6	26.7	73.6
95	3,584	57.3	1.9	0.9	3.5	14.3	26.9	78.0
105	3,828	60.4	2.0	0.9	3.7	15.0	27.0	81.9
115	4,040	63.0	2.0	0.9	3.9	15.6	27.0	85.3
125	4,222	65.3	2.1	0.9	4.0	16.1	27.1	88.3

B5.— Regional estimates of timber volume and carbon stocks for spruce-balsam fir stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	73.5	2.1
5	0.0	7.0	0.7	1.8	0.6	5.0	73.7	15.1
15	11.5	20.1	2.0	1.6	1.9	13.0	75.6	38.5
25	29.1	32.5	3.3	1.5	3.0	19.0	78.9	59.3
35	51.6	45.7	4.6	1.4	4.2	23.7	83.0	79.7
45	76.9	57.4	5.7	1.4	5.3	27.5	87.1	97.4
55	102.6	68.7	6.9	1.4	6.3	30.7	90.7	113.9
65	126.4	78.6	7.4	1.3	7.3	33.3	93.5	127.9
75	149.3	87.9	7.6	1.3	8.1	35.5	95.4	140.5
85	170.9	96.5	7.8	1.3	8.9	37.4	96.6	152.0
95	191.6	104.5	8.0	1.3	9.6	39.1	97.3	162.5
105	211.1	111.9	8.2	1.3	10.3	40.6	97.7	172.2
115	229.6	118.8	8.3	1.3	11.0	41.9	97.9	181.2
125	247.1	125.3	8.4	1.3	11.6	43.0	97.9	189.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	0.0	0.0	29.7	0.9
5	0	2.8	0.3	0.7	0.3	2.0	29.8	6.1
15	164	8.1	0.8	0.6	0.8	5.2	30.6	15.6
25	416	13.2	1.3	0.6	1.2	7.7	31.9	24.0
35	738	18.5	1.9	0.6	1.7	9.6	33.6	32.2
45	1,099	23.2	2.3	0.6	2.1	11.1	35.2	39.4
55	1,466	27.8	2.8	0.6	2.6	12.4	36.7	46.1
65	1,807	31.8	3.0	0.5	2.9	13.5	37.8	51.8
75	2,133	35.6	3.1	0.5	3.3	14.4	38.6	56.9
85	2,443	39.0	3.2	0.5	3.6	15.2	39.1	61.5
95	2,738	42.3	3.2	0.5	3.9	15.8	39.4	65.8
105	3,017	45.3	3.3	0.5	4.2	16.4	39.5	69.7
115	3,281	48.1	3.4	0.5	4.4	16.9	39.6	73.3
125	3,532	50.7	3.4	0.5	4.7	17.4	39.6	76.7

B6.— Regional estimates of timber volume and carbon stocks for white-red-jack pine stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	58.6	2.1
5	0.0	7.3	0.7	2.2	0.4	3.1	58.8	13.8
15	30.0	28.6	2.9	1.8	1.6	7.1	60.3	41.9
25	54.4	44.7	3.9	1.8	2.5	9.4	62.9	62.3
35	77.9	57.7	4.3	1.7	3.2	11.0	66.2	77.9
45	100.6	69.4	4.6	1.7	3.8	12.2	69.4	91.7
55	122.5	78.7	4.8	1.6	4.3	13.0	72.3	102.5
65	142.3	86.8	5.0	1.6	4.8	13.7	74.5	111.9
75	160.9	94.3	5.2	1.6	5.2	14.2	76.1	120.5
85	178.4	101.2	5.3	1.6	5.6	14.7	77.0	128.4
95	194.7	107.6	5.4	1.6	5.9	15.0	77.6	135.6
105	210.0	113.5	5.5	1.6	6.3	15.4	77.9	142.2
115	224.1	118.9	5.6	1.6	6.6	15.6	78.0	148.2
125	237.1	123.8	5.7	1.6	6.8	15.9	78.1	153.8
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	23.7	0.8
5	0	3.0	0.3	0.9	0.2	1.3	23.8	5.6
15	429	11.6	1.2	0.7	0.6	2.9	24.4	17.0
25	777	18.1	1.6	0.7	1.0	3.8	25.5	25.2
35	1,113	23.3	1.7	0.7	1.3	4.5	26.8	31.5
45	1,438	28.1	1.9	0.7	1.5	4.9	28.1	37.1
55	1,751	31.8	2.0	0.7	1.8	5.3	29.3	41.5
65	2,034	35.1	2.0	0.7	1.9	5.5	30.2	45.3
75	2,300	38.2	2.1	0.7	2.1	5.8	30.8	48.8
85	2,550	41.0	2.1	0.6	2.3	5.9	31.2	52.0
95	2,783	43.5	2.2	0.6	2.4	6.1	31.4	54.9
105	3,001	45.9	2.2	0.6	2.5	6.2	31.5	57.6
115	3,202	48.1	2.3	0.6	2.7	6.3	31.6	60.0
125	3,389	50.1	2.3	0.6	2.8	6.4	31.6	62.2

B7.— Regional estimates of timber volume and carbon stocks for aspen-birch stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	0.0	0.0	109.6	2.0
5	0.0	7.3	0.5	2.1	0.6	1.6	109.9	12.1
15	2.9	13.9	1.4	2.1	1.1	4.0	112.7	22.5
25	21.5	26.8	2.7	2.1	2.2	5.8	117.6	39.6
35	47.2	40.8	4.1	2.0	3.3	7.3	123.7	57.4
45	72.8	53.5	5.3	2.0	4.3	8.4	129.8	73.6
55	97.1	64.9	6.1	2.0	5.2	9.3	135.2	87.6
65	119.5	75.0	6.7	2.0	6.1	10.1	139.4	99.8
75	139.7	83.8	7.1	2.0	6.8	10.7	142.2	110.4
85	157.5	91.5	7.4	2.0	7.4	11.3	144.1	119.6
95	173.0	98.0	7.7	2.0	7.9	11.8	145.1	127.4
105	186.0	103.4	7.9	2.0	8.4	12.2	145.6	133.9
115	196.4	107.7	8.1	2.0	8.7	12.5	145.9	139.1
125	204.3	110.9	8.3	2.0	9.0	12.9	146.0	143.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	44.3	0.8
5	0	3.0	0.2	0.8	0.2	0.6	44.5	4.9
15	42	5.6	0.6	0.8	0.5	1.6	45.6	9.1
25	307	10.9	1.1	0.8	0.9	2.4	47.6	16.0
35	674	16.5	1.6	0.8	1.3	2.9	50.1	23.2
45	1,041	21.6	2.2	0.8	1.7	3.4	52.5	29.8
55	1,388	26.2	2.5	0.8	2.1	3.8	54.7	35.4
65	1,708	30.3	2.7	0.8	2.5	4.1	56.4	40.4
75	1,996	33.9	2.9	0.8	2.7	4.3	57.6	44.7
85	2,251	37.0	3.0	0.8	3.0	4.6	58.3	48.4
95	2,472	39.7	3.1	0.8	3.2	4.8	58.7	51.5
105	2,658	41.8	3.2	0.8	3.4	4.9	58.9	54.2
115	2,807	43.6	3.3	0.8	3.5	5.1	59.0	56.3
125	2,920	44.9	3.3	0.8	3.6	5.2	59.1	57.9

B8.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	0.0	0.0	134.9	2.0
5	0.0	3.9	0.4	1.9	0.2	4.2	135.4	10.7
15	2.4	10.3	1.0	1.9	0.6	10.8	138.8	24.7
25	13.2	20.1	2.0	1.9	1.2	15.8	144.9	41.1
35	25.2	29.8	3.0	1.9	1.8	19.7	152.4	56.2
45	37.4	38.7	3.9	1.9	2.4	22.7	159.9	69.7
55	49.8	47.1	4.7	1.9	2.9	25.3	166.5	81.9
65	62.3	55.6	5.3	1.9	3.4	27.4	171.6	93.7
75	74.9	62.8	5.6	1.9	3.9	29.1	175.2	103.4
85	87.5	69.9	5.8	1.9	4.3	30.7	177.4	112.6
95	100.1	76.8	6.0	1.9	4.7	32.0	178.7	121.4
105	112.9	83.6	6.2	1.9	5.1	33.1	179.4	130.0
115	125.8	90.4	6.4	1.9	5.6	34.2	179.7	138.5
125	139.2	97.4	6.5	1.9	6.0	35.1	179.8	147.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	54.6	0.8
5	0	1.6	0.2	0.8	0.1	1.7	54.8	4.3
15	35	4.2	0.4	0.8	0.3	4.4	56.2	10.0
25	189	8.1	0.8	0.8	0.5	6.4	58.6	16.6
35	360	12.0	1.2	0.8	0.7	8.0	61.7	22.7
45	535	15.7	1.6	0.8	1.0	9.2	64.7	28.2
55	712	19.1	1.9	0.8	1.2	10.2	67.4	33.1
65	890	22.5	2.2	0.8	1.4	11.1	69.5	37.9
75	1,070	25.4	2.3	0.8	1.6	11.8	70.9	41.8
85	1,250	28.3	2.4	0.8	1.7	12.4	71.8	45.6
95	1,431	31.1	2.4	0.8	1.9	12.9	72.3	49.1
105	1,613	33.8	2.5	0.8	2.1	13.4	72.6	52.6
115	1,798	36.6	2.6	0.8	2.2	13.8	72.7	56.0
125	1,990	39.4	2.7	0.8	2.4	14.2	72.8	59.5

B9.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	100.7	2.1
5	0.0	5.1	0.5	2.0	0.4	4.2	101.0	12.2
15	4.3	13.4	1.3	1.7	1.0	10.8	103.6	28.3
25	24.6	30.3	3.0	1.6	2.3	15.8	108.1	53.0
35	48.1	47.7	4.0	1.5	3.6	19.7	113.7	76.5
45	72.5	62.9	4.4	1.4	4.8	22.7	119.3	96.2
55	96.9	77.3	4.7	1.4	5.9	25.3	124.3	114.5
65	121.3	91.1	4.9	1.4	6.9	27.4	128.1	131.7
75	145.3	104.4	5.1	1.4	7.9	29.1	130.7	147.9
85	168.9	117.1	5.3	1.3	8.9	30.7	132.4	163.3
95	191.9	129.3	5.4	1.3	9.8	32.0	133.4	177.8
105	214.4	140.9	5.6	1.3	10.7	33.1	133.9	191.6
115	236.0	151.9	5.7	1.3	11.5	34.2	134.1	204.6
125	256.9	162.4	5.8	1.3	12.3	35.1	134.2	216.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	0.0	0.0	40.8	0.9
5	0	2.1	0.2	0.8	0.2	1.7	40.9	4.9
15	62	5.4	0.5	0.7	0.4	4.4	41.9	11.5
25	351	12.2	1.2	0.6	0.9	6.4	43.8	21.4
35	688	19.3	1.6	0.6	1.5	8.0	46.0	31.0
45	1,036	25.4	1.8	0.6	1.9	9.2	48.3	38.9
55	1,385	31.3	1.9	0.6	2.4	10.2	50.3	46.3
65	1,733	36.9	2.0	0.6	2.8	11.1	51.8	53.3
75	2,076	42.2	2.1	0.6	3.2	11.8	52.9	59.9
85	2,414	47.4	2.1	0.5	3.6	12.4	53.6	66.1
95	2,743	52.3	2.2	0.5	4.0	12.9	54.0	72.0
105	3,064	57.0	2.3	0.5	4.3	13.4	54.2	77.5
115	3,373	61.5	2.3	0.5	4.7	13.8	54.3	82.8
125	3,671	65.7	2.3	0.5	5.0	14.2	54.3	87.8

B10.— Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	72.8	2.1
5	0.0	6.7	0.7	2.2	0.5	0.9	73.1	11.0
15	4.1	17.0	1.7	2.0	1.3	2.5	74.9	24.5
25	21.9	33.6	3.1	1.9	2.6	3.9	78.2	45.0
35	42.5	50.3	3.6	1.8	3.9	5.2	82.2	64.8
45	64.9	66.7	3.9	1.8	5.2	6.3	86.3	83.9
55	88.7	83.6	4.2	1.8	6.5	7.2	89.9	103.3
65	113.4	99.1	4.5	1.7	7.7	8.1	92.6	121.1
75	139.0	114.7	4.7	1.7	8.9	8.9	94.5	138.9
85	165.2	130.3	4.9	1.7	10.1	9.7	95.8	156.7
95	192.1	146.0	5.1	1.7	11.3	10.3	96.4	174.4
105	219.2	161.6	5.3	1.7	12.5	10.9	96.8	192.0
115	246.4	177.0	5.4	1.6	13.7	11.5	97.0	209.2
125	272.5	191.6	5.5	1.6	14.8	12.0	97.1	225.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	29.5	0.8
5	0	2.7	0.3	0.9	0.2	0.4	29.6	4.4
15	58	6.9	0.7	0.8	0.5	1.0	30.3	9.9
25	313	13.6	1.2	0.8	1.0	1.6	31.6	18.2
35	608	20.4	1.4	0.7	1.6	2.1	33.3	26.2
45	928	27.0	1.6	0.7	2.1	2.5	34.9	33.9
55	1,267	33.8	1.7	0.7	2.6	2.9	36.4	41.8
65	1,620	40.1	1.8	0.7	3.1	3.3	37.5	49.0
75	1,986	46.4	1.9	0.7	3.6	3.6	38.3	56.2
85	2,361	52.7	2.0	0.7	4.1	3.9	38.7	63.4
95	2,745	59.1	2.1	0.7	4.6	4.2	39.0	70.6
105	3,133	65.4	2.1	0.7	5.1	4.4	39.2	77.7
115	3,521	71.6	2.2	0.7	5.5	4.7	39.2	84.7
125	3,895	77.5	2.2	0.7	6.0	4.9	39.3	91.3

B11.— Regional estimates of timber volume and carbon stocks for spruce-balsam fir stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	196.4	2.1
5	0.0	3.4	0.3	2.1	0.3	5.0	197.0	11.1
15	3.0	9.3	0.9	2.6	0.8	13.0	202.0	26.5
25	23.2	24.3	2.4	1.9	2.1	19.0	210.8	49.7
35	51.1	41.2	4.1	1.6	3.6	23.7	221.7	74.2
45	77.2	56.0	5.1	1.5	4.8	27.5	232.7	94.9
55	100.7	67.4	5.8	1.4	5.8	30.7	242.3	111.1
65	121.6	77.2	6.4	1.3	6.7	33.3	249.7	124.8
75	140.2	85.5	6.8	1.3	7.4	35.5	254.9	136.5
85	156.5	92.8	7.2	1.2	8.0	37.4	258.2	146.6
95	170.9	99.0	7.5	1.2	8.6	39.1	260.0	155.3
105	183.5	104.3	7.7	1.2	9.0	40.6	261.0	162.9
115	194.4	109.0	7.9	1.2	9.4	41.9	261.5	169.3
125	203.8	112.9	8.1	1.2	9.8	43.0	261.7	174.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	0.0	0.0	79.5	0.9
5	0	1.4	0.1	0.9	0.1	2.0	79.7	4.5
15	43	3.7	0.4	1.0	0.3	5.2	81.7	10.7
25	332	9.8	1.0	0.8	0.8	7.7	85.3	20.1
35	730	16.7	1.7	0.7	1.4	9.6	89.7	30.0
45	1,103	22.7	2.1	0.6	2.0	11.1	94.2	38.4
55	1,439	27.3	2.4	0.6	2.4	12.4	98.0	45.0
65	1,738	31.2	2.6	0.5	2.7	13.5	101.1	50.5
75	2,003	34.6	2.7	0.5	3.0	14.4	103.2	55.3
85	2,237	37.5	2.9	0.5	3.2	15.2	104.5	59.3
95	2,442	40.1	3.0	0.5	3.5	15.8	105.2	62.9
105	2,622	42.2	3.1	0.5	3.7	16.4	105.6	65.9
115	2,778	44.1	3.2	0.5	3.8	16.9	105.8	68.5
125	2,912	45.7	3.3	0.5	4.0	17.4	105.9	70.8

B12.— Regional estimates of timber volume and carbon stocks for white-red-jack pine stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	0.0	0.0	90.6	2.0
5	0.0	0.4	0.0	2.0	0.0	3.1	90.9	5.7
15	6.6	8.0	0.8	2.0	0.6	7.1	93.2	18.5
25	48.1	35.4	3.5	2.0	2.5	9.4	97.3	52.9
35	104.7	62.9	4.9	2.0	4.5	11.0	102.3	85.3
45	158.9	85.8	5.5	2.0	6.2	12.2	107.4	111.6
55	209.1	105.3	5.9	2.0	7.6	13.0	111.8	133.8
65	255.1	122.2	6.2	2.0	8.8	13.7	115.2	152.9
75	297.4	137.1	6.5	2.0	9.9	14.2	117.6	169.6
85	336.1	150.3	6.7	2.0	10.8	14.7	119.1	184.4
95	371.7	162.0	6.9	2.0	11.7	15.0	120.0	197.5
105	404.2	172.5	7.0	2.0	12.4	15.4	120.5	209.3
115	434.0	182.0	7.2	2.0	13.1	15.6	120.7	219.8
125	461.3	190.5	7.3	1.9	13.7	15.9	120.8	229.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	36.7	0.8
5	0	0.2	0.0	0.8	0.0	1.3	36.8	2.3
15	94	3.3	0.3	0.8	0.2	2.9	37.7	7.5
25	688	14.3	1.4	0.8	1.0	3.8	39.4	21.4
35	1,496	25.5	2.0	0.8	1.8	4.5	41.4	34.5
45	2,271	34.7	2.2	0.8	2.5	4.9	43.5	45.2
55	2,988	42.6	2.4	0.8	3.1	5.3	45.3	54.2
65	3,646	49.5	2.5	0.8	3.6	5.5	46.6	61.9
75	4,250	55.5	2.6	0.8	4.0	5.8	47.6	68.6
85	4,804	60.8	2.7	0.8	4.4	5.9	48.2	74.6
95	5,312	65.6	2.8	0.8	4.7	6.1	48.6	79.9
105	5,777	69.8	2.8	0.8	5.0	6.2	48.7	84.7
115	6,203	73.6	2.9	0.8	5.3	6.3	48.8	88.9
125	6,593	77.1	2.9	0.8	5.5	6.4	48.9	92.8

B13.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands with afforestation of land in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	63.6	2.1
5	0.0	3.9	0.4	2.1	0.3	4.2	63.8	10.8
15	0.0	8.7	0.9	2.7	0.6	10.8	65.4	23.7
25	5.8	15.5	1.6	2.4	1.1	15.8	68.3	36.4
35	21.8	27.7	2.8	2.2	1.9	19.7	71.8	54.3
45	45.1	43.2	4.3	2.0	3.0	22.7	75.4	75.3
55	73.0	60.2	5.6	1.9	4.2	25.3	78.5	97.1
65	104.1	78.9	6.1	1.8	5.5	27.4	80.9	119.7
75	137.4	96.5	6.5	1.8	6.7	29.1	82.6	140.6
85	171.9	114.0	6.9	1.7	7.9	30.7	83.6	161.2
95	206.8	131.3	7.2	1.7	9.1	32.0	84.2	181.3
105	241.7	148.2	7.5	1.6	10.3	33.1	84.5	200.7
115	275.8	164.3	7.8	1.6	11.4	34.2	84.7	219.2
125	308.6	179.6	8.0	1.6	12.4	35.1	84.7	236.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	25.7	0.8
5	0	1.6	0.2	0.8	0.1	1.7	25.8	4.4
15	0	3.5	0.4	1.1	0.2	4.4	26.5	9.6
25	83	6.3	0.6	1.0	0.4	6.4	27.6	14.7
35	312	11.2	1.1	0.9	0.8	8.0	29.1	22.0
45	644	17.5	1.7	0.8	1.2	9.2	30.5	30.5
55	1,043	24.3	2.3	0.8	1.7	10.2	31.8	39.3
65	1,488	31.9	2.5	0.7	2.2	11.1	32.7	48.4
75	1,964	39.0	2.6	0.7	2.7	11.8	33.4	56.9
85	2,456	46.1	2.8	0.7	3.2	12.4	33.8	65.2
95	2,956	53.1	2.9	0.7	3.7	12.9	34.1	73.4
105	3,454	60.0	3.0	0.7	4.2	13.4	34.2	81.2
115	3,941	66.5	3.2	0.6	4.6	13.8	34.3	88.7
125	4,410	72.7	3.2	0.6	5.0	14.2	34.3	95.8

B14.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands with afforestation of land in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	48.6	2.1
5	0.0	5.1	0.5	2.2	0.3	4.2	48.8	12.4
15	0.9	10.5	1.1	1.9	0.7	10.8	50.0	25.0
25	8.2	18.5	1.8	1.7	1.2	15.8	52.2	39.0
35	21.4	29.7	3.0	1.6	1.9	19.7	54.9	55.7
45	38.2	41.3	3.8	1.5	2.6	22.7	57.7	71.9
55	57.4	53.6	4.2	1.4	3.4	25.3	60.0	87.9
65	78.6	66.5	4.5	1.3	4.2	27.4	61.9	103.9
75	101.0	79.6	4.7	1.3	5.1	29.1	63.2	119.8
85	124.4	92.9	4.9	1.2	5.9	30.7	64.0	135.7
95	148.6	106.2	5.1	1.2	6.7	32.0	64.4	151.2
105	173.1	119.4	5.3	1.2	7.6	33.1	64.7	166.6
115	197.4	132.1	5.5	1.2	8.4	34.2	64.8	181.3
125	220.5	144.0	5.6	1.1	9.1	35.1	64.8	195.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	0.0	0.0	19.7	0.9
5	0	2.1	0.2	0.9	0.1	1.7	19.8	5.0
15	13	4.3	0.4	0.8	0.3	4.4	20.3	10.1
25	117	7.5	0.7	0.7	0.5	6.4	21.1	15.8
35	306	12.0	1.2	0.6	0.8	8.0	22.2	22.6
45	546	16.7	1.5	0.6	1.1	9.2	23.3	29.1
55	821	21.7	1.7	0.6	1.4	10.2	24.3	35.6
65	1,123	26.9	1.8	0.5	1.7	11.1	25.0	42.1
75	1,443	32.2	1.9	0.5	2.0	11.8	25.6	48.5
85	1,778	37.6	2.0	0.5	2.4	12.4	25.9	54.9
95	2,123	43.0	2.1	0.5	2.7	12.9	26.1	61.2
105	2,474	48.3	2.2	0.5	3.1	13.4	26.2	67.4
115	2,821	53.5	2.2	0.5	3.4	13.8	26.2	73.4
125	3,151	58.3	2.3	0.5	3.7	14.2	26.2	78.9

B15.— Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	34.5	2.1
5	0.0	6.7	0.6	2.4	0.5	0.9	34.6	11.0
15	2.1	15.6	1.6	2.1	1.1	2.5	35.4	22.9
25	13.0	27.5	2.7	2.0	1.9	3.9	37.0	37.9
35	27.4	40.0	3.2	1.9	2.7	5.2	38.9	53.0
45	43.0	52.2	3.6	1.8	3.5	6.3	40.8	67.4
55	59.1	64.3	3.9	1.8	4.3	7.2	42.5	81.5
65	74.9	74.7	4.1	1.7	5.0	8.1	43.8	93.7
75	90.2	84.6	4.3	1.7	5.7	8.9	44.7	105.2
85	104.7	93.7	4.4	1.7	6.3	9.7	45.3	115.8
95	118.3	102.1	4.5	1.6	6.9	10.3	45.6	125.5
105	130.8	109.7	4.7	1.6	7.4	10.9	45.8	134.4
115	142.0	116.5	4.7	1.6	7.9	11.5	45.9	142.3
125	151.9	122.5	4.8	1.6	8.3	12.0	45.9	149.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	13.9	0.8
5	0	2.7	0.2	1.0	0.2	0.4	14.0	4.5
15	30	6.3	0.6	0.9	0.4	1.0	14.3	9.3
25	186	11.1	1.1	0.8	0.8	1.6	15.0	15.3
35	391	16.2	1.3	0.8	1.1	2.1	15.7	21.4
45	615	21.1	1.4	0.7	1.4	2.5	16.5	27.3
55	844	26.0	1.6	0.7	1.8	2.9	17.2	33.0
65	1,070	30.2	1.7	0.7	2.0	3.3	17.7	37.9
75	1,289	34.2	1.7	0.7	2.3	3.6	18.1	42.6
85	1,497	37.9	1.8	0.7	2.6	3.9	18.3	46.9
95	1,691	41.3	1.8	0.7	2.8	4.2	18.5	50.8
105	1,869	44.4	1.9	0.7	3.0	4.4	18.5	54.4
115	2,030	47.2	1.9	0.7	3.2	4.7	18.6	57.6
125	2,171	49.6	2.0	0.7	3.3	4.9	18.6	60.4

B16.— Regional estimates of timber volume and carbon stocks for oak-pine stands with afforestation of land in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	m^3*/hectare*	------------------------------------- *tonnes carbon/hectare* -------------------------------------						
0	0.0	0.0	0.0	4.2	0.0	0.0	27.1	4.2
5	0.0	5.1	0.4	4.2	0.4	3.8	27.2	13.9
15	4.5	13.8	1.2	4.3	1.0	10.3	27.9	30.6
25	28.4	29.8	2.6	3.6	2.1	15.6	29.1	53.6
35	57.9	47.4	3.4	3.3	3.3	19.9	30.6	77.2
45	86.7	63.3	4.0	3.1	4.4	23.5	32.1	98.2
55	113.2	77.0	4.4	2.9	5.3	26.6	33.5	116.2
65	137.1	89.4	4.7	2.9	6.2	29.2	34.5	132.5
75	158.1	98.9	5.0	2.8	6.8	31.6	35.2	145.1
85	176.0	106.8	5.2	2.7	7.4	33.6	35.7	155.7
95	190.8	113.3	5.4	2.7	7.8	35.4	35.9	164.6
105	202.4	118.3	5.5	2.7	8.2	37.0	36.0	171.7
115	210.9	121.9	5.6	2.7	8.4	38.4	36.1	177.1
125	216.1	124.1	5.7	2.7	8.6	39.7	36.1	180.8
years	ft^3*/acre*	--------------------------------------- *tonnes carbon/acre* ---------------------------------------						
0	0	0.0	0.0	1.7	0.0	0.0	11.0	1.7
5	0	2.1	0.2	1.7	0.1	1.6	11.0	5.6
15	65	5.6	0.5	1.7	0.4	4.2	11.3	12.4
25	406	12.1	1.0	1.5	0.8	6.3	11.8	21.7
35	828	19.2	1.4	1.3	1.3	8.0	12.4	31.3
45	1,239	25.6	1.6	1.2	1.8	9.5	13.0	39.7
55	1,618	31.2	1.8	1.2	2.2	10.8	13.5	47.0
65	1,959	36.2	1.9	1.2	2.5	11.8	14.0	53.6
75	2,259	40.0	2.0	1.1	2.8	12.8	14.2	58.7
85	2,515	43.2	2.1	1.1	3.0	13.6	14.4	63.0
95	2,727	45.8	2.2	1.1	3.2	14.3	14.5	66.6
105	2,893	47.9	2.2	1.1	3.3	15.0	14.6	69.5
115	3,014	49.3	2.3	1.1	3.4	15.6	14.6	71.7
125	3,088	50.2	2.3	1.1	3.5	16.1	14.6	73.2

B17.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	0.0	0.0	71.1	4.6
5	0.0	2.7	0.3	4.4	0.3	5.2	71.3	12.7
15	3.8	8.7	0.9	4.1	0.9	13.0	73.1	27.5
25	47.7	38.3	3.8	3.7	3.9	18.6	76.3	68.3
35	119.0	75.1	7.5	3.6	7.7	22.9	80.2	116.7
45	184.7	104.0	10.0	3.5	10.7	26.2	84.2	154.3
55	241.8	127.3	10.9	3.4	13.1	28.9	87.7	183.6
65	290.9	146.4	11.5	3.4	15.0	31.1	90.4	207.5
75	332.7	162.2	12.0	3.4	16.6	33.0	92.3	227.2
85	368.3	175.3	12.4	3.4	18.0	34.5	93.4	243.6
95	398.6	186.2	12.7	3.4	19.1	35.9	94.1	257.2
105	424.4	195.4	13.0	3.3	20.0	37.0	94.5	268.7
115	446.4	203.1	13.2	3.3	20.8	38.0	94.6	278.4
125	465.2	209.6	13.3	3.3	21.5	39.0	94.7	286.7
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	28.8	1.9
5	0	1.1	0.1	1.8	0.1	2.1	28.9	5.2
15	54	3.5	0.4	1.7	0.4	5.2	29.6	11.1
25	682	15.5	1.5	1.5	1.6	7.5	30.9	27.7
35	1,701	30.4	3.0	1.4	3.1	9.3	32.5	47.2
45	2,639	42.1	4.1	1.4	4.3	10.6	34.1	62.5
55	3,456	51.5	4.4	1.4	5.3	11.7	35.5	74.3
65	4,157	59.3	4.7	1.4	6.1	12.6	36.6	84.0
75	4,755	65.6	4.9	1.4	6.7	13.3	37.3	91.9
85	5,264	70.9	5.0	1.4	7.3	14.0	37.8	98.6
95	5,697	75.4	5.1	1.4	7.7	14.5	38.1	104.1
105	6,065	79.1	5.2	1.4	8.1	15.0	38.2	108.8
115	6,379	82.2	5.3	1.4	8.4	15.4	38.3	112.7
125	6,648	84.8	5.4	1.3	8.7	15.8	38.3	116.0

B18.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	46.6	4.8
5	0.0	3.1	0.3	4.1	0.3	5.2	46.8	13.0
15	0.0	5.8	0.6	3.7	0.6	13.0	47.9	23.7
25	15.2	15.5	1.6	3.2	1.6	18.6	50.0	40.5
35	52.1	33.9	3.4	2.8	3.6	22.9	52.6	66.6
45	97.4	53.0	5.3	2.6	5.6	26.2	55.2	92.7
55	144.4	71.3	7.1	2.5	7.6	28.9	57.5	117.5
65	189.7	88.3	8.8	2.4	9.4	31.1	59.3	140.0
75	231.5	103.3	10.3	2.4	11.0	33.0	60.5	160.0
85	268.7	116.4	11.6	2.3	12.4	34.5	61.3	177.3
95	301.0	127.6	12.8	2.3	13.6	35.9	61.7	192.0
105	328.2	136.9	13.7	2.3	14.5	37.0	62.0	204.4
115	350.6	144.4	14.4	2.2	15.3	38.0	62.1	214.4
125	368.3	150.3	15.0	2.2	16.0	39.0	62.1	222.5
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	18.9	1.9
5	0	1.3	0.1	1.7	0.1	2.1	18.9	5.3
15	0	2.3	0.2	1.5	0.2	5.2	19.4	9.6
25	217	6.3	0.6	1.3	0.7	7.5	20.3	16.4
35	745	13.7	1.4	1.1	1.5	9.3	21.3	27.0
45	1,392	21.4	2.1	1.1	2.3	10.6	22.4	37.5
55	2,063	28.9	2.9	1.0	3.1	11.7	23.3	47.5
65	2,711	35.7	3.6	1.0	3.8	12.6	24.0	56.7
75	3,308	41.8	4.2	1.0	4.4	13.3	24.5	64.7
85	3,840	47.1	4.7	0.9	5.0	14.0	24.8	71.7
95	4,302	51.6	5.2	0.9	5.5	14.5	25.0	77.7
105	4,691	55.4	5.5	0.9	5.9	15.0	25.1	82.7
115	5,010	58.4	5.8	0.9	6.2	15.4	25.1	86.8
125	5,264	60.8	6.1	0.9	6.5	15.8	25.1	90.0

B19.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands with afforestation of land in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	39.0	4.8
5	0.0	1.9	0.2	4.8	0.2	2.4	39.1	9.5
15	6.6	8.1	0.8	3.5	0.8	6.4	40.1	19.6
25	40.8	24.3	2.4	2.6	2.3	9.8	41.9	41.4
35	81.7	40.1	4.0	2.3	3.7	12.6	44.1	62.8
45	120.5	54.0	5.4	2.2	5.0	14.9	46.2	81.5
55	156.3	64.5	6.4	2.1	6.0	17.0	48.1	95.9
65	189.3	73.6	7.4	2.0	6.9	18.7	49.6	108.5
75	219.9	81.7	8.2	1.9	7.6	20.3	50.7	119.7
85	248.0	88.9	8.9	1.9	8.3	21.7	51.3	129.6
95	274.0	95.4	9.5	1.9	8.9	22.9	51.7	138.5
105	298.2	101.2	10.1	1.8	9.4	24.0	51.9	146.6
115	320.5	106.5	10.6	1.8	9.9	25.0	52.0	153.8
125	341.2	111.4	10.9	1.8	10.4	25.8	52.0	160.3
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	0.0	0.0	15.8	2.0
5	0	0.8	0.1	2.0	0.1	1.0	15.8	3.8
15	95	3.3	0.3	1.4	0.3	2.6	16.2	7.9
25	583	9.8	1.0	1.1	0.9	4.0	17.0	16.8
35	1,168	16.2	1.6	0.9	1.5	5.1	17.8	25.4
45	1,722	21.8	2.2	0.9	2.0	6.0	18.7	33.0
55	2,234	26.1	2.6	0.8	2.4	6.9	19.5	38.8
65	2,706	29.8	3.0	0.8	2.8	7.6	20.1	43.9
75	3,142	33.1	3.3	0.8	3.1	8.2	20.5	48.4
85	3,544	36.0	3.6	0.8	3.3	8.8	20.8	52.4
95	3,916	38.6	3.9	0.8	3.6	9.3	20.9	56.1
105	4,261	41.0	4.1	0.7	3.8	9.7	21.0	59.3
115	4,580	43.1	4.3	0.7	4.0	10.1	21.0	62.2
125	4,876	45.1	4.4	0.7	4.2	10.5	21.0	64.9

B20.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands with afforestation of land in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live Tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	38.0	4.8
5	0.0	3.3	0.3	4.6	0.3	2.4	38.1	10.8
15	4.1	7.9	0.8	3.8	0.8	6.4	39.1	19.7
25	21.6	17.3	1.7	3.2	1.8	9.8	40.8	33.7
35	40.8	26.2	2.6	2.9	2.7	12.6	42.9	47.0
45	61.4	34.9	3.3	2.8	3.6	14.9	45.1	59.4
55	83.3	43.6	3.7	2.6	4.5	17.0	46.9	71.5
65	106.0	52.5	4.2	2.5	5.4	18.7	48.4	83.3
75	129.3	61.3	4.6	2.4	6.3	20.3	49.4	94.9
85	153.0	70.0	4.9	2.4	7.2	21.7	50.0	106.2
95	176.8	78.6	5.3	2.3	8.1	22.9	50.3	117.2
105	200.4	87.0	5.6	2.3	9.0	24.0	50.5	127.7
115	223.6	95.1	5.9	2.2	9.8	25.0	50.6	137.9
125	246.0	102.8	6.1	2.2	10.6	25.8	50.7	147.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	15.4	1.9
5	0	1.3	0.1	1.8	0.1	1.0	15.4	4.4
15	59	3.2	0.3	1.5	0.3	2.6	15.8	8.0
25	309	7.0	0.7	1.3	0.7	4.0	16.5	13.7
35	583	10.6	1.1	1.2	1.1	5.1	17.4	19.0
45	878	14.1	1.3	1.1	1.5	6.0	18.2	24.0
55	1,190	17.7	1.5	1.1	1.8	6.9	19.0	28.9
65	1,515	21.2	1.7	1.0	2.2	7.6	19.6	33.7
75	1,848	24.8	1.8	1.0	2.6	8.2	20.0	38.4
85	2,187	28.3	2.0	1.0	2.9	8.8	20.2	43.0
95	2,527	31.8	2.1	0.9	3.3	9.3	20.4	47.4
105	2,864	35.2	2.3	0.9	3.6	9.7	20.5	51.7
115	3,195	38.5	2.4	0.9	4.0	10.1	20.5	55.8
125	3,515	41.6	2.5	0.9	4.3	10.5	20.5	59.7

B21.— Regional estimates of timber volume and carbon stocks for alder-maple stands with afforestation of land in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	86.4	4.7
5	0.0	8.0	0.8	4.7	0.8	1.8	86.7	16.1
15	49.5	31.0	3.1	3.7	2.9	4.4	88.9	45.2
25	229.7	99.4	9.9	2.8	9.4	6.2	92.8	127.8
35	380.8	153.8	15.4	2.5	14.6	7.6	97.6	193.9
45	513.7	200.8	20.1	2.4	19.0	8.6	102.4	250.9
55	633.3	242.5	22.2	2.3	23.0	9.4	106.7	299.4
65	742.1	280.1	23.9	2.2	26.5	10.1	109.9	342.8
75	842.1	314.4	25.3	2.2	29.8	10.7	112.2	382.4
85	934.5	346.0	26.6	2.1	32.8	11.1	113.6	418.6
95	1,020.3	375.2	27.7	2.1	35.5	11.5	114.5	452.0
105	1,100.3	402.2	28.7	2.0	38.1	11.9	114.9	483.0
115	1,175.0	427.4	29.6	2.1	40.5	12.2	115.1	511.8
125	1,244.9	450.9	30.4	2.3	42.7	12.4	115.2	538.7
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	35.0	1.9
5	0	3.2	0.3	1.9	0.3	0.7	35.1	6.5
15	708	12.6	1.3	1.5	1.2	1.8	36.0	18.3
25	3,282	40.2	4.0	1.1	3.8	2.5	37.6	51.7
35	5,442	62.3	6.2	1.0	5.9	3.1	39.5	78.5
45	7,342	81.3	8.1	1.0	7.7	3.5	41.5	101.5
55	9,050	98.1	9.0	0.9	9.3	3.8	43.2	121.1
65	10,605	113.3	9.7	0.9	10.7	4.1	44.5	138.7
75	12,034	127.2	10.3	0.9	12.1	4.3	45.4	154.7
85	13,355	140.0	10.8	0.9	13.3	4.5	46.0	169.4
95	14,582	151.8	11.2	0.8	14.4	4.7	46.3	182.9
105	15,725	162.8	11.6	0.8	15.4	4.8	46.5	195.4
115	16,792	173.0	12.0	0.9	16.4	4.9	46.6	207.1
125	17,791	182.5	12.3	0.9	17.3	5.0	46.6	218.0

B22.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	0.0	0.0	71.1	4.6
5	0.0	8.4	0.8	4.5	0.8	3.6	71.3	18.1
15	37.4	30.3	3.0	3.9	3.0	10.0	73.1	50.3
25	208.9	107.1	10.7	3.4	10.7	15.4	76.3	147.3
35	391.8	181.6	17.4	3.2	18.2	20.2	80.2	240.6
45	554.7	246.1	21.2	3.1	24.6	24.4	84.2	319.4
55	698.4	302.2	24.1	3.0	30.2	28.0	87.7	387.5
65	826.0	351.4	26.4	3.0	35.1	31.3	90.4	447.2
75	939.9	394.9	28.4	2.9	39.5	34.2	92.3	500.0
85	1,042.1	433.7	30.1	2.9	43.4	36.9	93.4	547.0
95	1,134.5	468.6	31.6	2.9	46.9	39.3	94.1	589.1
105	1,218.3	500.1	32.9	2.9	50.0	41.4	94.5	627.2
115	1,294.7	528.7	34.0	2.9	52.9	43.4	94.6	661.8
125	1,364.7	554.8	35.0	2.8	55.5	45.3	94.7	693.4
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	28.8	1.9
5	0	3.4	0.3	1.8	0.3	1.5	28.9	7.3
15	535	12.3	1.2	1.6	1.2	4.0	29.6	20.3
25	2,985	43.3	4.3	1.4	4.3	6.2	30.9	59.6
35	5,600	73.5	7.1	1.3	7.3	8.2	32.5	97.4
45	7,927	99.6	8.6	1.3	10.0	9.9	34.1	129.2
55	9,981	122.3	9.7	1.2	12.2	11.3	35.5	156.8
65	11,804	142.2	10.7	1.2	14.2	12.7	36.6	181.0
75	13,432	159.8	11.5	1.2	16.0	13.9	37.3	202.3
85	14,893	175.5	12.2	1.2	17.6	14.9	37.8	221.3
95	16,213	189.6	12.8	1.2	19.0	15.9	38.1	238.4
105	17,411	202.4	13.3	1.2	20.2	16.8	38.2	253.8
115	18,503	213.9	13.8	1.2	21.4	17.6	38.3	267.8
125	19,503	224.5	14.2	1.1	22.5	18.3	38.3	280.6

B23.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Pacific Northwest, West; volumes are for high-productivity sites (growth rate greater than 165 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock, fertilization, and precommercial thinning)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	0.0	0.0	71.1	4.6
5	0.0	9.5	0.9	4.4	0.9	3.6	71.3	19.3
15	19.8	23.4	2.3	4.0	2.3	10.0	73.1	42.0
25	169.7	84.6	8.5	3.5	8.5	15.4	76.3	120.5
35	445.7	187.4	10.0	3.2	18.7	20.2	80.2	239.6
45	718.8	286.2	10.6	3.0	28.6	24.4	84.2	352.8
55	924.1	359.4	10.9	3.0	35.9	28.0	87.7	437.2
65	1,086.5	416.7	11.1	2.9	41.7	31.3	90.4	503.6
75	1,225.8	465.6	11.2	2.9	46.6	34.2	92.3	560.5
85	1,346.8	507.8	11.3	2.9	50.8	36.9	93.4	609.7
95	1,452.4	544.6	11.4	2.8	54.5	39.3	94.1	652.5
105	1,544.4	576.5	11.5	2.9	57.6	41.4	94.5	690.0
115	1,544.4	576.5	11.5	2.9	57.6	43.4	94.6	692.0
125	1,544.4	576.5	11.5	2.9	57.6	45.3	94.7	693.8
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	28.8	1.9
5	0	3.8	0.4	1.8	0.4	1.5	28.9	7.8
15	283	9.5	0.9	1.6	0.9	4.0	29.6	17.0
25	2,425	34.2	3.4	1.4	3.4	6.2	30.9	48.8
35	6,370	75.9	4.1	1.3	7.6	8.2	32.5	97.0
45	10,272	115.8	4.3	1.2	11.6	9.9	34.1	142.8
55	13,207	145.4	4.4	1.2	14.5	11.3	35.5	176.9
65	15,527	168.6	4.5	1.2	16.9	12.7	36.6	203.8
75	17,518	188.4	4.5	1.2	18.8	13.9	37.3	226.8
85	19,248	205.5	4.6	1.2	20.6	14.9	37.8	246.7
95	20,756	220.4	4.6	1.2	22.0	15.9	38.1	264.1
105	22,072	233.3	4.7	1.2	23.3	16.8	38.2	279.2
115	22,072	233.3	4.7	1.2	23.3	17.6	38.3	280.0
125	22,072	233.3	4.7	1.2	23.3	18.3	38.3	280.8

B24.— Regional estimates of timber volume, and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	46.6	4.8
5	0.0	3.2	0.3	4.8	0.3	5.5	46.8	14.0
15	8.2	11.6	1.2	3.9	1.0	13.6	47.9	31.4
25	62.3	42.5	4.3	3.2	3.8	19.4	50.0	73.2
35	145.5	84.3	8.4	2.8	7.6	23.8	52.6	126.9
45	238.7	128.7	12.9	2.6	11.5	27.2	55.2	183.0
55	333.9	168.2	16.8	2.5	15.1	29.9	57.5	232.5
65	427.0	205.1	20.5	2.5	18.4	32.1	59.3	278.5
75	515.8	239.2	23.9	2.4	21.4	33.9	60.5	320.8
85	599.0	270.3	27.0	2.3	24.2	35.4	61.3	359.3
95	676.0	298.5	29.8	2.3	26.8	36.8	61.7	394.2
105	746.6	323.9	32.4	2.3	29.0	37.9	62.0	425.5
115	810.8	346.7	34.1	2.3	31.1	38.9	62.1	453.0
125	869.1	367.2	35.1	2.2	32.9	39.8	62.1	477.2
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	18.9	1.9
5	0	1.3	0.1	1.9	0.1	2.2	18.9	5.7
15	117	4.7	0.5	1.6	0.4	5.5	19.4	12.7
25	890	17.2	1.7	1.3	1.5	7.9	20.3	29.6
35	2,080	34.1	3.4	1.1	3.1	9.6	21.3	51.3
45	3,412	52.1	5.2	1.1	4.7	11.0	22.4	74.0
55	4,772	68.1	6.8	1.0	6.1	12.1	23.3	94.1
65	6,103	83.0	8.3	1.0	7.4	13.0	24.0	112.7
75	7,371	96.8	9.7	1.0	8.7	13.7	24.5	129.8
85	8,560	109.4	10.9	0.9	9.8	14.3	24.8	145.4
95	9,661	120.8	12.1	0.9	10.8	14.9	25.0	159.5
105	10,670	131.1	13.1	0.9	11.7	15.3	25.1	172.2
115	11,588	140.3	13.8	0.9	12.6	15.7	25.1	183.3
125	12,421	148.6	14.2	0.9	13.3	16.1	25.1	193.1

B25.— Regional estimates of timber volume and carbon stocks for hemlock-Sitka spruce stands with afforestation of land in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	87.3	4.7
5	0.0	5.9	0.6	4.7	0.6	3.6	87.6	15.3
15	33.7	22.5	2.2	4.1	2.2	10.0	89.8	41.0
25	184.1	78.0	7.8	3.1	7.7	15.4	93.7	112.1
35	350.8	139.8	14.0	2.7	13.8	20.2	98.5	190.5
45	516.7	201.6	20.2	2.5	19.9	24.4	103.4	268.5
55	678.7	256.6	25.7	2.4	25.3	28.0	107.7	338.0
65	835.1	309.1	30.9	2.3	30.5	31.3	111.0	404.1
75	985.6	359.2	35.9	2.2	35.4	34.2	113.3	467.0
85	1,129.8	406.7	40.1	2.2	40.1	36.9	114.7	526.0
95	1,267.4	451.8	42.8	2.3	44.5	39.3	115.6	580.7
105	1,398.3	494.4	45.2	2.5	48.7	41.4	116.0	632.3
115	1,522.4	534.7	47.4	2.7	52.7	43.4	116.2	680.9
125	1,639.6	572.6	49.4	2.9	56.4	45.3	116.3	726.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	35.3	1.9
5	0	2.4	0.2	1.9	0.2	1.5	35.4	6.2
15	482	9.1	0.9	1.6	0.9	4.0	36.3	16.6
25	2,631	31.6	3.2	1.3	3.1	6.2	37.9	45.3
35	5,013	56.6	5.7	1.1	5.6	8.2	39.9	77.1
45	7,385	81.6	8.2	1.0	8.0	9.9	41.8	108.7
55	9,699	103.9	10.4	1.0	10.2	11.3	43.6	136.8
65	11,935	125.1	12.5	0.9	12.3	12.7	44.9	163.6
75	14,086	145.4	14.5	0.9	14.3	13.9	45.8	189.0
85	16,146	164.6	16.2	0.9	16.2	14.9	46.4	212.8
95	18,113	182.8	17.3	0.9	18.0	15.9	46.8	235.0
105	19,983	200.1	18.3	1.0	19.7	16.8	46.9	255.9
115	21,757	216.4	19.2	1.1	21.3	17.6	47.0	275.6
125	23,432	231.7	20.0	1.2	22.8	18.3	47.1	294.0

B26.— Regional estimates of timber volume and carbon stocks for hemlock-Sitka spruce stands with afforestation of land in the Pacific Northwest, West; volumes are for high productivity sites (growth rate greater than 225 cubic feet wood/acre/year)

Age	Mean volume	Mean carbon density: Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	87.3	4.7
5	0.0	5.9	0.6	4.7	0.6	3.6	87.6	15.3
15	80.3	36.4	3.6	3.7	3.6	10.0	89.8	57.2
25	221.7	90.4	9.0	3.0	8.9	15.4	93.7	126.8
35	413.7	161.0	16.1	2.7	15.9	20.2	98.5	215.8
45	669.6	253.6	25.4	2.4	25.0	24.4	103.4	330.7
55	903.9	332.1	33.2	2.3	32.7	28.0	107.7	428.3
65	1,119.3	403.3	39.9	2.2	39.8	31.3	111.0	516.4
75	1,318.1	468.3	43.7	2.3	46.2	34.2	113.3	594.8
85	1,502.0	528.1	47.1	2.6	52.1	36.9	114.7	666.7
95	1,672.1	583.0	50.0	2.9	57.5	39.3	115.6	732.7
105	1,829.1	633.5	52.6	3.2	62.5	41.4	116.0	793.1
115	1,973.0	679.5	54.9	3.4	67.0	43.4	116.2	848.2
125	2,103.3	721.0	56.9	3.6	71.1	45.3	116.3	897.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	35.3	1.9
5	0	2.4	0.2	1.9	0.2	1.5	35.4	6.2
15	1,148	14.7	1.5	1.5	1.5	4.0	36.3	23.2
25	3,169	36.6	3.7	1.2	3.6	6.2	37.9	51.3
35	5,912	65.1	6.5	1.1	6.4	8.2	39.9	87.3
45	9,570	102.6	10.3	1.0	10.1	9.9	41.8	133.8
55	12,918	134.4	13.4	0.9	13.2	11.3	43.6	173.3
65	15,996	163.2	16.1	0.9	16.1	12.7	44.9	209.0
75	18,837	189.5	17.7	0.9	18.7	13.9	45.8	240.7
85	21,465	213.7	19.0	1.1	21.1	14.9	46.4	269.8
95	23,896	235.9	20.2	1.2	23.3	15.9	46.8	296.5
105	26,140	256.4	21.3	1.3	25.3	16.8	46.9	321.0
115	28,197	275.0	22.2	1.4	27.1	17.6	47.0	343.2
125	30,059	291.8	23.0	1.5	28.8	18.3	47.1	363.3

B27.— Regional estimates of timber volume and carbon stocks for mixed conifer stands with afforestation of land in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live Tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	37.4	4.8
5	0.0	4.2	0.3	4.8	0.4	5.2	37.5	14.8
15	2.0	8.1	0.8	4.8	0.8	13.0	38.4	27.4
25	11.1	14.6	1.5	6.9	1.5	18.6	40.1	43.0
35	24.4	22.3	2.2	4.9	2.2	22.9	42.2	54.5
45	44.5	32.9	3.3	3.6	3.3	26.2	44.3	69.4
55	71.9	46.5	4.7	2.8	4.7	28.9	46.1	87.5
65	106.6	62.8	6.3	2.2	6.3	31.1	47.5	108.7
75	147.9	81.4	8.1	1.8	8.2	33.0	48.5	132.5
85	195.4	102.0	10.2	1.5	10.2	34.5	49.1	158.5
95	248.3	124.2	12.4	1.3	12.4	35.9	49.5	186.2
105	305.6	147.5	14.8	1.1	14.8	37.0	49.7	215.2
115	366.7	171.8	17.2	1.0	17.2	38.0	49.7	245.2
125	430.5	196.6	19.7	1.0	19.7	39.0	49.8	275.9
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	15.1	1.9
5	0	1.7	0.1	1.9	0.2	2.1	15.2	6.0
15	29	3.3	0.3	1.9	0.3	5.2	15.5	11.1
25	159	5.9	0.6	2.8	0.6	7.5	16.2	17.4
35	349	9.0	0.9	2.0	0.9	9.3	17.1	22.1
45	636	13.3	1.3	1.5	1.3	10.6	17.9	28.1
55	1,028	18.8	1.9	1.1	1.9	11.7	18.7	35.4
65	1,523	25.4	2.5	0.9	2.6	12.6	19.2	44.0
75	2,114	33.0	3.3	0.7	3.3	13.3	19.6	53.6
85	2,793	41.3	4.1	0.6	4.1	14.0	19.9	64.1
95	3,548	50.2	5.0	0.5	5.0	14.5	20.0	75.3
105	4,368	59.7	6.0	0.5	6.0	15.0	20.1	87.1
115	5,240	69.5	7.0	0.4	7.0	15.4	20.1	99.2
125	6,152	79.6	8.0	0.4	8.0	15.8	20.1	111.7

B28.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live Tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	38.9	4.8
5	0.0	3.2	0.3	4.8	0.3	5.2	39.1	13.8
15	2.0	7.9	0.8	4.2	0.9	13.0	40.0	26.7
25	13.7	17.3	1.7	3.4	1.9	18.6	41.8	43.0
35	32.4	29.5	3.0	2.9	3.2	22.9	43.9	61.5
45	58.8	45.2	4.5	2.6	4.9	26.2	46.1	83.5
55	94.0	63.1	6.3	2.4	6.9	28.9	48.0	107.6
65	136.7	83.5	8.4	2.2	9.1	31.1	49.5	134.3
75	185.6	105.7	10.6	2.1	11.5	33.0	50.5	162.7
85	239.2	128.9	12.9	2.0	14.0	34.5	51.2	192.4
95	296.6	153.0	15.3	1.9	16.6	35.9	51.5	222.6
105	356.8	177.4	17.7	1.8	19.3	37.0	51.7	253.3
115	419.1	202.0	20.2	1.8	22.0	38.0	51.8	284.0
125	482.7	226.6	22.7	1.7	24.6	39.0	51.9	314.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	15.8	1.9
5	0	1.3	0.1	1.9	0.1	2.1	15.8	5.6
15	28	3.2	0.3	1.7	0.3	5.2	16.2	10.8
25	196	7.0	0.7	1.4	0.8	7.5	16.9	17.4
35	463	11.9	1.2	1.2	1.3	9.3	17.8	24.9
45	840	18.3	1.8	1.1	2.0	10.6	18.7	33.8
55	1,343	25.5	2.6	1.0	2.8	11.7	19.4	43.5
65	1,954	33.8	3.4	0.9	3.7	12.6	20.0	54.3
75	2,652	42.8	4.3	0.8	4.6	13.3	20.4	65.9
85	3,419	52.2	5.2	0.8	5.7	14.0	20.7	77.8
95	4,239	61.9	6.2	0.8	6.7	14.5	20.9	90.1
105	5,099	71.8	7.2	0.7	7.8	15.0	20.9	102.5
115	5,989	81.8	8.2	0.7	8.9	15.4	21.0	114.9
125	6,899	91.7	9.2	0.7	10.0	15.8	21.0	127.3

B29.— Regional estimates of timber volume and carbon stocks for western oak stands with afforestation of land in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	20.7	4.7
5	0.0	2.6	0.2	4.6	0.1	3.7	20.8	11.3
15	0.0	5.7	0.6	4.5	0.2	9.8	21.3	20.8
25	1.0	8.8	0.9	4.4	0.4	14.4	22.2	28.8
35	25.9	30.6	3.1	4.2	1.3	18.1	23.4	57.3
45	76.3	65.1	4.5	4.1	2.7	21.1	24.5	97.5
55	127.8	98.3	5.4	4.0	4.1	23.6	25.5	135.3
65	174.4	124.0	6.0	4.0	5.1	25.6	26.3	164.8
75	215.0	145.3	6.5	4.0	6.0	27.4	26.9	189.2
85	249.4	162.7	6.8	4.0	6.8	29.0	27.2	209.2
95	278.4	177.1	7.1	4.0	7.4	30.3	27.4	225.8
105	302.8	189.0	7.3	3.9	7.8	31.5	27.5	239.6
115	323.3	198.8	7.4	3.9	8.3	32.6	27.5	251.0
125	340.6	207.0	7.6	3.9	8.6	33.5	27.6	260.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	8.4	1.9
5	0	1.1	0.1	1.9	0.0	1.5	8.4	4.6
15	0	2.3	0.2	1.8	0.1	3.9	8.6	8.4
25	15	3.6	0.4	1.8	0.1	5.8	9.0	11.7
35	370	12.4	1.2	1.7	0.5	7.3	9.5	23.2
45	1,090	26.3	1.8	1.7	1.1	8.5	9.9	39.4
55	1,826	39.8	2.2	1.6	1.7	9.5	10.3	54.8
65	2,493	50.2	2.4	1.6	2.1	10.4	10.6	66.7
75	3,072	58.8	2.6	1.6	2.4	11.1	10.9	76.6
85	3,564	65.9	2.8	1.6	2.7	11.7	11.0	84.7
95	3,979	71.7	2.9	1.6	3.0	12.3	11.1	91.4
105	4,328	76.5	2.9	1.6	3.2	12.7	11.1	97.0
115	4,620	80.5	3.0	1.6	3.3	13.2	11.1	101.6
125	4,868	83.8	3.1	1.6	3.5	13.6	11.2	105.5

B30.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m*^{3}*/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	29.1	4.7
5	0.0	2.7	0.3	4.7	0.2	5.2	29.2	13.0
15	1.1	6.1	0.6	4.7	0.4	13.0	30.0	24.8
25	19.7	21.5	2.2	3.4	1.3	18.6	31.3	47.0
35	57.1	44.3	4.4	2.7	2.8	22.9	32.9	77.0
45	100.9	66.5	6.7	2.3	4.1	26.2	34.5	105.8
55	145.9	87.2	8.7	2.1	5.4	28.9	35.9	132.3
65	189.3	105.9	10.1	1.9	6.6	31.1	37.1	155.6
75	229.7	122.5	10.7	1.8	7.6	33.0	37.8	175.6
85	266.3	137.0	11.2	1.8	8.5	34.5	38.3	193.0
95	298.6	149.4	11.6	1.7	9.3	35.9	38.6	207.9
105	326.6	159.9	12.0	1.7	9.9	37.0	38.7	220.5
115	350.1	168.6	12.2	1.6	10.5	38.0	38.8	231.0
125	369.5	175.7	12.4	1.6	10.9	39.0	38.8	239.6
years	*ft*^{3}*/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	11.8	1.9
5	0	1.1	0.1	1.9	0.1	2.1	11.8	5.2
15	16	2.5	0.2	1.9	0.2	5.2	12.1	10.0
25	281	8.7	0.9	1.4	0.5	7.5	12.7	19.0
35	816	17.9	1.8	1.1	1.1	9.3	13.3	31.2
45	1,442	26.9	2.7	0.9	1.7	10.6	14.0	42.8
55	2,085	35.3	3.5	0.8	2.2	11.7	14.5	53.6
65	2,705	42.9	4.1	0.8	2.7	12.6	15.0	63.0
75	3,283	49.6	4.3	0.7	3.1	13.3	15.3	71.1
85	3,806	55.4	4.5	0.7	3.4	14.0	15.5	78.1
95	4,268	60.5	4.7	0.7	3.8	14.5	15.6	84.1
105	4,667	64.7	4.8	0.7	4.0	15.0	15.7	89.2
115	5,003	68.2	4.9	0.7	4.2	15.4	15.7	93.5
125	5,280	71.1	5.0	0.7	4.4	15.8	15.7	97.0

B31.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	------------ *tonnes carbon/hectare* ------------						
0	0.0	0.0	0.0	4.7	0.0	0.0	33.1	4.7
5	0.0	3.1	0.3	4.7	0.3	5.2	33.2	13.6
15	0.0	5.8	0.6	4.7	0.6	13.0	34.0	24.7
25	18.2	17.0	1.7	3.4	1.7	18.6	35.5	42.4
35	61.6	38.1	3.8	2.7	3.8	22.9	37.4	71.2
45	113.8	59.5	5.9	2.3	6.0	26.2	39.2	100.0
55	167.2	80.0	8.0	2.1	8.0	28.9	40.8	127.0
65	218.2	98.6	9.9	2.0	9.9	31.1	42.1	151.4
75	264.6	115.0	11.5	1.9	11.6	33.0	43.0	172.9
85	305.4	129.1	12.9	1.8	13.0	34.5	43.5	191.3
95	340.2	140.9	14.1	1.8	14.2	35.9	43.8	206.8
105	368.8	150.5	15.0	1.7	15.1	37.0	44.0	219.4
115	391.6	158.0	15.8	1.7	15.9	38.0	44.1	229.4
125	408.8	163.7	16.4	1.7	16.4	39.0	44.1	237.1
years	*ft³/acre*	------------ *tonnes carbon/acre* ------------						
0	0	0.0	0.0	1.9	0.0	0.0	13.4	1.9
5	0	1.3	0.1	1.9	0.1	2.1	13.4	5.5
15	0	2.3	0.2	1.9	0.2	5.2	13.8	10.0
25	260	6.9	0.7	1.4	0.7	7.5	14.4	17.2
35	880	15.4	1.5	1.1	1.5	9.3	15.1	28.8
45	1,626	24.1	2.4	0.9	2.4	10.6	15.9	40.4
55	2,390	32.4	3.2	0.9	3.3	11.7	16.5	51.4
65	3,118	39.9	4.0	0.8	4.0	12.6	17.0	61.3
75	3,782	46.5	4.7	0.8	4.7	13.3	17.4	70.0
85	4,365	52.2	5.2	0.7	5.2	14.0	17.6	77.4
95	4,862	57.0	5.7	0.7	5.7	14.5	17.7	83.7
105	5,271	60.9	6.1	0.7	6.1	15.0	17.8	88.8
115	5,596	63.9	6.4	0.7	6.4	15.4	17.8	92.8
125	5,842	66.2	6.6	0.7	6.7	15.8	17.8	95.9

B32.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands with afforestation of land in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	27.9	4.8
5	0.0	1.9	0.1	4.8	0.1	2.4	28.0	9.2
15	0.2	4.1	0.3	4.8	0.2	6.4	28.7	15.9
25	15.9	14.3	1.4	3.5	0.8	9.8	29.9	29.8
35	51.6	29.9	3.0	2.4	1.7	12.6	31.5	49.6
45	94.3	45.8	4.6	1.9	2.7	14.9	33.0	69.9
55	138.8	59.4	5.9	1.7	3.4	17.0	34.4	87.5
65	182.1	71.6	7.2	1.5	4.2	18.7	35.5	103.2
75	223.1	82.5	8.3	1.4	4.8	20.3	36.2	117.3
85	261.0	92.1	9.2	1.4	5.3	21.7	36.7	129.7
95	295.3	100.5	10.1	1.3	5.8	22.9	36.9	140.6
105	325.9	107.8	10.7	1.3	6.3	24.0	37.1	150.0
115	353.2	114.2	11.1	1.2	6.6	25.0	37.1	158.1
125	377.3	119.7	11.5	1.2	6.9	25.8	37.2	165.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	11.3	1.9
5	0	0.8	0.0	1.9	0.0	1.0	11.3	3.7
15	3	1.7	0.1	1.9	0.1	2.6	11.6	6.4
25	227	5.8	0.6	1.4	0.3	4.0	12.1	12.1
35	737	12.1	1.2	1.0	0.7	5.1	12.7	20.1
45	1,348	18.5	1.9	0.8	1.1	6.0	13.4	28.3
55	1,983	24.0	2.4	0.7	1.4	6.9	13.9	35.4
65	2,603	29.0	2.9	0.6	1.7	7.6	14.4	41.8
75	3,189	33.4	3.3	0.6	1.9	8.2	14.6	47.5
85	3,730	37.3	3.7	0.6	2.2	8.8	14.8	52.5
95	4,220	40.7	4.1	0.5	2.4	9.3	14.9	56.9
105	4,658	43.6	4.3	0.5	2.5	9.7	15.0	60.7
115	5,048	46.2	4.5	0.5	2.7	10.1	15.0	64.0
125	5,392	48.4	4.6	0.5	2.8	10.5	15.0	66.8

B33.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands with afforestation of land in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	25.7	4.8
5	0.0	3.3	0.2	4.8	0.3	2.4	25.8	10.9
15	1.3	6.3	0.6	4.3	0.6	6.4	26.5	18.2
25	18.6	15.9	1.6	3.2	1.4	9.8	27.6	31.8
35	51.8	30.9	3.0	2.5	2.7	12.6	29.0	51.6
45	89.4	46.1	3.9	2.2	4.0	14.9	30.5	71.1
55	127.1	60.4	4.5	2.0	5.3	17.0	31.7	89.2
65	162.2	73.3	5.1	1.9	6.4	18.7	32.7	105.4
75	193.8	84.6	5.5	1.8	7.4	20.3	33.4	119.6
85	221.0	94.2	5.8	1.7	8.2	21.7	33.8	131.6
95	243.7	102.0	6.1	1.7	8.9	22.9	34.1	141.6
105	261.8	108.2	6.3	1.6	9.5	24.0	34.2	149.6
115	275.6	112.9	6.4	1.6	9.9	25.0	34.3	155.7
125	285.1	116.1	6.5	1.6	10.1	25.8	34.3	160.2
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	10.4	1.9
5	0	1.3	0.1	1.9	0.1	1.0	10.4	4.4
15	19	2.6	0.2	1.8	0.2	2.6	10.7	7.4
25	266	6.4	0.6	1.3	0.6	4.0	11.2	12.9
35	740	12.5	1.2	1.0	1.1	5.1	11.8	20.9
45	1,278	18.6	1.6	0.9	1.6	6.0	12.3	28.8
55	1,816	24.5	1.8	0.8	2.1	6.9	12.8	36.1
65	2,318	29.7	2.0	0.8	2.6	7.6	13.2	42.7
75	2,769	34.2	2.2	0.7	3.0	8.2	13.5	48.4
85	3,159	38.1	2.4	0.7	3.3	8.8	13.7	53.3
95	3,483	41.3	2.5	0.7	3.6	9.3	13.8	57.3
105	3,742	43.8	2.5	0.7	3.8	9.7	13.8	60.5
115	3,938	45.7	2.6	0.6	4.0	10.1	13.9	63.0
125	4,075	47.0	2.6	0.6	4.1	10.5	13.9	64.8

B34.— Regional estimates of timber volume and carbon stocks for aspen-birch stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	44.1	4.7
5	0.0	3.1	0.3	4.7	0.2	3.7	44.2	12.1
15	0.0	6.4	0.6	4.7	0.4	9.8	45.4	22.0
25	6.3	13.9	1.4	4.8	0.9	14.4	47.4	35.3
35	22.7	25.7	2.6	4.5	1.7	18.1	49.8	52.5
45	45.0	38.8	3.9	4.3	2.5	21.1	52.3	70.5
55	70.7	52.3	5.2	4.2	3.4	23.6	54.4	88.6
65	98.1	64.7	6.5	4.1	4.2	25.6	56.1	105.0
75	126.5	76.6	7.7	4.0	4.9	27.4	57.3	120.6
85	155.0	88.0	8.8	3.9	5.7	29.0	58.0	135.3
95	183.1	98.8	9.9	3.9	6.3	30.3	58.4	149.2
105	210.5	108.8	10.9	3.8	7.0	31.5	58.6	162.1
115	236.8	118.3	11.8	3.8	7.6	32.6	58.7	174.0
125	261.8	127.0	12.4	3.8	8.2	33.5	58.8	184.8
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	17.8	1.9
5	0	1.2	0.1	1.9	0.1	1.5	17.9	4.9
15	0	2.6	0.3	1.9	0.2	3.9	18.4	8.9
25	90	5.6	0.6	1.9	0.4	5.8	19.2	14.3
35	324	10.4	1.0	1.8	0.7	7.3	20.2	21.3
45	643	15.7	1.6	1.7	1.0	8.5	21.1	28.5
55	1,010	21.2	2.1	1.7	1.4	9.5	22.0	35.9
65	1,402	26.2	2.6	1.6	1.7	10.4	22.7	42.5
75	1,808	31.0	3.1	1.6	2.0	11.1	23.2	48.8
85	2,215	35.6	3.6	1.6	2.3	11.7	23.5	54.8
95	2,617	40.0	4.0	1.6	2.6	12.3	23.6	60.4
105	3,008	44.0	4.4	1.6	2.8	12.7	23.7	65.6
115	3,384	47.9	4.8	1.5	3.1	13.2	23.8	70.4
125	3,741	51.4	5.0	1.5	3.3	13.6	23.8	74.8

B35.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	23.2	4.8
5	0.0	2.6	0.3	4.8	0.2	5.2	23.3	13.1
15	1.6	7.2	0.7	4.8	0.6	13.0	23.8	26.3
25	15.3	19.8	2.0	4.4	1.5	18.6	24.9	46.2
35	39.1	37.2	3.7	2.0	2.8	22.9	26.2	68.6
45	66.2	54.6	5.5	1.2	4.2	26.2	27.5	91.7
55	93.9	71.6	7.2	0.9	5.5	28.9	28.6	114.1
65	120.8	85.9	8.6	0.7	6.6	31.1	29.5	132.9
75	146.1	98.8	9.9	0.6	7.6	33.0	30.1	149.8
85	169.5	110.3	11.0	0.6	8.5	34.5	30.5	164.9
95	190.7	120.6	12.1	0.6	9.2	35.9	30.7	178.3
105	209.8	129.5	12.9	0.6	9.9	37.0	30.8	190.0
115	227.0	137.5	13.3	0.7	10.5	38.0	30.9	200.1
125	242.3	144.4	13.8	0.7	11.1	39.0	30.9	208.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	0.0	0.0	9.4	2.0
5	0	1.1	0.1	2.0	0.1	2.1	9.4	5.3
15	23	2.9	0.3	2.0	0.2	5.2	9.7	10.6
25	219	8.0	0.8	1.8	0.6	7.5	10.1	18.7
35	559	15.0	1.5	0.8	1.2	9.3	10.6	27.8
45	946	22.1	2.2	0.5	1.7	10.6	11.1	37.1
55	1,342	29.0	2.9	0.4	2.2	11.7	11.6	46.2
65	1,726	34.8	3.5	0.3	2.7	12.6	11.9	53.8
75	2,088	40.0	4.0	0.2	3.1	13.3	12.2	60.6
85	2,422	44.7	4.5	0.2	3.4	14.0	12.3	66.7
95	2,726	48.8	4.9	0.2	3.7	14.5	12.4	72.2
105	2,999	52.4	5.2	0.3	4.0	15.0	12.5	76.9
115	3,244	55.6	5.4	0.3	4.3	15.4	12.5	81.0
125	3,463	58.5	5.6	0.3	4.5	15.8	12.5	84.6

B36.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	23.6	4.8
5	0.0	1.8	0.2	4.8	0.1	5.2	23.7	12.1
15	0.0	4.0	0.4	4.8	0.3	13.0	24.3	22.5
25	8.5	12.0	1.2	4.3	0.9	18.6	25.3	37.0
35	27.7	24.4	2.4	2.8	1.9	22.9	26.7	54.5
45	49.5	36.7	3.7	2.3	2.9	26.2	28.0	71.7
55	71.9	48.7	4.9	1.9	3.8	28.9	29.1	88.2
65	94.1	58.6	5.9	1.7	4.6	31.1	30.0	101.9
75	115.7	67.8	6.8	1.6	5.3	33.0	30.6	114.4
85	136.5	76.2	7.6	1.5	6.0	34.5	31.0	125.8
95	156.4	84.0	8.4	1.4	6.6	35.9	31.3	136.3
105	175.2	91.2	9.1	1.3	7.2	37.0	31.4	145.8
115	193.0	97.8	9.8	1.3	7.7	38.0	31.4	154.6
125	209.6	103.8	10.4	1.2	8.2	39.0	31.5	162.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	0.0	0.0	9.6	2.0
5	0	0.7	0.1	2.0	0.1	2.1	9.6	4.9
15	0	1.6	0.2	2.0	0.1	5.2	9.8	9.1
25	122	4.8	0.5	1.7	0.4	7.5	10.3	15.0
35	396	9.9	1.0	1.1	0.8	9.3	10.8	22.1
45	708	14.8	1.5	0.9	1.2	10.6	11.3	29.0
55	1,028	19.7	2.0	0.8	1.6	11.7	11.8	35.7
65	1,345	23.7	2.4	0.7	1.9	12.6	12.1	41.2
75	1,654	27.4	2.7	0.6	2.2	13.3	12.4	46.3
85	1,951	30.8	3.1	0.6	2.4	14.0	12.6	50.9
95	2,235	34.0	3.4	0.6	2.7	14.5	12.7	55.1
105	2,504	36.9	3.7	0.5	2.9	15.0	12.7	59.0
115	2,758	39.6	4.0	0.5	3.1	15.4	12.7	62.6
125	2,995	42.0	4.2	0.5	3.3	15.8	12.7	65.8

B37.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	20.2	4.8
5	0.0	2.1	0.2	4.8	0.2	2.4	20.3	9.7
15	0.0	4.3	0.4	4.8	0.4	6.4	20.8	16.4
25	5.0	9.2	0.9	4.8	0.9	9.8	21.7	25.5
35	18.3	16.9	1.7	3.4	1.7	12.6	22.8	36.2
45	37.0	25.9	2.6	2.5	2.5	14.9	24.0	48.4
55	58.5	34.1	3.4	2.0	3.4	17.0	25.0	59.9
65	81.2	42.0	4.2	1.7	4.1	18.7	25.7	70.8
75	104.1	49.5	4.9	1.5	4.9	20.3	26.3	81.1
85	126.7	56.4	5.6	1.4	5.6	21.7	26.6	90.7
95	148.3	62.8	6.3	1.3	6.2	22.9	26.8	99.4
105	168.6	68.6	6.9	1.2	6.8	24.0	26.9	107.4
115	187.3	73.8	7.4	1.1	7.3	25.0	26.9	114.5
125	204.1	78.3	7.8	1.1	7.7	25.8	27.0	120.8
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	8.2	1.9
5	0	0.9	0.1	1.9	0.1	1.0	8.2	3.9
15	0	1.7	0.2	1.9	0.2	2.6	8.4	6.6
25	71	3.7	0.4	1.9	0.4	4.0	8.8	10.3
35	262	6.8	0.7	1.4	0.7	5.1	9.2	14.6
45	529	10.5	1.0	1.0	1.0	6.0	9.7	19.6
55	836	13.8	1.4	0.8	1.4	6.9	10.1	24.2
65	1,160	17.0	1.7	0.7	1.7	7.6	10.4	28.7
75	1,488	20.0	2.0	0.6	2.0	8.2	10.6	32.8
85	1,810	22.8	2.3	0.6	2.2	8.8	10.8	36.7
95	2,120	25.4	2.5	0.5	2.5	9.3	10.8	40.2
105	2,410	27.8	2.8	0.5	2.7	9.7	10.9	43.5
115	2,677	29.8	3.0	0.5	2.9	10.1	10.9	46.3
125	2,917	31.7	3.2	0.4	3.1	10.5	10.9	48.9

B38.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live Tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	18.1	4.8
5	0.0	1.8	0.2	4.8	0.2	2.4	18.1	9.4
15	0.0	3.7	0.4	4.8	0.3	6.4	18.6	15.6
25	4.4	9.4	0.9	4.8	0.8	9.8	19.4	25.7
35	16.2	18.6	1.9	2.9	1.5	12.6	20.4	37.5
45	32.2	28.8	2.7	2.1	2.4	14.9	21.4	50.9
55	50.3	38.2	3.0	1.7	3.1	17.0	22.3	63.1
65	69.3	47.1	3.3	1.5	3.9	18.7	23.0	74.5
75	88.4	55.5	3.6	1.3	4.6	20.3	23.5	85.2
85	107.2	63.2	3.8	1.2	5.2	21.7	23.8	95.1
95	125.5	70.4	4.0	1.1	5.8	22.9	24.0	104.2
105	143.0	77.1	4.1	1.0	6.3	24.0	24.0	112.5
115	159.5	83.2	4.3	1.0	6.8	25.0	24.1	120.2
125	175.1	88.8	4.4	0.9	7.3	25.8	24.1	127.2
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	0.0	0.0	7.3	2.0
5	0	0.7	0.1	2.0	0.1	1.0	7.3	3.8
15	0	1.5	0.1	2.0	0.1	2.6	7.5	6.3
25	63	3.8	0.4	2.0	0.3	4.0	7.9	10.4
35	231	7.5	0.8	1.2	0.6	5.1	8.3	15.2
45	460	11.7	1.1	0.9	1.0	6.0	8.7	20.6
55	719	15.5	1.2	0.7	1.3	6.9	9.0	25.5
65	990	19.1	1.4	0.6	1.6	7.6	9.3	30.2
75	1,263	22.4	1.5	0.5	1.8	8.2	9.5	34.5
85	1,532	25.6	1.5	0.5	2.1	8.8	9.6	38.5
95	1,793	28.5	1.6	0.4	2.3	9.3	9.7	42.2
105	2,043	31.2	1.7	0.4	2.6	9.7	9.7	45.5
115	2,280	33.7	1.7	0.4	2.8	10.1	9.7	48.6
125	2,503	35.9	1.8	0.4	3.0	10.5	9.8	51.5

B39.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	54.7	4.2
5	0.0	11.1	0.7	4.0	0.9	3.2	54.9	19.8
10	19.1	22.6	1.3	3.6	1.8	5.5	55.4	34.8
15	36.7	31.3	1.6	3.4	2.5	7.3	56.3	46.1
20	60.4	40.8	1.9	3.2	3.3	8.7	57.4	57.9
25	85.5	50.3	2.1	3.1	4.1	9.8	58.7	69.4
30	108.7	58.2	2.3	3.1	4.7	10.7	60.2	79.0
35	131.2	65.6	2.4	3.0	5.3	11.5	61.8	87.9
40	152.3	72.5	2.5	3.0	5.9	12.2	63.3	96.1
45	172.3	78.9	2.7	2.9	6.4	12.7	64.8	103.6
50	191.4	85.0	2.7	2.9	6.9	13.2	66.2	110.7
55	208.4	90.3	2.8	2.9	7.3	13.7	67.5	116.9
60	223.9	95.1	2.9	2.8	7.7	14.1	68.6	122.6
65	238.4	99.6	2.9	2.8	8.1	14.4	69.6	127.8
70	252.9	104.0	3.0	2.8	8.4	14.7	70.4	133.0
75	264.6	107.6	3.0	2.8	8.7	15.0	71.0	137.1
80	277.1	111.4	3.1	2.8	9.0	15.2	71.5	141.5
85	289.5	115.1	3.1	2.8	9.3	15.5	71.9	145.8
90	299.6	118.2	3.2	2.7	9.6	15.7	72.2	149.3
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	22.1	1.7
5	0	4.5	0.3	1.6	0.4	1.3	22.2	8.0
10	273	9.2	0.5	1.4	0.7	2.2	22.4	14.1
15	525	12.7	0.7	1.4	1.0	2.9	22.8	18.7
20	863	16.5	0.8	1.3	1.3	3.5	23.2	23.4
25	1,222	20.4	0.9	1.3	1.6	4.0	23.8	28.1
30	1,554	23.5	0.9	1.2	1.9	4.3	24.4	32.0
35	1,875	26.6	1.0	1.2	2.2	4.7	25.0	35.6
40	2,177	29.3	1.0	1.2	2.4	4.9	25.6	38.9
45	2,462	31.9	1.1	1.2	2.6	5.2	26.2	41.9
50	2,736	34.4	1.1	1.2	2.8	5.4	26.8	44.8
55	2,978	36.5	1.1	1.2	3.0	5.5	27.3	47.3
60	3,200	38.5	1.2	1.1	3.1	5.7	27.8	49.6
65	3,407	40.3	1.2	1.1	3.3	5.8	28.2	51.7
70	3,614	42.1	1.2	1.1	3.4	6.0	28.5	53.8
75	3,782	43.5	1.2	1.1	3.5	6.1	28.7	55.5
80	3,960	45.1	1.3	1.1	3.7	6.2	28.9	57.3
85	4,138	46.6	1.3	1.1	3.8	6.3	29.1	59.0
90	4,281	47.8	1.3	1.1	3.9	6.3	29.2	60.4

B40.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands with afforestation of land in the Southeast; volumes are for high productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	0.0	0.0	54.7	4.1
5	0.0	11.0	0.7	4.0	0.4	3.2	54.9	19.3
10	47.7	31.9	1.4	3.8	1.2	5.5	55.4	43.8
15	146.5	67.4	1.9	3.7	2.5	7.3	56.3	82.9
20	244.8	102.3	2.1	3.7	3.8	8.7	57.4	120.6
25	315.2	124.2	2.3	3.7	4.7	9.8	58.7	144.6
30	347.3	134.1	2.4	3.7	5.0	10.7	60.2	155.8
35	351.5	135.4	2.4	3.7	5.1	11.5	61.8	158.0
40	355.0	136.5	2.4	3.7	5.1	12.2	63.3	159.8
45	358.5	137.5	2.4	3.6	5.2	12.7	64.8	161.4
50	362.0	138.6	2.4	3.6	5.2	13.2	66.2	163.1
55	362.0	138.6	2.4	3.6	5.2	13.7	67.5	163.5
60	362.0	138.6	2.4	3.6	5.2	14.1	68.6	163.9
65	362.0	138.6	2.4	3.6	5.2	14.4	69.6	164.2
70	362.0	138.6	2.4	3.6	5.2	14.7	70.4	164.5
75	362.0	138.6	2.4	3.6	5.2	15.0	71.0	164.8
80	362.0	138.6	2.4	3.6	5.2	15.2	71.5	165.1
85	362.0	138.6	2.4	3.6	5.2	15.5	71.9	165.3
90	362.0	138.6	2.4	3.6	5.2	15.7	72.2	165.5
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	22.1	1.7
5	0	4.5	0.3	1.6	0.2	1.3	22.2	7.8
10	682	12.9	0.6	1.6	0.5	2.2	22.4	17.7
15	2,094	27.3	0.8	1.5	1.0	2.9	22.8	33.5
20	3,498	41.4	0.9	1.5	1.5	3.5	23.2	48.8
25	4,504	50.3	0.9	1.5	1.9	4.0	23.8	58.5
30	4,963	54.3	1.0	1.5	2.0	4.3	24.4	63.1
35	5,024	54.8	1.0	1.5	2.1	4.7	25.0	63.9
40	5,074	55.2	1.0	1.5	2.1	4.9	25.6	64.7
45	5,124	55.7	1.0	1.5	2.1	5.2	26.2	65.3
50	5,174	56.1	1.0	1.5	2.1	5.4	26.8	66.0
55	5,174	56.1	1.0	1.5	2.1	5.5	27.3	66.2
60	5,174	56.1	1.0	1.5	2.1	5.7	27.8	66.3
65	5,174	56.1	1.0	1.5	2.1	5.8	28.2	66.5
70	5,174	56.1	1.0	1.5	2.1	6.0	28.5	66.6
75	5,174	56.1	1.0	1.5	2.1	6.1	28.7	66.7
80	5,174	56.1	1.0	1.5	2.1	6.2	28.9	66.8
85	5,174	56.1	1.0	1.5	2.1	6.3	29.1	66.9
90	5,174	56.1	1.0	1.5	2.1	6.3	29.2	67.0

B41.— Regional estimates of timber volume and carbon stocks for longleaf-slash pine stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	82.5	4.2
5	0.0	5.3	0.4	4.2	0.4	3.2	82.8	13.6
10	19.1	14.1	0.9	3.8	1.1	5.5	83.6	25.4
15	36.7	21.4	1.0	3.6	1.7	7.3	84.9	34.9
20	60.4	30.4	1.1	3.4	2.5	8.7	86.6	46.0
25	85.5	39.2	1.1	3.3	3.2	9.8	88.6	56.6
30	108.7	47.2	1.2	3.2	3.8	10.7	90.9	66.1
35	131.2	54.8	1.2	3.1	4.4	11.5	93.2	75.1
40	152.3	61.9	1.3	3.0	5.0	12.2	95.5	83.4
45	172.3	68.5	1.3	3.0	5.6	12.7	97.8	91.1
50	191.4	74.8	1.3	2.9	6.1	13.2	99.9	98.4
55	208.4	80.4	1.3	2.9	6.5	13.7	101.8	104.8
60	223.9	85.4	1.3	2.9	6.9	14.1	103.5	110.6
65	238.4	90.1	1.4	2.9	7.3	14.4	105.0	116.1
70	252.9	94.8	1.4	2.8	7.7	14.7	106.2	121.4
75	264.6	98.6	1.4	2.8	8.0	15.0	107.1	125.8
80	277.1	102.6	1.4	2.8	8.3	15.2	107.9	130.3
85	289.5	106.6	1.4	2.8	8.6	15.5	108.5	134.9
90	299.6	109.8	1.4	2.8	8.9	15.7	109.0	138.5
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	33.4	1.7
5	0	2.2	0.2	1.7	0.2	1.3	33.5	5.5
10	273	5.7	0.3	1.5	0.5	2.2	33.8	10.3
15	525	8.7	0.4	1.4	0.7	2.9	34.4	14.1
20	863	12.3	0.4	1.4	1.0	3.5	35.0	18.6
25	1,222	15.9	0.5	1.3	1.3	4.0	35.9	22.9
30	1,554	19.1	0.5	1.3	1.5	4.3	36.8	26.7
35	1,875	22.2	0.5	1.3	1.8	4.7	37.7	30.4
40	2,177	25.0	0.5	1.2	2.0	4.9	38.7	33.7
45	2,462	27.7	0.5	1.2	2.2	5.2	39.6	36.9
50	2,736	30.3	0.5	1.2	2.5	5.4	40.4	39.8
55	2,978	32.5	0.5	1.2	2.6	5.5	41.2	42.4
60	3,200	34.6	0.5	1.2	2.8	5.7	41.9	44.8
65	3,407	36.5	0.6	1.2	3.0	5.8	42.5	47.0
70	3,614	38.4	0.6	1.1	3.1	6.0	43.0	49.1
75	3,782	39.9	0.6	1.1	3.2	6.1	43.4	50.9
80	3,960	41.5	0.6	1.1	3.4	6.2	43.7	52.7
85	4,138	43.1	0.6	1.1	3.5	6.3	43.9	54.6
90	4,281	44.4	0.6	1.1	3.6	6.3	44.1	56.1

B42.— Regional estimates of timber volume and carbon stocks for longleaf-slash pine stands with afforestation of land in the Southeast; volumes are for high productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	0.0	0.0	82.5	4.1
5	0.0	8.8	0.4	4.0	0.3	3.2	82.8	16.7
10	47.7	27.2	0.8	3.9	1.0	5.5	83.6	38.4
15	146.5	60.1	0.8	3.8	2.2	7.3	84.9	74.2
20	244.8	91.2	0.9	3.7	3.4	8.7	86.6	107.9
25	315.2	113.5	0.9	3.7	4.2	9.8	88.6	132.1
30	347.3	122.8	0.9	3.7	4.6	10.7	90.9	142.7
35	351.5	124.0	0.9	3.7	4.6	11.5	93.2	144.8
40	355.0	125.0	0.9	3.7	4.7	12.2	95.5	146.5
45	358.5	126.0	0.9	3.7	4.7	12.7	97.8	148.1
50	362.0	127.0	0.9	3.7	4.8	13.2	99.9	149.6
55	362.0	127.0	0.9	3.7	4.8	13.7	101.8	150.1
60	362.0	127.0	0.9	3.7	4.8	14.1	103.5	150.4
65	362.0	127.0	0.9	3.7	4.8	14.4	105.0	150.8
70	362.0	127.0	0.9	3.7	4.8	14.7	106.2	151.1
75	362.0	127.0	0.9	3.7	4.8	15.0	107.1	151.4
80	362.0	127.0	0.9	3.7	4.8	15.2	107.9	151.6
85	362.0	127.0	0.9	3.7	4.8	15.5	108.5	151.9
90	362.0	127.0	0.9	3.7	4.8	15.7	109.0	152.1
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	33.4	1.7
5	0	3.6	0.2	1.6	0.1	1.3	33.5	6.8
10	682	11.0	0.3	1.6	0.4	2.2	33.8	15.5
15	2,094	24.3	0.3	1.5	0.9	2.9	34.4	30.0
20	3,498	36.9	0.4	1.5	1.4	3.5	35.0	43.6
25	4,504	45.9	0.4	1.5	1.7	4.0	35.9	53.5
30	4,963	49.7	0.4	1.5	1.9	4.3	36.8	57.7
35	5,024	50.2	0.4	1.5	1.9	4.7	37.7	58.6
40	5,074	50.6	0.4	1.5	1.9	4.9	38.7	59.3
45	5,124	51.0	0.4	1.5	1.9	5.2	39.6	59.9
50	5,174	51.4	0.4	1.5	1.9	5.4	40.4	60.6
55	5,174	51.4	0.4	1.5	1.9	5.5	41.2	60.7
60	5,174	51.4	0.4	1.5	1.9	5.7	41.9	60.9
65	5,174	51.4	0.4	1.5	1.9	5.8	42.5	61.0
70	5,174	51.4	0.4	1.5	1.9	6.0	43.0	61.1
75	5,174	51.4	0.4	1.5	1.9	6.1	43.4	61.3
80	5,174	51.4	0.4	1.5	1.9	6.2	43.7	61.4
85	5,174	51.4	0.4	1.5	1.9	6.3	43.9	61.5
90	5,174	51.4	0.4	1.5	1.9	6.3	44.1	61.5

B43.— Regional estimates of timber volume and carbon stocks for oak-gum-cypress stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	1.8	0.0	0.0	118.5	1.8
5	0.0	6.7	0.7	1.9	0.4	1.1	118.9	10.9
10	9.8	18.8	1.9	1.8	1.2	2.1	120.1	25.8
15	19.9	28.3	2.4	1.7	1.8	3.0	121.9	37.2
20	32.7	38.0	2.8	1.7	2.4	3.7	124.4	48.6
25	45.4	46.8	3.1	1.6	3.0	4.4	127.2	58.9
30	58.1	54.0	3.4	1.6	3.4	5.0	130.5	67.5
35	73.4	62.3	3.6	1.6	4.0	5.5	133.8	77.0
40	92.2	71.9	3.9	1.6	4.6	6.0	137.2	88.0
45	110.7	80.9	4.2	1.6	5.1	6.4	140.4	98.2
50	128.1	89.0	4.4	1.5	5.7	6.8	143.5	107.4
55	146.3	97.3	4.6	1.5	6.2	7.2	146.2	116.7
60	166.1	105.9	4.7	1.5	6.7	7.5	148.7	126.4
65	186.4	114.5	4.9	1.5	7.3	7.8	150.7	136.1
70	205.7	122.5	5.1	1.5	7.8	8.1	152.4	145.0
75	222.5	129.3	5.2	1.5	8.2	8.4	153.8	152.6
80	237.9	135.4	5.3	1.5	8.6	8.6	155.0	159.4
85	257.3	142.9	5.5	1.5	9.1	8.9	155.8	167.8
90	278.9	151.2	5.6	1.5	9.6	9.1	156.5	177.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.7	0.0	0.0	48.0	0.7
5	0	2.7	0.3	0.8	0.2	0.5	48.1	4.4
10	140	7.6	0.8	0.7	0.5	0.9	48.6	10.4
15	284	11.5	1.0	0.7	0.7	1.2	49.3	15.1
20	467	15.4	1.1	0.7	1.0	1.5	50.3	19.7
25	649	18.9	1.3	0.7	1.2	1.8	51.5	23.8
30	830	21.9	1.4	0.7	1.4	2.0	52.8	27.3
35	1,049	25.2	1.5	0.6	1.6	2.2	54.2	31.2
40	1,318	29.1	1.6	0.6	1.9	2.4	55.5	35.6
45	1,582	32.7	1.7	0.6	2.1	2.6	56.8	39.7
50	1,830	36.0	1.8	0.6	2.3	2.8	58.1	43.5
55	2,091	39.4	1.8	0.6	2.5	2.9	59.2	47.2
60	2,374	42.9	1.9	0.6	2.7	3.1	60.2	51.2
65	2,664	46.3	2.0	0.6	2.9	3.2	61.0	55.1
70	2,940	49.6	2.1	0.6	3.2	3.3	61.7	58.7
75	3,180	52.3	2.1	0.6	3.3	3.4	62.3	61.8
80	3,400	54.8	2.2	0.6	3.5	3.5	62.7	64.5
85	3,677	57.8	2.2	0.6	3.7	3.6	63.1	67.9
90	3,986	61.2	2.3	0.6	3.9	3.7	63.3	71.6

B44.—Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	33.9	4.2
5	0.0	8.1	0.8	4.2	0.5	1.1	34.1	14.7
10	11.7	21.0	2.1	3.8	1.2	2.1	34.4	30.2
15	21.2	30.3	2.5	3.5	1.8	3.0	34.9	41.0
20	33.8	40.0	2.8	3.3	2.4	3.7	35.6	52.2
25	46.6	49.5	3.0	3.2	2.9	4.4	36.4	63.1
30	60.2	57.5	3.2	3.1	3.4	5.0	37.4	72.3
35	76.3	66.6	3.4	3.0	4.0	5.5	38.3	82.5
40	94.3	76.2	3.6	2.9	4.5	6.0	39.3	93.3
45	114.1	86.4	3.8	2.9	5.1	6.4	40.2	104.6
50	133.0	95.8	4.0	2.8	5.7	6.8	41.1	115.1
55	151.4	104.8	4.1	2.8	6.2	7.2	41.9	125.0
60	168.9	113.0	4.2	2.7	6.7	7.5	42.6	134.2
65	185.6	120.8	4.3	2.7	7.2	7.8	43.2	142.8
70	201.5	128.0	4.4	2.7	7.6	8.1	43.7	150.8
75	215.7	134.4	4.5	2.6	8.0	8.4	44.1	157.9
80	229.4	140.5	4.6	2.6	8.3	8.6	44.4	164.6
85	242.5	146.2	4.6	2.6	8.7	8.9	44.6	171.0
90	254.1	151.3	4.7	2.6	9.0	9.1	44.8	176.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	13.7	1.7
5	0	3.3	0.3	1.7	0.2	0.5	13.8	6.0
10	167	8.5	0.8	1.5	0.5	0.9	13.9	12.2
15	303	12.3	1.0	1.4	0.7	1.2	14.1	16.6
20	483	16.2	1.1	1.3	1.0	1.5	14.4	21.1
25	666	20.1	1.2	1.3	1.2	1.8	14.7	25.5
30	860	23.3	1.3	1.3	1.4	2.0	15.1	29.3
35	1,091	26.9	1.4	1.2	1.6	2.2	15.5	33.4
40	1,348	30.8	1.5	1.2	1.8	2.4	15.9	37.8
45	1,630	35.0	1.5	1.2	2.1	2.6	16.3	42.4
50	1,901	38.8	1.6	1.1	2.3	2.8	16.6	46.6
55	2,164	42.4	1.7	1.1	2.5	2.9	16.9	50.6
60	2,414	45.7	1.7	1.1	2.7	3.1	17.2	54.3
65	2,652	48.9	1.7	1.1	2.9	3.2	17.5	57.8
70	2,880	51.8	1.8	1.1	3.1	3.3	17.7	61.0
75	3,082	54.4	1.8	1.1	3.2	3.4	17.8	63.9
80	3,278	56.8	1.8	1.1	3.4	3.5	18.0	66.6
85	3,465	59.2	1.9	1.0	3.5	3.6	18.1	69.2
90	3,632	61.2	1.9	1.0	3.6	3.7	18.1	71.5

B45.— Regional estimates of timber volume and carbon stocks for oak-pine stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	m^3*/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	46.1	4.2
5	0.0	7.4	0.6	4.1	0.5	3.1	46.2	15.6
10	13.6	19.6	1.2	3.6	1.2	5.1	46.7	30.8
15	27.8	29.3	1.6	3.5	1.9	6.6	47.4	42.8
20	43.9	39.0	1.9	3.4	2.5	7.7	48.3	54.5
25	59.3	46.8	2.1	3.3	3.0	8.5	49.5	63.7
30	77.2	55.4	2.3	3.2	3.5	9.2	50.7	73.7
35	96.8	64.4	2.5	3.2	4.1	9.8	52.0	83.9
40	117.2	73.4	2.7	3.1	4.7	10.2	53.3	94.1
45	136.4	81.6	2.8	3.1	5.2	10.6	54.6	103.3
50	154.1	88.9	2.9	3.1	5.6	11.0	55.8	111.5
55	171.4	96.0	3.0	3.0	6.1	11.3	56.8	119.4
60	189.6	103.2	3.1	3.0	6.6	11.5	57.8	127.4
65	204.5	109.1	3.2	3.0	6.9	11.8	58.6	134.0
70	218.8	114.6	3.3	3.0	7.3	12.0	59.2	140.1
75	234.5	120.6	3.4	2.9	7.7	12.1	59.8	146.7
80	247.6	125.5	3.5	2.9	8.0	12.3	60.2	152.2
85	259.4	129.9	3.5	2.9	8.2	12.5	60.6	157.1
90	272.3	134.7	3.6	2.9	8.5	12.6	60.8	162.3
years	ft^3*/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	18.6	1.7
5	0	3.0	0.3	1.7	0.2	1.2	18.7	6.3
10	195	7.9	0.5	1.5	0.5	2.1	18.9	12.5
15	397	11.9	0.6	1.4	0.8	2.7	19.2	17.3
20	628	15.8	0.8	1.4	1.0	3.1	19.6	22.0
25	848	19.0	0.8	1.3	1.2	3.5	20.0	25.8
30	1,104	22.4	0.9	1.3	1.4	3.7	20.5	29.8
35	1,384	26.1	1.0	1.3	1.7	4.0	21.0	34.0
40	1,675	29.7	1.1	1.3	1.9	4.1	21.6	38.1
45	1,950	33.0	1.1	1.2	2.1	4.3	22.1	41.8
50	2,202	36.0	1.2	1.2	2.3	4.4	22.6	45.1
55	2,450	38.8	1.2	1.2	2.5	4.6	23.0	48.3
60	2,710	41.8	1.3	1.2	2.7	4.7	23.4	51.6
65	2,923	44.1	1.3	1.2	2.8	4.8	23.7	54.2
70	3,127	46.4	1.3	1.2	2.9	4.8	24.0	56.7
75	3,352	48.8	1.4	1.2	3.1	4.9	24.2	59.4
80	3,539	50.8	1.4	1.2	3.2	5.0	24.4	61.6
85	3,707	52.6	1.4	1.2	3.3	5.0	24.5	63.6
90	3,891	54.5	1.4	1.2	3.5	5.1	24.6	65.7

B46.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands with afforestation of land in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	m^3*/hectare*	------------------------------------- *tonnes carbon/hectare* -------------------------------------						
0	0.0	0.0	0.0	4.2	0.0	0.0	37.4	4.2
5	0.0	8.6	0.9	4.9	0.6	1.1	37.5	16.0
10	11.7	18.3	1.8	4.1	1.2	2.1	37.9	27.6
15	21.2	27.0	2.7	3.7	1.8	3.0	38.5	38.2
20	33.8	36.3	3.3	3.5	2.4	3.7	39.2	49.1
25	46.6	45.1	3.6	3.3	3.0	4.4	40.2	59.4
30	60.2	53.8	3.8	3.2	3.6	5.0	41.2	69.4
35	76.3	63.3	4.1	3.1	4.2	5.5	42.2	80.2
40	94.3	73.3	4.4	2.9	4.9	6.0	43.3	91.5
45	114.1	83.8	4.6	2.9	5.6	6.4	44.3	103.3
50	133.0	95.1	4.8	2.8	6.3	6.8	45.3	115.9
55	151.4	104.2	5.0	2.7	6.9	7.2	46.2	126.0
60	168.9	112.7	5.1	2.7	7.5	7.5	46.9	135.5
65	185.6	120.7	5.3	2.6	8.0	7.8	47.6	144.5
70	201.5	128.4	5.4	2.6	8.5	8.1	48.1	153.0
75	215.7	135.1	5.5	2.6	9.0	8.4	48.6	160.6
80	229.4	141.6	5.6	2.5	9.4	8.6	48.9	167.8
85	242.5	147.8	5.7	2.5	9.8	8.9	49.2	174.7
90	254.1	153.4	5.8	2.5	10.2	9.1	49.4	180.9
years	ft^3*/acre*	------------------------------------- *tonnes carbon/acre* -------------------------------------						
0	0	0.0	0.0	1.7	0.0	0.0	15.1	1.7
5	0	3.5	0.3	2.0	0.2	0.5	15.2	6.5
10	167	7.4	0.7	1.7	0.5	0.9	15.3	11.2
15	303	10.9	1.1	1.5	0.7	1.2	15.6	15.5
20	483	14.7	1.3	1.4	1.0	1.5	15.9	19.9
25	666	18.3	1.4	1.3	1.2	1.8	16.3	24.0
30	860	21.8	1.6	1.3	1.4	2.0	16.7	28.1
35	1,091	25.6	1.7	1.2	1.7	2.2	17.1	32.4
40	1,348	29.7	1.8	1.2	2.0	2.4	17.5	37.0
45	1,630	33.9	1.9	1.2	2.3	2.6	17.9	41.8
50	1,901	38.5	1.9	1.1	2.6	2.8	18.3	46.9
55	2,164	42.2	2.0	1.1	2.8	2.9	18.7	51.0
60	2,414	45.6	2.1	1.1	3.0	3.1	19.0	54.8
65	2,652	48.9	2.1	1.1	3.2	3.2	19.3	58.5
70	2,880	52.0	2.2	1.0	3.5	3.3	19.5	61.9
75	3,082	54.7	2.2	1.0	3.6	3.4	19.7	65.0
80	3,278	57.3	2.3	1.0	3.8	3.5	19.8	67.9
85	3,465	59.8	2.3	1.0	4.0	3.6	19.9	70.7
90	3,632	62.1	2.3	1.0	4.1	3.7	20.0	73.2

B47.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands with afforestation of land in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	31.4	4.2
5	0.0	10.8	0.7	4.7	0.7	3.2	31.5	20.1
10	19.1	23.1	1.3	3.9	1.6	5.5	31.8	35.4
15	36.7	32.4	1.6	3.5	2.2	7.3	32.3	47.0
20	60.4	42.2	1.8	3.3	2.9	8.7	33.0	58.9
25	85.5	52.0	2.0	3.1	3.6	9.8	33.7	70.5
30	108.7	59.6	2.1	3.0	4.1	10.7	34.6	79.5
35	131.2	66.6	2.3	2.9	4.6	11.5	35.5	87.8
40	152.3	73.1	2.3	2.9	5.0	12.2	36.4	95.4
45	172.3	79.0	2.4	2.8	5.4	12.7	37.2	102.4
50	191.4	84.7	2.5	2.8	5.8	13.2	38.0	108.9
55	208.4	89.6	2.6	2.7	6.1	13.7	38.8	114.6
60	223.9	94.0	2.6	2.7	6.4	14.1	39.4	119.8
65	238.4	98.1	2.7	2.6	6.7	14.4	40.0	124.5
70	252.9	102.2	2.7	2.6	7.0	14.7	40.4	129.2
75	264.6	105.5	2.7	2.6	7.2	15.0	40.8	133.0
80	277.1	108.9	2.8	2.6	7.4	15.2	41.1	136.9
85	289.5	112.3	2.8	2.6	7.7	15.5	41.3	140.8
90	299.6	115.1	2.8	2.5	7.9	15.7	41.5	144.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	12.7	1.7
5	0	4.4	0.3	1.9	0.3	1.3	12.8	8.1
10	273	9.4	0.5	1.6	0.6	2.2	12.9	14.3
15	525	13.1	0.6	1.4	0.9	2.9	13.1	19.0
20	863	17.1	0.7	1.3	1.2	3.5	13.3	23.8
25	1,222	21.1	0.8	1.3	1.4	4.0	13.7	28.5
30	1,554	24.1	0.9	1.2	1.6	4.3	14.0	32.2
35	1,875	27.0	0.9	1.2	1.8	4.7	14.4	35.5
40	2,177	29.6	0.9	1.2	2.0	4.9	14.7	38.6
45	2,462	32.0	1.0	1.1	2.2	5.2	15.1	41.4
50	2,736	34.3	1.0	1.1	2.3	5.4	15.4	44.1
55	2,978	36.3	1.0	1.1	2.5	5.5	15.7	46.4
60	3,200	38.1	1.1	1.1	2.6	5.7	16.0	48.5
65	3,407	39.7	1.1	1.1	2.7	5.8	16.2	50.4
70	3,614	41.4	1.1	1.1	2.8	6.0	16.4	52.3
75	3,782	42.7	1.1	1.1	2.9	6.1	16.5	53.8
80	3,960	44.1	1.1	1.0	3.0	6.2	16.6	55.4
85	4,138	45.5	1.1	1.0	3.1	6.3	16.7	57.0
90	4,281	46.6	1.1	1.0	3.2	6.3	16.8	58.3

B48.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands with afforestation of land in the South Central; volumes are for high-productivity sites (growth rate greater than 120 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	0.0	0.0	31.4	4.1
5	0.0	10.8	0.4	4.1	0.4	3.2	31.5	18.9
10	47.7	34.2	0.9	3.9	1.3	5.5	31.8	45.7
15	146.5	68.7	1.0	3.8	2.7	7.3	32.3	83.4
20	244.8	99.2	1.1	3.7	3.8	8.7	33.0	116.5
25	315.2	118.3	1.1	3.7	4.6	9.8	33.7	137.6
30	347.3	126.8	1.1	3.7	4.9	10.7	34.6	147.3
35	351.5	127.9	1.1	3.7	5.0	11.5	35.5	149.2
40	355.0	128.8	1.1	3.7	5.0	12.2	36.4	150.8
45	358.5	129.8	1.1	3.7	5.0	12.7	37.2	152.4
50	362.0	130.7	1.1	3.7	5.1	13.2	38.0	153.8
55	362.0	130.7	1.1	3.7	5.1	13.7	38.8	154.2
60	362.0	130.7	1.1	3.7	5.1	14.1	39.4	154.6
65	362.0	130.7	1.1	3.7	5.1	14.4	40.0	155.0
70	362.0	130.7	1.1	3.7	5.1	14.7	40.4	155.3
75	362.0	130.7	1.1	3.7	5.1	15.0	40.8	155.6
80	362.0	130.7	1.1	3.7	5.1	15.2	41.1	155.8
85	362.0	130.7	1.1	3.7	5.1	15.5	41.3	156.0
90	362.0	130.7	1.1	3.7	5.1	15.7	41.5	156.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	12.7	1.7
5	0	4.4	0.2	1.6	0.2	1.3	12.8	7.6
10	682	13.8	0.3	1.6	0.5	2.2	12.9	18.5
15	2,094	27.8	0.4	1.5	1.1	2.9	13.1	33.8
20	3,498	40.1	0.4	1.5	1.6	3.5	13.3	47.1
25	4,504	47.9	0.4	1.5	1.9	4.0	13.7	55.7
30	4,963	51.3	0.5	1.5	2.0	4.3	14.0	59.6
35	5,024	51.8	0.5	1.5	2.0	4.7	14.4	60.4
40	5,074	52.1	0.5	1.5	2.0	4.9	14.7	61.0
45	5,124	52.5	0.5	1.5	2.0	5.2	15.1	61.7
50	5,174	52.9	0.5	1.5	2.0	5.4	15.4	62.2
55	5,174	52.9	0.5	1.5	2.0	5.5	15.7	62.4
60	5,174	52.9	0.5	1.5	2.0	5.7	16.0	62.6
65	5,174	52.9	0.5	1.5	2.0	5.8	16.2	62.7
70	5,174	52.9	0.5	1.5	2.0	6.0	16.4	62.8
75	5,174	52.9	0.5	1.5	2.0	6.1	16.5	63.0
80	5,174	52.9	0.5	1.5	2.0	6.2	16.6	63.1
85	5,174	52.9	0.5	1.5	2.0	6.3	16.7	63.1
90	5,174	52.9	0.5	1.5	2.0	6.3	16.8	63.2

B49.— Regional estimates of timber volume and carbon stocks for oak-gum-cypress stands with afforestation of land in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	1.8	0.0	0.0	39.6	1.8
5	0.0	5.4	0.5	2.1	0.3	1.1	39.7	9.5
10	9.8	17.8	1.8	1.8	1.1	2.1	40.1	24.7
15	19.9	28.4	2.8	1.7	1.8	3.0	40.7	37.8
20	32.7	39.3	3.2	1.7	2.5	3.7	41.5	50.4
25	45.4	48.8	3.4	1.6	3.1	4.4	42.5	61.3
30	58.1	57.2	3.5	1.6	3.6	5.0	43.6	70.9
35	73.4	66.9	3.6	1.6	4.2	5.5	44.7	81.8
40	92.2	76.9	3.7	1.6	4.9	6.0	45.8	93.0
45	110.7	86.1	3.7	1.5	5.4	6.4	46.9	103.3
50	128.1	94.4	3.8	1.5	6.0	6.8	47.9	112.6
55	146.3	102.8	3.9	1.5	6.5	7.2	48.8	121.9
60	166.1	111.6	3.9	1.5	7.0	7.5	49.7	131.6
65	186.4	120.3	4.0	1.5	7.6	7.8	50.3	141.2
70	205.7	128.3	4.0	1.5	8.1	8.1	50.9	150.0
75	222.5	135.1	4.1	1.5	8.5	8.4	51.4	157.6
80	237.9	141.2	4.1	1.5	8.9	8.6	51.8	164.4
85	257.3	148.8	4.1	1.5	9.4	8.9	52.0	172.6
90	278.9	157.0	4.2	1.4	9.9	9.1	52.3	181.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.7	0.0	0.0	16.0	0.7
5	0	2.2	0.2	0.8	0.1	0.5	16.1	3.9
10	140	7.2	0.7	0.7	0.5	0.9	16.2	10.0
15	284	11.5	1.1	0.7	0.7	1.2	16.5	15.3
20	467	15.9	1.3	0.7	1.0	1.5	16.8	20.4
25	649	19.7	1.4	0.7	1.2	1.8	17.2	24.8
30	830	23.1	1.4	0.7	1.5	2.0	17.6	28.7
35	1,049	27.1	1.4	0.6	1.7	2.2	18.1	33.1
40	1,318	31.1	1.5	0.6	2.0	2.4	18.5	37.6
45	1,582	34.9	1.5	0.6	2.2	2.6	19.0	41.8
50	1,830	38.2	1.5	0.6	2.4	2.8	19.4	45.6
55	2,091	41.6	1.6	0.6	2.6	2.9	19.8	49.3
60	2,374	45.2	1.6	0.6	2.9	3.1	20.1	53.3
65	2,664	48.7	1.6	0.6	3.1	3.2	20.4	57.1
70	2,940	51.9	1.6	0.6	3.3	3.3	20.6	60.7
75	3,180	54.7	1.6	0.6	3.5	3.4	20.8	63.8
80	3,400	57.2	1.7	0.6	3.6	3.5	20.9	66.5
85	3,677	60.2	1.7	0.6	3.8	3.6	21.1	69.9
90	3,986	63.5	1.7	0.6	4.0	3.7	21.1	73.5

B50.— Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	29.0	4.2
5	0.0	9.7	0.9	4.7	0.6	1.1	29.1	17.1
10	11.7	20.9	1.9	4.0	1.4	2.1	29.4	30.3
15	21.2	30.1	2.1	3.6	2.0	3.0	29.8	40.8
20	33.8	39.5	2.3	3.4	2.6	3.7	30.4	51.6
25	46.6	48.2	2.4	3.3	3.2	4.4	31.1	61.5
30	60.2	56.6	2.6	3.1	3.8	5.0	31.9	71.0
35	76.3	65.6	2.7	3.0	4.4	5.5	32.7	81.2
40	94.3	76.2	2.8	2.9	5.1	6.0	33.5	92.9
45	114.1	85.7	2.9	2.8	5.7	6.4	34.3	103.6
50	133.0	94.7	3.0	2.8	6.3	6.8	35.1	113.6
55	151.4	103.3	3.0	2.7	6.9	7.2	35.8	123.1
60	168.9	111.3	3.1	2.7	7.4	7.5	36.4	132.0
65	185.6	118.8	3.2	2.6	7.9	7.8	36.9	140.4
70	201.5	126.0	3.2	2.6	8.4	8.1	37.3	148.3
75	215.7	132.3	3.2	2.6	8.8	8.4	37.6	155.3
80	229.4	138.3	3.3	2.5	9.2	8.6	37.9	162.0
85	242.5	144.0	3.3	2.5	9.6	8.9	38.1	168.3
90	254.1	149.1	3.3	2.5	9.9	9.1	38.3	174.0
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	11.7	1.7
5	0	3.9	0.4	1.9	0.3	0.5	11.8	6.9
10	167	8.5	0.8	1.6	0.6	0.9	11.9	12.2
15	303	12.2	0.9	1.5	0.8	1.2	12.1	16.5
20	483	16.0	0.9	1.4	1.1	1.5	12.3	20.9
25	666	19.5	1.0	1.3	1.3	1.8	12.6	24.9
30	860	22.9	1.0	1.3	1.5	2.0	12.9	28.7
35	1,091	26.6	1.1	1.2	1.8	2.2	13.2	32.9
40	1,348	30.8	1.1	1.2	2.0	2.4	13.6	37.6
45	1,630	34.7	1.2	1.2	2.3	2.6	13.9	41.9
50	1,901	38.3	1.2	1.1	2.5	2.8	14.2	46.0
55	2,164	41.8	1.2	1.1	2.8	2.9	14.5	49.8
60	2,414	45.0	1.3	1.1	3.0	3.1	14.7	53.4
65	2,652	48.1	1.3	1.1	3.2	3.2	14.9	56.8
70	2,880	51.0	1.3	1.1	3.4	3.3	15.1	60.0
75	3,082	53.5	1.3	1.0	3.6	3.4	15.2	62.8
80	3,278	56.0	1.3	1.0	3.7	3.5	15.3	65.5
85	3,465	58.3	1.3	1.0	3.9	3.6	15.4	68.1
90	3,632	60.3	1.4	1.0	4.0	3.7	15.5	70.4

B51.— Regional estimates of timber volume and carbon stocks for oak-pine stands with afforestation of land in the South Central

Age	Mean volume	Mean carbon density: Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	31.3	4.2
5	0.0	8.7	0.7	4.4	0.6	3.1	31.4	17.5
10	13.6	21.4	1.4	3.7	1.5	5.1	31.7	33.1
15	27.8	31.9	1.7	3.5	2.3	6.6	32.2	46.0
20	43.9	41.8	2.0	3.3	3.0	7.7	32.8	57.8
25	59.3	50.9	2.2	3.2	3.7	8.5	33.6	68.5
30	77.2	59.2	2.5	3.1	4.3	9.2	34.4	78.2
35	96.8	67.9	2.6	3.0	4.9	9.8	35.3	88.2
40	117.2	76.5	2.8	2.9	5.5	10.2	36.2	98.1
45	136.4	84.4	3.0	2.9	6.1	10.6	37.0	107.0
50	154.1	91.4	3.1	2.8	6.6	11.0	37.9	115.0
55	171.4	98.2	3.2	2.8	7.1	11.3	38.6	122.6
60	189.6	105.2	3.3	2.8	7.6	11.5	39.2	130.4
65	204.5	110.7	3.4	2.7	8.0	11.8	39.8	136.7
70	218.8	116.0	3.5	2.7	8.4	12.0	40.2	142.6
75	234.5	121.8	3.6	2.7	8.8	12.1	40.6	149.0
80	247.6	126.5	3.6	2.7	9.2	12.3	40.9	154.2
85	259.4	130.7	3.7	2.7	9.5	12.5	41.1	158.9
90	272.3	135.2	3.8	2.6	9.8	12.6	41.3	164.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	12.7	1.7
5	0	3.5	0.3	1.8	0.3	1.2	12.7	7.1
10	195	8.6	0.6	1.5	0.6	2.1	12.8	13.4
15	397	12.9	0.7	1.4	0.9	2.7	13.0	18.6
20	628	16.9	0.8	1.3	1.2	3.1	13.3	23.4
25	848	20.6	0.9	1.3	1.5	3.5	13.6	27.7
30	1,104	24.0	1.0	1.2	1.7	3.7	13.9	31.7
35	1,384	27.5	1.1	1.2	2.0	4.0	14.3	35.7
40	1,675	31.0	1.1	1.2	2.2	4.1	14.6	39.7
45	1,950	34.2	1.2	1.2	2.5	4.3	15.0	43.3
50	2,202	37.0	1.3	1.2	2.7	4.4	15.3	46.5
55	2,450	39.7	1.3	1.1	2.9	4.6	15.6	49.6
60	2,710	42.6	1.3	1.1	3.1	4.7	15.9	52.8
65	2,923	44.8	1.4	1.1	3.2	4.8	16.1	55.3
70	3,127	47.0	1.4	1.1	3.4	4.8	16.3	57.7
75	3,352	49.3	1.4	1.1	3.6	4.9	16.4	60.3
80	3,539	51.2	1.5	1.1	3.7	5.0	16.5	62.4
85	3,707	52.9	1.5	1.1	3.8	5.0	16.6	64.3
90	3,891	54.7	1.5	1.1	4.0	5.1	16.7	66.4

APPENDIX C

Scenarios of Harvest and Carbon Accumulation in Harvested Wood Products[3,4]

Carbon Stocks on Forest Land and in Harvested Wood Products After Clearcut Harvest

C1. Maple-beech-birch, Northeast
C2. Oak-hickory, Northeast
C3. Spruce-balsam fir, Northeast
C4. Aspen-birch, Northern Lake States
C5. Maple-beech-birch, Northern Lake States
C6. White-red-jack pine, Northern Lake States
C7. Elm-ash-cottonwood, Northern Prairie States
C8. Oak-hickory, Northern Prairie States
C9. Douglas-fir, Pacific Northwest, East
C10. Ponderosa pine, Pacific Northwest, East
C11. Alder-maple, Pacific Northwest, West
C12. Douglas-fir, high productivity and management intensity, Pacific Northwest, West
C13. Hemlock-Sitka spruce, high productivity, Pacific Northwest, West
C14. Mixed conifer, Pacific Southwest
C15. Western oak, Pacific Southwest
C16. Douglas-fir, Rocky Mountain, North
C17. Lodgepole pine, Rocky Mountain, North
C18. Fir-spruce-mountain hemlock, Rocky Mountain, South
C19. Ponderosa pine, Rocky Mountain, South
C20. Loblolly-shortleaf pine, high productivity and management intensity, Southeast
C21. Oak-gum-cypress, Southeast
C22. Oak-hickory, Southeast
C23. Oak-pine, Southeast
C24. Loblolly-shortleaf pine, high productivity and management intensity, South Central
C25. Oak-gum-cypress, South Central
C26. Oak-hickory, South Central
C27. Oak-pine, South Central

[3] Note carbon mass is in metric tons (tonnes) in all tables, and age refers to stand age.
[4] These tables are example harvest scenarios; they are not recommendations for timing of harvest.

C1.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for maple-beech-birch stands in the Northeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m³/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	2.1	0.0	0.0	52.2					
5	0.0		7.4	0.7	2.1	0.5	4.2	52.3					
15	28.0		31.8	3.2	1.9	2.3	10.8	53.7					
25	58.1		53.2	5.3	1.8	3.8	15.8	56.0					
35	89.6		72.8	6.0	1.7	5.2	19.7	58.9					
45	119.1		87.8	6.6	1.7	6.2	22.7	61.8					
55	146.6		101.1	7.0	1.7	7.2	25.3	64.4					
65	0.0	172.1	0.0	0.0	2.1	32.0	27.7	66.3	34.5	0.0	39.7	14.1	7.5
5	0.0		7.4	0.7	2.1	21.7	20.3	67.1	22.9	4.7	43.1	17.5	
15	28.0		31.8	3.2	1.9	11.5	16.3	68.2	13.2	8.1	46.2	20.7	
25	58.1		53.2	5.3	1.8	7.8	17.6	68.9	10.3	8.8	47.1	22.0	
35	89.6		72.8	6.0	1.7	6.9	20.3	69.2	8.7	9.1	47.5	22.9	
45	119.1		87.8	6.6	1.7	7.0	23.0	69.4	7.6	9.4	47.8	23.5	
55	146.6		101.1	7.0	1.7	7.5	25.3	69.5	6.7	9.6	47.9	24.0	
65	0.0	172.1	0.0	0.0	2.1	32.0	27.7	69.5	40.4	9.8	87.8	38.5	7.7
years	*ft³/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	0.8	0.0	0.0	21.1					
5	0		3.0	0.3	0.8	0.2	1.7	21.2					
15	400		12.9	1.3	0.8	0.9	4.4	21.7					
25	830		21.5	2.1	0.7	1.5	6.4	22.7					
35	1,280		29.5	2.4	0.7	2.1	8.0	23.8					
45	1,702		35.5	2.7	0.7	2.5	9.2	25.0					
55	2,095		40.9	2.8	0.7	2.9	10.2	26.0					
65	0	2,460	0.0	0.0	0.8	13.0	11.2	26.8	13.9	0.0	16.1	5.7	3.0
5	0		3.0	0.3	0.8	8.8	8.2	27.2	9.3	1.9	17.5	7.1	
15	400		12.9	1.3	0.8	4.7	6.6	27.6	5.3	3.3	18.7	8.4	
25	830		21.5	2.1	0.7	3.2	7.1	27.9	4.2	3.6	19.0	8.9	
35	1,280		29.5	2.4	0.7	2.8	8.2	28.0	3.5	3.7	19.2	9.3	
45	1,702		35.5	2.7	0.7	2.8	9.3	28.1	3.1	3.8	19.3	9.5	
55	2,095		40.9	2.8	0.7	3.0	10.3	28.1	2.7	3.9	19.4	9.7	
65	0	2,460	0.0	0.0	0.8	13.0	11.2	28.1	16.4	4.0	35.5	15.6	3.1

C2.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-hickory stands in the Northeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m^3/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	2.1	0.0	0.0	39.8					
5	0.0		6.9	0.7	2.1	0.5	0.9	39.9					
15	54.5		43.0	3.6	1.9	2.9	2.5	40.9					
25	95.7		71.9	4.0	1.9	4.9	3.9	42.7					
35	135.3		96.2	4.2	1.8	6.6	5.2	44.9					
45	173.3		118.2	4.5	1.8	8.1	6.3	47.2					
55	209.6		136.8	4.6	1.8	9.4	7.2	49.1					
65	0.0	244.3	0.0	0.0	2.1	46.7	8.2	50.6	45.0	0.0	57.5	17.8	2.2
5	0.0		6.9	0.7	2.1	31.4	5.7	51.2	30.6	6.3	61.6	21.8	
15	54.5		43.0	3.6	1.9	16.5	4.1	52.1	18.0	11.3	65.3	25.7	
25	95.7		71.9	4.0	1.9	10.8	4.5	52.6	13.8	12.7	66.6	27.3	
35	135.3		96.2	4.2	1.8	9.2	5.3	52.8	11.4	13.3	67.3	28.4	
45	173.3		118.2	4.5	1.8	9.2	6.3	53.0	9.7	13.7	67.7	29.2	
55	209.6		136.8	4.6	1.8	9.9	7.3	53.0	8.4	14.0	68.0	29.9	
65	0.0	244.3	0.0	0.0	2.1	46.7	8.2	53.1	52.4	14.3	125.7	48.2	2.4
years	*ft^3/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	0.8	0.0	0.0	16.1					
5	0		2.8	0.3	0.8	0.2	0.4	16.2					
15	779		17.4	1.4	0.8	1.2	1.0	16.6					
25	1,368		29.1	1.6	0.7	2.0	1.6	17.3					
35	1,934		38.9	1.7	0.7	2.7	2.1	18.2					
45	2,477		47.8	1.8	0.7	3.3	2.5	19.1					
55	2,996		55.4	1.9	0.7	3.8	2.9	19.9					
65	0	3,492	0.0	0.0	0.8	18.9	3.3	20.5	18.2	0.0	23.3	7.2	0.9
5	0		2.8	0.3	0.8	12.7	2.3	20.7	12.4	2.5	24.9	8.8	
15	779		17.4	1.4	0.8	6.7	1.7	21.1	7.3	4.6	26.4	10.4	
25	1,368		29.1	1.6	0.7	4.4	1.8	21.3	5.6	5.1	26.9	11.0	
35	1,934		38.9	1.7	0.7	3.7	2.2	21.4	4.6	5.4	27.2	11.5	
45	2,477		47.8	1.8	0.7	3.7	2.6	21.4	3.9	5.5	27.4	11.8	
55	2,996		55.4	1.9	0.7	4.0	2.9	21.5	3.4	5.7	27.5	12.1	
65	0	3,492	0.0	0.0	0.8	18.9	3.3	21.5	21.2	5.8	50.9	19.5	1.0

C3.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for spruce-balsam fir stands in the Northeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- m^3*/hectare* -------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	2.1	0.0	0.0	73.5					
5	0.0		7.0	0.7	1.8	0.6	5.0	73.7					
15	11.5		20.1	2.0	1.6	1.9	13.0	75.6					
25	29.1		32.5	3.3	1.5	3.0	19.0	78.9					
35	51.6		45.7	4.6	1.4	4.2	23.7	83.0					
45	76.9		57.4	5.7	1.4	5.3	27.5	87.1					
55	102.6		68.7	6.9	1.4	6.3	30.7	90.7					
65	0.0	126.4	0.0	0.0	2.1	20.3	33.7	93.5	23.6	0.0	22.2	11.1	14.8
5	0.0		7.0	0.7	1.8	16.0	23.6	94.5	13.4	3.5	25.8	14.2	
15	11.5		20.1	2.0	1.6	10.6	18.6	96.1	5.7	5.6	28.8	16.9	
25	29.1		32.5	3.3	1.5	8.0	20.7	97.0	4.1	5.6	29.3	17.9	
35	51.6		45.7	4.6	1.4	7.1	24.2	97.5	3.5	5.4	29.5	18.6	
45	76.9		57.4	5.7	1.4	6.9	27.7	97.8	3.0	5.4	29.6	19.0	
55	102.6		68.7	6.9	1.4	7.3	30.7	97.9	2.6	5.3	29.6	19.3	
65	0.0	126.4	0.0	0.0	2.1	20.3	33.7	98.0	26.0	5.4	51.9	30.7	15.4
years	-------- ft^3*/acre* ----------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	0.9	0.0	0.0	29.7					
5	0		2.8	0.3	0.7	0.3	2.0	29.8					
15	164		8.1	0.8	0.6	0.8	5.2	30.6					
25	416		13.2	1.3	0.6	1.2	7.7	31.9					
35	738		18.5	1.9	0.6	1.7	9.6	33.6					
45	1,099		23.2	2.3	0.6	2.1	11.1	35.2					
55	1,466		27.8	2.8	0.6	2.6	12.4	36.7					
65	0	1,807	0.0	0.0	0.9	8.2	13.6	37.8	9.6	0.0	9.0	4.5	6.0
5	0		2.8	0.3	0.7	6.5	9.5	38.3	5.4	1.4	10.5	5.7	
15	164		8.1	0.8	0.6	4.3	7.5	38.9	2.3	2.3	11.6	6.8	
25	416		13.2	1.3	0.6	3.2	8.4	39.3	1.7	2.3	11.9	7.3	
35	738		18.5	1.9	0.6	2.9	9.8	39.5	1.4	2.2	11.9	7.5	
45	1,099		23.2	2.3	0.6	2.8	11.2	39.6	1.2	2.2	12.0	7.7	
55	1,466		27.8	2.8	0.6	2.9	12.4	39.6	1.1	2.2	12.0	7.8	
65	0	1,807	0.0	0.0	0.9	8.2	13.6	39.6	10.5	2.2	21.0	12.4	6.2

C4.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for aspen-birch stands in the Northern Lake States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare*-------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	2.0	0.0	0.0	109.6					
5	0.0		7.3	0.5	2.1	0.6	1.6	109.9					
15	2.9		13.9	1.4	2.1	1.1	4.0	112.7					
25	21.5		26.8	2.7	2.1	2.2	5.8	117.6					
35	47.2		40.8	4.1	2.0	3.3	7.3	123.7					
45	72.8		53.5	5.3	2.0	4.3	8.4	129.8					
55	0.0	97.1	0.0	0.0	2.0	13.4	10.2	135.2	12.7	0.0	12.1	4.8	32.4
5	0.0		7.3	0.5	2.1	9.5	7.5	137.4	8.7	1.6	13.3	6.0	
15	2.9		13.9	1.4	2.1	5.0	6.0	140.9	5.4	2.8	14.3	7.1	
25	21.5		26.8	2.7	2.1	3.9	6.5	143.3	4.3	3.1	14.6	7.6	
35	47.2		40.8	4.1	2.0	4.0	7.5	144.7	3.7	3.2	14.8	7.9	
45	72.8		53.5	5.3	2.0	4.6	8.5	145.4	3.2	3.3	14.9	8.1	
55	0.0	97.1	0.0	0.0	2.0	13.4	10.2	145.8	15.5	3.4	27.1	13.1	32.5
years	--------ft^3/*acre* ---------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	0.8	0.0	0.0	44.3					
5	0		3.0	0.2	0.8	0.2	0.6	44.5					
15	42		5.6	0.6	0.8	0.5	1.6	45.6					
25	307		10.9	1.1	0.8	0.9	2.4	47.6					
35	674		16.5	1.6	0.8	1.3	2.9	50.1					
45	1,041		21.6	2.2	0.8	1.7	3.4	52.5					
55	0	1,388	0.0	0.0	0.8	5.4	4.1	54.7	5.1	0.0	4.9	1.9	13.1
5	0		3.0	0.2	0.8	3.8	3.0	55.6	3.5	0.6	5.4	2.4	
15	42		5.6	0.6	0.8	2.0	2.4	57.0	2.2	1.1	5.8	2.9	
25	307		10.9	1.1	0.8	1.6	2.6	58.0	1.7	1.2	5.9	3.1	
35	674		16.5	1.6	0.8	1.6	3.0	58.5	1.5	1.3	6.0	3.2	
45	1,041		21.6	2.2	0.8	1.9	3.4	58.8	1.3	1.3	6.0	3.3	
55	0	1,388	0.0	0.0	0.8	5.4	4.1	59.0	6.3	1.4	11.0	5.3	13.2

C5.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for maple-beech-birch stands in the Northern Lake States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m³/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	2.1	0.0	0.0	100.7					
5	0.0		5.1	0.5	2.0	0.4	4.2	101.0					
15	4.3		13.4	1.3	1.7	1.0	10.8	103.6					
25	24.6		30.3	3.0	1.6	2.3	15.8	108.1					
35	48.1		47.7	4.0	1.5	3.6	19.7	113.7					
45	72.5		62.9	4.4	1.4	4.8	22.7	119.3					
55	96.9		77.3	4.7	1.4	5.9	25.3	124.3					
65	0.0	121.3	0.0	0.0	2.1	19.5	27.7	128.1	19.0	0.0	19.0	7.2	37.1
5	0.0		5.1	0.5	2.0	13.3	20.3	129.5	13.3	2.4	20.7	8.9	
15	4.3		13.4	1.3	1.7	6.7	16.3	131.7	8.3	4.3	22.2	10.5	
25	24.6		30.3	3.0	1.6	4.8	17.6	132.9	6.6	4.8	22.6	11.2	
35	48.1		47.7	4.0	1.5	4.7	20.3	133.6	5.6	5.1	22.9	11.6	
45	72.5		62.9	4.4	1.4	5.2	23.0	134.0	4.9	5.3	23.1	12.0	
55	96.9		77.3	4.7	1.4	6.1	25.3	134.2	4.3	5.5	23.2	12.3	
65	0.0	121.3	0.0	0.0	2.1	19.5	27.7	134.2	22.9	5.6	42.3	19.8	37.2
years	*ft³/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	0.9	0.0	0.0	40.8					
5	0		2.1	0.2	0.8	0.2	1.7	40.9					
15	62		5.4	0.5	0.7	0.4	4.4	41.9					
25	351		12.2	1.2	0.6	0.9	6.4	43.8					
35	688		19.3	1.6	0.6	1.5	8.0	46.0					
45	1,036		25.4	1.8	0.6	1.9	9.2	48.3					
55	1,385		31.3	1.9	0.6	2.4	10.2	50.3					
65	0	1,733	0.0	0.0	0.9	7.9	11.2	51.8	7.7	0.0	7.7	2.9	15.0
5	0		2.1	0.2	0.8	5.4	8.2	52.4	5.4	1.0	8.4	3.6	
15	62		5.4	0.5	0.7	2.7	6.6	53.3	3.3	1.7	9.0	4.3	
25	351		12.2	1.2	0.6	1.9	7.1	53.8	2.7	2.0	9.2	4.5	
35	688		19.3	1.6	0.6	1.9	8.2	54.1	2.3	2.1	9.3	4.7	
45	1,036		25.4	1.8	0.6	2.1	9.3	54.2	2.0	2.1	9.3	4.9	
55	1,385		31.3	1.9	0.6	2.5	10.3	54.3	1.7	2.2	9.4	5.0	
65	0	1,733	0.0	0.0	0.9	7.9	11.2	54.3	9.3	2.3	17.1	8.0	15.1

C6.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for white-red-jack pine stands in the Northern Lake States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	-------- m^3*/hectare* -------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	2.0	0.0	0.0	90.6					
5	0.0		0.4	0.0	2.0	0.0	3.1	90.9					
15	6.6		8.0	0.8	2.0	0.6	7.1	93.2					
25	48.1		35.4	3.5	2.0	2.5	9.4	97.3					
35	104.7		62.9	4.9	2.0	4.5	11.0	102.3					
45	158.9		85.8	5.5	2.0	6.2	12.2	107.4					
55	0.0	209.1	0.0	0.0	2.0	25.5	13.8	111.8	25.0	0.0	20.5	9.1	37.9
5	0.0		0.4	0.0	2.0	19.3	10.7	113.7	16.8	3.3	23.2	11.3	
15	6.6		8.0	0.8	2.0	11.6	9.4	116.6	9.7	5.8	25.7	13.4	
25	48.1		35.4	3.5	2.0	8.8	10.1	118.5	7.4	6.5	26.4	14.3	
35	104.7		62.9	4.9	2.0	8.1	11.2	119.6	6.1	6.8	26.7	14.9	
45	158.9		85.8	5.5	2.0	8.2	12.2	120.3	5.2	7.0	27.0	15.4	
55	0.0	209.1	0.0	0.0	2.0	25.5	13.8	120.6	29.5	7.2	47.6	24.8	39.1
years	----------- ft^3*/acre* ---------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	0.8	0.0	0.0	36.7					
5	0		0.2	0.0	0.8	0.0	1.3	36.8					
15	94		3.3	0.3	0.8	0.2	2.9	37.7					
25	688		14.3	1.4	0.8	1.0	3.8	39.4					
35	1,496		25.5	2.0	0.8	1.8	4.5	41.4					
45	2,271		34.7	2.2	0.8	2.5	4.9	43.5					
55	0	2,988	0.0	0.0	0.8	10.3	5.6	45.3	10.1	0.0	8.3	3.7	15.3
5	0		0.2	0.0	0.8	7.8	4.3	46.0	6.8	1.3	9.4	4.6	
15	94		3.3	0.3	0.8	4.7	3.8	47.2	3.9	2.4	10.4	5.4	
25	688		14.3	1.4	0.8	3.6	4.1	48.0	3.0	2.6	10.7	5.8	
35	1,496		25.5	2.0	0.8	3.3	4.6	48.4	2.5	2.7	10.8	6.0	
45	2,271		34.7	2.2	0.8	3.3	5.0	48.7	2.1	2.8	10.9	6.2	
55	0	2,988	0.0	0.0	0.8	10.3	5.6	48.8	12.0	2.9	19.3	10.1	15.8

C7.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for elm-ash-cottonwood stands in the Northern Prairie States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m^3/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	2.1	0.0	0.0	63.6					
5	0.0		3.9	0.4	2.1	0.3	4.2	63.8					
15	0.0		8.7	0.9	2.7	0.6	10.8	65.4					
25	5.8		15.5	1.6	2.4	1.1	15.8	68.3					
35	21.8		27.7	2.8	2.2	1.9	19.7	71.8					
45	45.1		43.2	4.3	2.0	3.0	22.7	75.4					
55	0.0	73.0	0.0	0.0	2.1	11.3	27.7	78.5	10.0	0.0	10.9	3.9	31.2
5	0.0		3.9	0.4	2.1	7.7	20.3	79.8	7.0	1.3	11.7	4.7	
15	0.0		8.7	0.9	2.7	3.9	16.3	81.8	4.3	2.5	12.5	5.5	
25	5.8		15.5	1.6	2.4	2.5	17.6	83.1	3.4	2.8	12.7	5.9	
35	21.8		27.7	2.8	2.2	2.5	20.3	84.0	2.8	2.9	12.9	6.1	
45	45.1		43.2	4.3	2.0	3.3	23.0	84.4	2.4	3.1	13.0	6.3	
55	0.0	73.0	0.0	0.0	2.1	11.3	27.7	84.6	12.2	3.1	23.9	10.4	31.4
years	*ft^3/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	0.8	0.0	0.0	25.7					
5	0		1.6	0.2	0.8	0.1	1.7	25.8					
15	0		3.5	0.4	1.1	0.2	4.4	26.5					
25	83		6.3	0.6	1.0	0.4	6.4	27.6					
35	312		11.2	1.1	0.9	0.8	8.0	29.1					
45	644		17.5	1.7	0.8	1.2	9.2	30.5					
55	0	1,043	0.0	0.0	0.8	4.6	11.2	31.8	4.1	0.0	4.4	1.6	12.6
5	0		1.6	0.2	0.8	3.1	8.2	32.3	2.8	0.5	4.7	1.9	
15	0		3.5	0.4	1.1	1.6	6.6	33.1	1.8	1.0	5.0	2.2	
25	83		6.3	0.6	1.0	1.0	7.1	33.6	1.4	1.1	5.2	2.4	
35	312		11.2	1.1	0.9	1.0	8.2	34.0	1.1	1.2	5.2	2.5	
45	644		17.5	1.7	0.8	1.3	9.3	34.2	1.0	1.2	5.3	2.6	
55	0	1,043	0.0	0.0	0.8	4.6	11.2	34.2	4.9	1.3	9.7	4.2	12.7

C8.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-hickory stands in the Northern Prairie States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare*-------		------- *tonnes carbon/hectare* -------										
0	0.0		0.0	0.0	2.1	0.0	0.0	34.5					
5	0.0		6.7	0.6	2.4	0.5	0.9	34.6					
15	2.1		15.6	1.6	2.1	1.1	2.5	35.4					
25	13.0		27.5	2.7	2.0	1.9	3.9	37.0					
35	27.4		40.0	3.2	1.9	2.7	5.2	38.9					
45	43.0		52.2	3.6	1.8	3.5	6.3	40.8					
55	59.1		64.3	3.9	1.8	4.3	7.2	42.5					
65	0.0	74.9	0.0	0.0	2.1	14.1	8.2	43.8	13.2	0.0	13.9	5.1	37.1
5	0.0		6.7	0.6	2.4	9.8	5.7	44.3	9.2	1.7	15.0	6.2	
15	2.1		15.6	1.6	2.1	5.2	4.1	45.1	5.7	3.1	16.0	7.3	
25	13.0		27.5	2.7	2.0	3.7	4.5	45.5	4.5	3.5	16.4	7.8	
35	27.4		40.0	3.2	1.9	3.5	5.3	45.7	3.8	3.7	16.5	8.1	
45	43.0		52.2	3.6	1.8	3.9	6.3	45.9	3.3	3.9	16.7	8.3	
55	59.1		64.3	3.9	1.8	4.5	7.3	45.9	2.9	4.0	16.8	8.5	
65	0.0	74.9	0.0	0.0	2.1	14.1	8.2	45.9	15.8	4.1	30.7	13.8	37.2
years	--------ft^3/*acre* ---------		------- *tonnes carbon/acre* -------										
0	0		0.0	0.0	0.8	0.0	0.0	13.9					
5	0		2.7	0.2	1.0	0.2	0.4	14.0					
15	30		6.3	0.6	0.9	0.4	1.0	14.3					
25	186		11.1	1.1	0.8	0.8	1.6	15.0					
35	391		16.2	1.3	0.8	1.1	2.1	15.7					
45	615		21.1	1.4	0.7	1.4	2.5	16.5					
55	844		26.0	1.6	0.7	1.8	2.9	17.2					
65	0	1,070	0.0	0.0	0.8	5.7	3.3	17.7	5.4	0.0	5.6	2.1	15.0
5	0		2.7	0.2	1.0	4.0	2.3	17.9	3.7	0.7	6.1	2.5	
15	30		6.3	0.6	0.9	2.1	1.7	18.2	2.3	1.3	6.5	3.0	
25	186		11.1	1.1	0.8	1.5	1.8	18.4	1.8	1.4	6.6	3.1	
35	391		16.2	1.3	0.8	1.4	2.2	18.5	1.5	1.5	6.7	3.3	
45	615		21.1	1.4	0.7	1.6	2.6	18.6	1.3	1.6	6.7	3.4	
55	844		26.0	1.6	0.7	1.8	2.9	18.6	1.2	1.6	6.8	3.5	
65	0	1,070	0.0	0.0	0.8	5.7	3.3	18.6	6.4	1.6	12.4	5.6	15.1

C9.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for Douglas-fir stands in the Pacific Northwest, East

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.6	0.0	0.0	71.1					
5	0.0		2.7	0.3	4.4	0.3	5.2	71.3					
15	3.8		8.7	0.9	4.1	0.9	13.0	73.1					
25	47.7		38.3	3.8	3.7	3.9	18.6	76.3					
35	119.0		75.1	7.5	3.6	7.7	22.9	80.2					
45	184.7		104.0	10.0	3.5	10.7	26.2	84.2					
55	241.8		127.3	10.9	3.4	13.1	28.9	87.7					
65	290.9		146.4	11.5	3.4	15.0	31.1	90.4					
75	0.0	332.7	0.0	0.0	4.6	26.0	37.2	92.3	41.1	0.0	27.3	16.1	74.9
5	0.0		2.7	0.3	4.4	22.5	35.4	92.9	31.8	4.2	29.9	18.6	
15	3.8		8.7	0.9	4.1	17.2	32.9	93.8	22.6	8.2	32.3	21.3	
25	47.7		38.3	3.8	3.7	15.9	31.8	94.3	18.5	9.9	33.3	22.8	
35	119.0		75.1	7.5	3.6	16.5	31.6	94.6	15.8	11.0	33.9	23.9	
45	184.7		104.0	10.0	3.5	17.1	32.0	94.7	13.7	11.8	34.2	24.8	
55	241.8		127.3	10.9	3.4	17.8	32.7	94.7	12.1	12.4	34.5	25.6	
65	290.9		146.4	11.5	3.4	18.5	33.6	94.8	10.7	12.9	34.6	26.2	
75	0.0	332.7	0.0	0.0	4.6	26.0	37.2	94.8	50.7	13.4	62.0	42.9	79.1

Continued

C9.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft*^{3}*/acre* --------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	1.9	0.0	0.0	28.8					
5	0		1.1	0.1	1.8	0.1	2.1	28.9					
15	54		3.5	0.4	1.7	0.4	5.2	29.6					
25	682		15.5	1.5	1.5	1.6	7.5	30.9					
35	1,701		30.4	3.0	1.4	3.1	9.3	32.5					
45	2,639		42.1	4.1	1.4	4.3	10.6	34.1					
55	3,456		51.5	4.4	1.4	5.3	11.7	35.5					
65	4,157		59.3	4.7	1.4	6.1	12.6	36.6					
75	0	4,755	0.0	0.0	1.9	10.5	15.1	37.3	16.6	0.0	11.1	6.5	30.3
5	0		1.1	0.1	1.8	9.1	14.3	37.6	12.9	1.7	12.1	7.5	
15	54		3.5	0.4	1.7	7.0	13.3	38.0	9.1	3.3	13.1	8.6	
25	682		15.5	1.5	1.5	6.4	12.9	38.2	7.5	4.0	13.5	9.2	
35	1,701		30.4	3.0	1.4	6.7	12.8	38.3	6.4	4.5	13.7	9.7	
45	2,639		42.1	4.1	1.4	6.9	12.9	38.3	5.5	4.8	13.9	10.0	
55	3,456		51.5	4.4	1.4	7.2	13.2	38.3	4.9	5.0	14.0	10.3	
65	4,157		59.3	4.7	1.4	7.5	13.6	38.3	4.3	5.2	14.0	10.6	
75	0	4,755	0.0	0.0	1.9	10.5	15.1	38.3	20.5	5.4	25.1	17.4	32.0

C10.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for ponderosa pine stands in the Pacific Northwest, East

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m^3/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	4.8	0.0	0.0	38.0					
5	0.0		3.3	0.3	4.6	0.3	2.4	38.1					
15	4.1		7.9	0.8	3.8	0.8	6.4	39.1					
25	21.6		17.3	1.7	3.2	1.8	9.8	40.8					
35	40.8		26.2	2.6	2.9	2.7	12.6	42.9					
45	61.4		34.9	3.3	2.8	3.6	14.9	45.1					
55	83.3		43.6	3.7	2.6	4.5	17.0	46.9					
65	106.0		52.5	4.2	2.5	5.4	18.7	48.4					
75	0.0	129.3	0.0	0.0	4.8	9.6	24.1	49.4	14.4	0.0	9.4	5.6	27.0
5	0.0		3.3	0.3	4.6	8.5	22.0	49.7	11.1	1.5	10.3	6.5	
15	4.1		7.9	0.8	3.8	6.8	19.4	50.2	7.9	2.9	11.2	7.5	
25	21.6		17.3	1.7	3.2	6.2	18.3	50.5	6.5	3.5	11.5	8.0	
35	40.8		26.2	2.6	2.9	5.9	18.2	50.6	5.5	3.8	11.7	8.3	
45	61.4		34.9	3.3	2.8	6.0	18.7	50.7	4.8	4.1	11.8	8.7	
55	83.3		43.6	3.7	2.6	6.3	19.4	50.7	4.2	4.3	11.9	8.9	
65	106.0		52.5	4.2	2.5	6.7	20.4	50.7	3.8	4.5	12.0	9.2	
75	0.0	129.3	0.0	0.0	4.8	9.6	24.1	50.7	17.7	4.7	21.4	15.0	29.0

Continued

C10.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*ft³/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	1.9	0.0	0.0	15.4					
5	0		1.3	0.1	1.8	0.1	1.0	15.4					
15	59		3.2	0.3	1.5	0.3	2.6	15.8					
25	309		7.0	0.7	1.3	0.7	4.0	16.5					
35	583		10.6	1.1	1.2	1.1	5.1	17.4					
45	878		14.1	1.3	1.1	1.5	6.0	18.2					
55	1,190		17.7	1.5	1.1	1.8	6.9	19.0					
65	1,515		21.2	1.7	1.0	2.2	7.6	19.6					
75	0	1,848	0.0	0.0	1.9	3.9	9.8	20.0	5.8	0.0	3.8	2.3	10.9
5	0		1.3	0.1	1.8	3.5	8.9	20.1	4.5	0.6	4.2	2.6	
15	59		3.2	0.3	1.5	2.8	7.8	20.3	3.2	1.2	4.5	3.0	
25	309		7.0	0.7	1.3	2.5	7.4	20.4	2.6	1.4	4.7	3.2	
35	583		10.6	1.1	1.2	2.4	7.4	20.5	2.2	1.6	4.7	3.4	
45	878		14.1	1.3	1.1	2.4	7.6	20.5	1.9	1.7	4.8	3.5	
55	1,190		17.7	1.5	1.1	2.5	7.9	20.5	1.7	1.8	4.8	3.6	
65	1,515		21.2	1.7	1.0	2.7	8.2	20.5	1.5	1.8	4.8	3.7	
75	0	1,848	0.0	0.0	1.9	3.9	9.8	20.5	7.2	1.9	8.7	6.1	11.7

C11.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for alder-maple stands in the Pacific Northwest, West

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- m^3/*hectare* -------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.7	0.0	0.0	86.4					
5	0.0		8.0	0.8	4.7	0.8	1.8	86.7					
15	49.5		31.0	3.1	3.7	2.9	4.4	88.9					
25	229.7		99.4	9.9	2.8	9.4	6.2	92.8					
35	380.8		153.8	15.4	2.5	14.6	7.6	97.6					
45	0.0	513.7	0.0	0.0	4.7	32.2	9.3	102.4	42.6	0.0	95.0	16.6	50.6
5	0.0		8.0	0.8	4.7	22.0	3.9	104.6	30.3	5.4	98.7	19.8	
15	49.5		31.0	3.1	3.7	12.3	4.5	108.4	18.8	10.1	102.1	23.1	
25	229.7		99.4	9.9	2.8	13.5	6.2	111.2	14.5	11.7	103.3	24.7	
35	380.8		153.8	15.4	2.5	16.4	7.6	113.0	11.8	12.5	103.9	25.8	
45	0.0	513.7	0.0	0.0	4.7	32.2	9.3	114.1	52.6	13.1	199.3	43.3	51.4
years	------ ft^3/*acre* ---------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	1.9	0.0	0.0	35.0					
5	0		3.2	0.3	1.9	0.3	0.7	35.1					
15	708		12.6	1.3	1.5	1.2	1.8	36.0					
25	3,282		40.2	4.0	1.1	3.8	2.5	37.6					
35	5,442		62.3	6.2	1.0	5.9	3.1	39.5					
45	0	7,342	0.0	0.0	1.9	13.0	3.8	41.5	17.2	0.0	38.4	6.7	20.5
5	0		3.2	0.3	1.9	8.9	1.6	42.3	12.2	2.2	39.9	8.0	
15	708		12.6	1.3	1.5	5.0	1.8	43.9	7.6	4.1	41.3	9.3	
25	3,282		40.2	4.0	1.1	5.5	2.5	45.0	5.9	4.7	41.8	10.0	
35	5,442		62.3	6.2	1.0	6.6	3.1	45.7	4.8	5.1	42.1	10.4	
45	0	7,342	0.0	0.0	1.9	13.0	3.8	46.2	21.3	5.3	80.7	17.5	20.8

C12.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for Douglas-fir stands in the Pacific Northwest, West; volumes are for high-productivity sites (growth rate greater than 165 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock, fertilization, and precommercial thinning)

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m^3/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	4.6	0.0	0.0	71.1					
5	0.0		9.5	0.9	4.4	0.9	3.6	71.3					
15	19.8		23.4	2.3	4.0	2.3	10.0	73.1					
25	169.7		84.6	8.5	3.5	8.5	15.4	76.3					
35	445.7		187.4	10.0	3.2	18.7	20.2	80.2					
45	0.0	718.8	0.0	0.0	4.6	49.3	27.5	84.2	100.1	0.0	57.0	31.8	82.6
5	0.0		9.5	0.9	4.4	43.1	23.7	86.0	76.9	10.9	63.0	38.0	
15	19.8		23.4	2.3	4.0	33.3	20.7	89.2	53.3	21.6	68.9	45.1	
25	169.7		84.6	8.5	3.5	31.2	21.2	91.4	42.5	26.1	71.2	49.0	
35	445.7		187.4	10.0	3.2	35.4	23.3	92.9	35.6	28.8	72.6	51.8	
45	0.0	718.8	0.0	0.0	4.6	49.3	27.5	93.8	130.6	30.7	130.5	85.9	96.5
years	*ft^3/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	1.9	0.0	0.0	28.8					
5	0		3.8	0.4	1.8	0.4	1.5	28.9					
15	283		9.5	0.9	1.6	0.9	4.0	29.6					
25	2,425		34.2	3.4	1.4	3.4	6.2	30.9					
35	6,370		75.9	4.1	1.3	7.6	8.2	32.5					
45	0	10,272	0.0	0.0	1.9	19.9	11.1	34.1	40.5	0.0	23.1	12.9	33.4
5	0		3.8	0.4	1.8	17.5	9.6	34.8	31.1	4.4	25.5	15.4	
15	283		9.5	0.9	1.6	13.5	8.4	36.1	21.6	8.7	27.9	18.3	
25	2,425		34.2	3.4	1.4	12.6	8.6	37.0	17.2	10.6	28.8	19.8	
35	6,370		75.9	4.1	1.3	14.3	9.4	37.6	14.4	11.7	29.4	21.0	
45	0	10,272	0.0	0.0	1.9	19.9	11.1	38.0	52.9	12.4	52.8	34.8	39.0

C13.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for hemlock-Sitka spruce stands in the Pacific Northwest, West; volumes are for high productivity sites (growth rate greater than 225 cubic feet wood/acre/year)

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m³/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	4.7	0.0	0.0	87.3					
5	0.0		5.9	0.6	4.7	0.6	3.6	87.6					
15	80.3		36.4	3.6	3.7	3.6	10.0	89.8					
25	221.7		90.4	9.0	3.0	8.9	15.4	93.7					
35	413.7		161.0	16.1	2.7	15.9	20.2	98.5					
45	0.0	669.6	0.0	0.0	4.7	42.7	27.5	103.4	85.8	0.0	49.3	27.3	93.4
5	0.0		5.9	0.6	4.7	37.1	23.7	105.6	65.8	9.4	54.5	32.7	
15	80.3		36.4	3.6	3.7	30.4	20.7	109.5	45.5	18.5	59.6	38.8	
25	221.7		90.4	9.0	3.0	28.6	21.2	112.3	36.3	22.4	61.6	42.1	
35	413.7		161.0	16.1	2.7	30.3	23.3	114.1	30.4	24.7	62.8	44.6	
45	0.0	669.6	0.0	0.0	4.7	42.7	27.5	115.2	111.8	26.3	112.9	73.8	105.6
years	*ft³/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	1.9	0.0	0.0	35.3					
5	0		2.4	0.2	1.9	0.2	1.5	35.4					
15	1,148		14.7	1.5	1.5	1.5	4.0	36.3					
25	3,169		36.6	3.7	1.2	3.6	6.2	37.9					
35	5,912		65.1	6.5	1.1	6.4	8.2	39.9					
45	0	9,570	0.0	0.0	1.9	17.3	11.1	41.8	34.7	0.0	20.0	11.1	37.8
5	0		2.4	0.2	1.9	15.0	9.6	42.8	26.6	3.8	22.1	13.2	
15	1,148		14.7	1.5	1.5	12.3	8.4	44.3	18.4	7.5	24.1	15.7	
25	3,169		36.6	3.7	1.2	11.6	8.6	45.4	14.7	9.1	24.9	17.0	
35	5,912		65.1	6.5	1.1	12.3	9.4	46.2	12.3	10.0	25.4	18.0	
45	0	9,570	0.0	0.0	1.9	17.3	11.1	46.6	45.3	10.6	45.7	29.9	42.7

C14.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for mixed conifer stands in the Pacific Southwest

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.8	0.0	0.0	37.4					
5	0.0		4.2	0.3	4.8	0.4	5.2	37.5					
15	2.0		8.1	0.8	4.8	0.8	13.0	38.4					
25	11.1		14.6	1.5	6.9	1.5	18.6	40.1					
35	24.4		22.3	2.2	4.9	2.2	22.9	42.2					
45	44.5		32.9	3.3	3.6	3.3	26.2	44.3					
55	71.9		46.5	4.7	2.8	4.7	28.9	46.1					
65	106.6		62.8	6.3	2.2	6.3	31.1	47.5					
75	0.0	147.9	0.0	0.0	4.8	12.0	37.2	48.5	17.3	0.0	12.2	6.3	42.7
5	0.0		4.2	0.3	4.8	10.7	35.4	48.8	13.3	1.9	13.2	7.3	
15	2.0		8.1	0.8	4.8	8.4	32.9	49.3	9.3	3.7	14.3	8.5	
25	11.1		14.6	1.5	6.9	7.0	31.8	49.6	7.4	4.5	14.7	9.1	
35	24.4		22.3	2.2	4.9	6.3	31.6	49.7	6.2	4.9	15.0	9.6	
45	44.5		32.9	3.3	3.6	6.3	32.0	49.8	5.3	5.3	15.2	10.0	
55	71.9		46.5	4.7	2.8	6.9	32.7	49.8	4.7	5.5	15.3	10.3	
65	106.6		62.8	6.3	2.2	7.9	33.6	49.8	4.1	5.7	15.4	10.5	
75	0.0	147.9	0.0	0.0	4.8	12.0	37.2	49.8	20.9	5.9	27.6	17.0	45.6

Continued

C14.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*ft^3/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	1.9	0.0	0.0	15.1					
5	0		1.7	0.1	1.9	0.2	2.1	15.2					
15	29		3.3	0.3	1.9	0.3	5.2	15.5					
25	159		5.9	0.6	2.8	0.6	7.5	16.2					
35	349		9.0	0.9	2.0	0.9	9.3	17.1					
45	636		13.3	1.3	1.5	1.3	10.6	17.9					
55	1,028		18.8	1.9	1.1	1.9	11.7	18.7					
65	1,523		25.4	2.5	0.9	2.6	12.6	19.2					
75	0	2,114	0.0	0.0	1.9	4.9	15.1	19.6	7.0	0.0	4.9	2.5	17.3
5	0		1.7	0.1	1.9	4.3	14.3	19.8	5.4	0.8	5.4	3.0	
15	29		3.3	0.3	1.9	3.4	13.3	20.0	3.7	1.5	5.8	3.4	
25	159		5.9	0.6	2.8	2.8	12.9	20.1	3.0	1.8	6.0	3.7	
35	349		9.0	0.9	2.0	2.6	12.8	20.1	2.5	2.0	6.1	3.9	
45	636		13.3	1.3	1.5	2.5	12.9	20.1	2.2	2.1	6.1	4.0	
55	1,028		18.8	1.9	1.1	2.8	13.2	20.1	1.9	2.2	6.2	4.2	
65	1,523		25.4	2.5	0.9	3.2	13.6	20.2	1.7	2.3	6.2	4.3	
75	0	2,114	0.0	0.0	1.9	4.9	15.1	20.2	8.5	2.4	11.2	6.9	18.4

C15.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for western oak stands in the Pacific Southwest

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.7	0.0	0.0	20.7					
5	0.0		2.6	0.2	4.6	0.1	3.7	20.8					
15	0.0		5.7	0.6	4.5	0.2	9.8	21.3					
25	1.0		8.8	0.9	4.4	0.4	14.4	22.2					
35	25.9		30.6	3.1	4.2	1.3	18.1	23.4					
45	76.3		65.1	4.5	4.1	2.7	21.1	24.5					
55	127.8		98.3	5.4	4.0	4.1	23.6	25.5					
65	174.4		124.0	6.0	4.0	5.1	25.6	26.3					
75	0.0	215.0	0.0	0.0	4.7	13.3	31.7	26.9	19.5	0.0	52.4	7.8	59.7
5	0.0		2.6	0.2	4.6	8.9	28.4	27.1	14.7	2.3	53.7	9.1	
15	0.0		5.7	0.6	4.5	4.1	24.6	27.3	9.8	4.4	55.1	10.4	
25	1.0		8.8	0.9	4.4	2.1	23.4	27.5	7.6	5.4	55.7	11.1	
35	25.9		30.6	3.1	4.2	2.0	23.5	27.5	6.2	5.9	56.0	11.6	
45	76.3		65.1	4.5	4.1	3.0	24.3	27.6	5.2	6.3	56.2	12.0	
55	127.8		98.3	5.4	4.0	4.2	25.5	27.6	4.5	6.5	56.4	12.4	
65	174.4		124.0	6.0	4.0	5.2	26.8	27.6	3.9	6.7	56.5	12.7	
75	0.0	215.0	0.0	0.0	4.7	13.3	31.7	27.6	22.9	6.9	109.0	20.7	60.4

Continued

C15.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*ft^3/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	1.9	0.0	0.0	8.4					
5	0		1.1	0.1	1.9	0.0	1.5	8.4					
15	0		2.3	0.2	1.8	0.1	3.9	8.6					
25	15		3.6	0.4	1.8	0.1	5.8	9.0					
35	370		12.4	1.2	1.7	0.5	7.3	9.5					
45	1,090		26.3	1.8	1.7	1.1	8.5	9.9					
55	1,826		39.8	2.2	1.6	1.7	9.5	10.3					
65	2,493		50.2	2.4	1.6	2.1	10.4	10.6					
75	0	3,072	0.0	0.0	1.9	5.4	12.8	10.9	7.9	0.0	21.2	3.2	24.1
5	0		1.1	0.1	1.9	3.6	11.5	10.9	5.9	0.9	21.7	3.7	
15	0		2.3	0.2	1.8	1.7	10.0	11.1	4.0	1.8	22.3	4.2	
25	15		3.6	0.4	1.8	0.8	9.5	11.1	3.1	2.2	22.5	4.5	
35	370		12.4	1.2	1.7	0.8	9.5	11.1	2.5	2.4	22.7	4.7	
45	1,090		26.3	1.8	1.7	1.2	9.8	11.2	2.1	2.5	22.8	4.9	
55	1,826		39.8	2.2	1.6	1.7	10.3	11.2	1.8	2.6	22.8	5.0	
65	2,493		50.2	2.4	1.6	2.1	10.9	11.2	1.6	2.7	22.9	5.1	
75	0	3,072	0.0	0.0	1.9	5.4	12.8	11.2	9.3	2.8	44.1	8.4	24.4

C16.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for Douglas-fir stands in the Rocky Mountain, North

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.7	0.0	0.0	29.1					
5	0.0		2.7	0.3	4.7	0.2	5.2	29.2					
15	1.1		6.1	0.6	4.7	0.4	13.0	30.0					
25	19.7		21.5	2.2	3.4	1.3	18.6	31.3					
35	57.1		44.3	4.4	2.7	2.8	22.9	32.9					
45	100.9		66.5	6.7	2.3	4.1	26.2	34.5					
55	145.9		87.2	8.7	2.1	5.4	28.9	35.9					
65	189.3		105.9	10.1	1.9	6.6	31.1	37.1					
75	0.0	229.7	0.0	0.0	4.7	22.4	37.2	37.8	40.7	0.0	31.8	8.1	30.6
5	0.0		2.7	0.3	4.7	20.2	35.4	38.1	31.2	4.4	35.1	9.9	
15	1.1		6.1	0.6	4.7	16.3	32.9	38.5	21.5	8.8	38.3	12.0	
25	19.7		21.5	2.2	3.4	14.0	31.8	38.7	17.2	10.7	39.6	13.3	
35	57.1		44.3	4.4	2.7	12.8	31.6	38.8	14.3	11.8	40.3	14.2	
45	100.9		66.5	6.7	2.3	12.1	32.0	38.8	12.3	12.5	40.8	15.1	
55	145.9		87.2	8.7	2.1	11.8	32.7	38.8	10.7	13.1	41.1	15.8	
65	189.3		105.9	10.1	1.9	11.6	33.6	38.8	9.4	13.6	41.3	16.4	
75	0.0	229.7	0.0	0.0	4.7	22.4	37.2	38.8	49.1	13.9	73.2	25.1	36.3

Continued

C16.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- ft^3*/acre* --------		------ *tonnes carbon/acre* ------										
0	0		0.0	0.0	1.9	0.0	0.0	11.8					
5	0		1.1	0.1	1.9	0.1	2.1	11.8					
15	16		2.5	0.2	1.9	0.2	5.2	12.1					
25	281		8.7	0.9	1.4	0.5	7.5	12.7					
35	816		17.9	1.8	1.1	1.1	9.3	13.3					
45	1,442		26.9	2.7	0.9	1.7	10.6	14.0					
55	2,085		35.3	3.5	0.8	2.2	11.7	14.5					
65	2,705		42.9	4.1	0.8	2.7	12.6	15.0					
75	0	3,283	0.0	0.0	1.9	9.1	15.1	15.3	16.5	0.0	12.9	3.3	12.4
5	0		1.1	0.1	1.9	8.2	14.3	15.4	12.6	1.8	14.2	4.0	
15	16		2.5	0.2	1.9	6.6	13.3	15.6	8.7	3.6	15.5	4.9	
25	281		8.7	0.9	1.4	5.6	12.9	15.6	6.9	4.3	16.0	5.4	
35	816		17.9	1.8	1.1	5.2	12.8	15.7	5.8	4.8	16.3	5.8	
45	1,442		26.9	2.7	0.9	4.9	12.9	15.7	5.0	5.1	16.5	6.1	
55	2,085		35.3	3.5	0.8	4.8	13.2	15.7	4.3	5.3	16.6	6.4	
65	2,705		42.9	4.1	0.8	4.7	13.6	15.7	3.8	5.5	16.7	6.6	
75	0	3,283	0.0	0.0	1.9	9.1	15.1	15.7	19.9	5.6	29.6	10.2	14.7

C17.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for lodgepole pine stands in the Rocky Mountain, North

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *m^3/hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.8	0.0	0.0	27.9					
5	0.0		1.9	0.1	4.8	0.1	2.4	28.0					
15	0.2		4.1	0.3	4.8	0.2	6.4	28.7					
25	15.9		14.3	1.4	3.5	0.8	9.8	29.9					
35	51.6		29.9	3.0	2.4	1.7	12.6	31.5					
45	94.3		45.8	4.6	1.9	2.7	14.9	33.0					
55	138.8		59.4	5.9	1.7	3.4	17.0	34.4					
65	182.1		71.6	7.2	1.5	4.2	18.7	35.5					
75	0.0	223.1	0.0	0.0	4.8	17.7	24.1	36.2	32.3	0.0	25.6	6.4	6.4
5	0.0		1.9	0.1	4.8	15.9	22.0	36.5	24.8	3.5	28.2	7.9	
15	0.2		4.1	0.3	4.8	12.8	19.4	36.8	17.1	7.0	30.7	9.5	
25	15.9		14.3	1.4	3.5	10.8	18.3	37.0	13.6	8.5	31.8	10.5	
35	51.6		29.9	3.0	2.4	9.6	18.2	37.1	11.4	9.3	32.4	11.3	
45	94.3		45.8	4.6	1.9	8.9	18.7	37.1	9.8	9.9	32.7	11.9	
55	138.8		59.4	5.9	1.7	8.4	19.4	37.2	8.5	10.4	33.0	12.5	
65	182.1		71.6	7.2	1.5	8.1	20.4	37.2	7.5	10.8	33.1	13.0	
75	0.0	223.1	0.0	0.0	4.8	17.7	24.1	37.2	39.0	11.1	58.8	19.9	10.6

Continued

C17.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft³/acre* --------		----------------------------------- *tonnes carbon/acre* -----------------------------------										
0	0		0.0	0.0	1.9	0.0	0.0	11.3					
5	0		0.8	0.0	1.9	0.0	1.0	11.3					
15	3		1.7	0.1	1.9	0.1	2.6	11.6					
25	227		5.8	0.6	1.4	0.3	4.0	12.1					
35	737		12.1	1.2	1.0	0.7	5.1	12.7					
45	1,348		18.5	1.9	0.8	1.1	6.0	13.4					
55	1,983		24.0	2.4	0.7	1.4	6.9	13.9					
65	2,603		29.0	2.9	0.6	1.7	7.6	14.4					
75	0	3,189	0.0	0.0	1.9	7.2	9.8	14.6	13.1	0.0	10.4	2.6	2.6
5	0		0.8	0.0	1.9	6.4	8.9	14.8	10.0	1.4	11.4	3.2	
15	3		1.7	0.1	1.9	5.2	7.8	14.9	6.9	2.8	12.4	3.9	
25	227		5.8	0.6	1.4	4.4	7.4	15.0	5.5	3.4	12.8	4.3	
35	737		12.1	1.2	1.0	3.9	7.4	15.0	4.6	3.8	13.1	4.6	
45	1,348		18.5	1.9	0.8	3.6	7.6	15.0	3.9	4.0	13.2	4.8	
55	1,983		24.0	2.4	0.7	3.4	7.9	15.0	3.4	4.2	13.3	5.1	
65	2,603		29.0	2.9	0.6	3.3	8.2	15.0	3.0	4.4	13.4	5.3	
75	0	3,189	0.0	0.0	1.9	7.2	9.8	15.0	15.8	4.5	23.8	8.1	4.3

C18.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for fir-spruce-mountain hemlock stands in the Rocky Mountain, South

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *m^3/hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.8	0.0	0.0	23.6					
5	0.0		1.8	0.2	4.8	0.1	5.2	23.7					
15	0.0		4.0	0.4	4.8	0.3	13.0	24.3					
25	8.5		12.0	1.2	4.3	0.9	18.6	25.3					
35	27.7		24.4	2.4	2.8	1.9	22.9	26.7					
45	49.5		36.7	3.7	2.3	2.9	26.2	28.0					
55	71.9		48.7	4.9	1.9	3.8	28.9	29.1					
65	94.1		58.6	5.9	1.7	4.6	31.1	30.0					
75	0.0	115.7	0.0	0.0	4.8	11.3	37.2	30.6	16.4	0.0	14.8	3.4	26.5
5	0.0		1.8	0.2	4.8	10.2	35.4	30.9	12.6	1.8	16.1	4.1	
15	0.0		4.0	0.4	4.8	8.3	32.9	31.2	8.7	3.6	17.4	5.0	
25	8.5		12.0	1.2	4.3	7.3	31.8	31.3	6.9	4.3	17.9	5.5	
35	27.7		24.4	2.4	2.8	7.0	31.6	31.4	5.7	4.8	18.2	5.9	
45	49.5		36.7	3.7	2.3	6.9	32.0	31.4	4.9	5.1	18.4	6.2	
55	71.9		48.7	4.9	1.9	7.0	32.7	31.5	4.3	5.3	18.6	6.5	
65	94.1		58.6	5.9	1.7	7.1	33.6	31.5	3.8	5.5	18.6	6.7	
75	0.0	115.7	0.0	0.0	4.8	11.3	37.2	31.5	19.8	5.6	33.5	10.3	30.2

Continued

C18.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft³/acre* --------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	2.0	0.0	0.0	9.6					
5	0		0.7	0.1	2.0	0.1	2.1	9.6					
15	0		1.6	0.2	2.0	0.1	5.2	9.8					
25	122		4.8	0.5	1.7	0.4	7.5	10.3					
35	396		9.9	1.0	1.1	0.8	9.3	10.8					
45	708		14.8	1.5	0.9	1.2	10.6	11.3					
55	1,028		19.7	2.0	0.8	1.6	11.7	11.8					
65	1,345		23.7	2.4	0.7	1.9	12.6	12.1					
75	0	1,654	0.0	0.0	2.0	4.6	15.1	12.4	6.6	0.0	6.0	1.4	10.7
5	0		0.7	0.1	2.0	4.1	14.3	12.5	5.1	0.7	6.5	1.7	
15	0		1.6	0.2	2.0	3.4	13.3	12.6	3.5	1.4	7.0	2.0	
25	122		4.8	0.5	1.7	3.0	12.9	12.7	2.8	1.7	7.3	2.2	
35	396		9.9	1.0	1.1	2.8	12.8	12.7	2.3	1.9	7.4	2.4	
45	708		14.8	1.5	0.9	2.8	12.9	12.7	2.0	2.0	7.5	2.5	
55	1,028		19.7	2.0	0.8	2.8	13.2	12.7	1.7	2.1	7.5	2.6	
65	1,345		23.7	2.4	0.7	2.9	13.6	12.7	1.5	2.2	7.5	2.7	
75	0	1,654	0.0	0.0	2.0	4.6	15.1	12.7	8.0	2.3	13.5	4.2	12.2

C19.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for ponderosa pine stands in the Rocky Mountain, South

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *m^3/hectare* ------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.8	0.0	0.0	18.1					
5	0.0		1.8	0.2	4.8	0.2	2.4	18.1					
15	0.0		3.7	0.4	4.8	0.3	6.4	18.6					
25	4.4		9.4	0.9	4.8	0.8	9.8	19.4					
35	16.2		18.6	1.9	2.9	1.5	12.6	20.4					
45	32.2		28.8	2.7	2.1	2.4	14.9	21.4					
55	50.3		38.2	3.0	1.7	3.1	17.0	22.3					
65	69.3		47.1	3.3	1.5	3.9	18.7	23.0					
75	0.0	88.4	0.0	0.0	4.8	9.7	24.1	23.5	14.2	0.0	11.1	2.8	18.5
5	0.0		1.8	0.2	4.8	8.8	22.0	23.6	10.9	1.6	12.2	3.5	
15	0.0		3.7	0.4	4.8	7.1	19.4	23.9	7.5	3.1	13.3	4.2	
25	4.4		9.4	0.9	4.8	6.2	18.3	24.0	6.0	3.7	13.8	4.6	
35	16.2		18.6	1.9	2.9	5.8	18.2	24.1	5.0	4.1	14.1	5.0	
45	32.2		28.8	2.7	2.1	5.8	18.7	24.1	4.3	4.4	14.2	5.3	
55	50.3		38.2	3.0	1.7	5.9	19.4	24.1	3.7	4.6	14.3	5.5	
65	69.3		47.1	3.3	1.5	6.0	20.4	24.1	3.3	4.7	14.4	5.7	
75	0.0	88.4	0.0	0.0	4.8	9.7	24.1	24.1	17.1	4.9	25.5	8.8	21.3

Continued

C19.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*ft³/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	2.0	0.0	0.0	7.3					
5	0		0.7	0.1	2.0	0.1	1.0	7.3					
15	0		1.5	0.1	2.0	0.1	2.6	7.5					
25	63		3.8	0.4	2.0	0.3	4.0	7.9					
35	231		7.5	0.8	1.2	0.6	5.1	8.3					
45	460		11.7	1.1	0.9	1.0	6.0	8.7					
55	719		15.5	1.2	0.7	1.3	6.9	9.0					
65	990		19.1	1.4	0.6	1.6	7.6	9.3					
75	0	1,263	0.0	0.0	2.0	3.9	9.8	9.5	5.8	0.0	4.5	1.2	7.5
5	0		0.7	0.1	2.0	3.5	8.9	9.6	4.4	0.6	4.9	1.4	
15	0		1.5	0.1	2.0	2.9	7.8	9.7	3.0	1.2	5.4	1.7	
25	63		3.8	0.4	2.0	2.5	7.4	9.7	2.4	1.5	5.6	1.9	
35	231		7.5	0.8	1.2	2.4	7.4	9.7	2.0	1.7	5.7	2.0	
45	460		11.7	1.1	0.9	2.3	7.6	9.8	1.7	1.8	5.8	2.1	
55	719		15.5	1.2	0.7	2.4	7.9	9.8	1.5	1.9	5.8	2.2	
65	990		19.1	1.4	0.6	2.4	8.2	9.8	1.3	1.9	5.8	2.3	
75	0	1,263	0.0	0.0	2.0	3.9	9.8	9.8	6.9	2.0	10.3	3.6	8.6

C20.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for loblolly-shortleaf pine stands in the Southeast; volumes are for high productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high intensity management (replanting with genetically improved stock)

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m^3/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	4.1	0.0	0.0	54.7					
5	0.0		11.0	0.7	4.0	0.4	3.2	54.9					
10	47.7		31.9	1.4	3.8	1.2	5.5	55.4					
15	146.5		67.4	1.9	3.7	2.5	7.3	56.3					
20	244.8		102.3	2.1	3.7	3.8	8.7	57.4					
25	0.0	315.2	0.0	0.0	4.1	20.4	12.2	58.7	41.1	0.0	30.3	14.2	22.2
5	0.0		11.0	0.7	4.0	15.9	6.5	60.2	26.9	5.4	35.2	18.3	
10	47.7		31.9	1.4	3.8	12.9	6.4	61.8	19.1	8.0	37.9	20.7	
15	146.5		67.4	1.9	3.7	11.4	7.5	63.3	15.2	9.2	39.3	22.1	
20	244.8		102.3	2.1	3.7	10.5	8.7	64.8	13.2	9.6	39.9	23.0	
25	0.0	315.2	0.0	0.0	4.1	20.4	12.2	66.2	53.0	9.9	70.6	37.9	27.3
years	*ft^3/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	1.7	0.0	0.0	22.1					
5	0		4.5	0.3	1.6	0.2	1.3	22.2					
10	682		12.9	0.6	1.6	0.5	2.2	22.4					
15	2,094		27.3	0.8	1.5	1.0	2.9	22.8					
20	3,498		41.4	0.9	1.5	1.5	3.5	23.2					
25	0	4,504	0.0	0.0	1.7	8.3	4.9	23.8	16.6	0.0	12.3	5.8	9.0
5	0		4.5	0.3	1.6	6.4	2.6	24.4	10.9	2.2	14.2	7.4	
10	682		12.9	0.6	1.6	5.2	2.6	25.0	7.7	3.2	15.3	8.4	
15	2,094		27.3	0.8	1.5	4.6	3.0	25.6	6.1	3.7	15.9	8.9	
20	3,498		41.4	0.9	1.5	4.3	3.5	26.2	5.3	3.9	16.2	9.3	
25	0	4,504	0.0	0.0	1.7	8.3	4.9	26.8	21.4	4.0	28.6	15.3	11.0

C21.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-gum-cypress stands in the Southeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		-------- *tonnes carbon/hectare* --------										
0	0.0		0.0	0.0	1.8	0.0	0.0	118.5					
5	0.0		6.7	0.7	1.9	0.4	1.1	118.9					
10	9.8		18.8	1.9	1.8	1.2	2.1	120.1					
15	19.9		28.3	2.4	1.7	1.8	3.0	121.9					
20	32.7		38.0	2.8	1.7	2.4	3.7	124.4					
25	45.4		46.8	3.1	1.6	3.0	4.4	127.2					
30	58.1		54.0	3.4	1.6	3.4	5.0	130.5					
35	73.4		62.3	3.6	1.6	4.0	5.5	133.8					
40	92.2		71.9	3.9	1.6	4.6	6.0	137.2					
45	110.7		80.9	4.2	1.6	5.1	6.4	140.4					
50	0.0	128.1	0.0	0.0	1.8	10.2	6.0	143.5	14.5	0.0	15.5	6.0	53.4
5	0.0		6.7	0.7	1.9	6.2	2.4	146.2	9.4	2.1	17.0	7.5	
10	9.8		18.8	1.9	1.8	4.5	2.4	148.7	6.6	3.1	17.8	8.4	
15	19.9		28.3	2.4	1.7	3.7	3.0	150.7	5.2	3.6	18.3	8.9	
20	32.7		38.0	2.8	1.7	3.5	3.8	152.4	4.4	3.8	18.5	9.3	
25	45.4		46.8	3.1	1.6	3.6	4.4	153.8	3.9	3.9	18.7	9.5	
30	58.1		54.0	3.4	1.6	3.8	5.0	155.0	3.5	4.0	18.8	9.7	
35	73.4		62.3	3.6	1.6	4.2	5.5	155.8	3.2	4.0	18.8	9.9	
40	92.2		71.9	3.9	1.6	4.7	6.0	156.5	3.0	4.1	18.9	10.0	
45	110.7		80.9	4.2	1.6	5.2	6.4	156.9	2.8	4.1	18.9	10.2	
50	0.0	128.1	0.0	0.0	1.8	10.2	6.0	157.3	17.0	4.2	34.4	16.3	53.4

Continued

C21.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- ft^3*/acre* --------		------ *tonnes carbon/acre* ------										
0	0		0.0	0.0	0.7	0.0	0.0	48.0					
5	0		2.7	0.3	0.8	0.2	0.5	48.1					
10	140		7.6	0.8	0.7	0.5	0.9	48.6					
15	284		11.5	1.0	0.7	0.7	1.2	49.3					
20	467		15.4	1.1	0.7	1.0	1.5	50.3					
25	649		18.9	1.3	0.7	1.2	1.8	51.5					
30	830		21.9	1.4	0.7	1.4	2.0	52.8					
35	1,049		25.2	1.5	0.6	1.6	2.2	54.2					
40	1,318		29.1	1.6	0.6	1.9	2.4	55.5					
45	1,582		32.7	1.7	0.6	2.1	2.6	56.8					
50	0	1,830	0.0	0.0	0.7	4.1	2.4	58.1	5.9	0.0	6.3	2.4	21.6
5	0		2.7	0.3	0.8	2.5	1.0	59.2	3.8	0.8	6.9	3.0	
10	140		7.6	0.8	0.7	1.8	1.0	60.2	2.7	1.3	7.2	3.4	
15	284		11.5	1.0	0.7	1.5	1.2	61.0	2.1	1.4	7.4	3.6	
20	467		15.4	1.1	0.7	1.4	1.5	61.7	1.8	1.5	7.5	3.7	
25	649		18.9	1.3	0.7	1.5	1.8	62.3	1.6	1.6	7.6	3.8	
30	830		21.9	1.4	0.7	1.5	2.0	62.7	1.4	1.6	7.6	3.9	
35	1,049		25.2	1.5	0.6	1.7	2.2	63.1	1.3	1.6	7.6	4.0	
40	1,318		29.1	1.6	0.6	1.9	2.4	63.3	1.2	1.6	7.6	4.1	
45	1,582		32.7	1.7	0.6	2.1	2.6	63.5	1.1	1.7	7.7	4.1	
50	0	1,830	0.0	0.0	0.7	4.1	2.4	63.7	6.9	1.7	13.9	6.6	21.6

C22.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-hickory stands in the Southeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- m^3/*hectare* -------		--- *tonnes carbon/hectare* ---										
0	0.0		0.0	0.0	4.2	0.0	0.0	33.9					
5	0.0		8.1	0.8	4.2	0.5	1.1	34.1					
10	11.7		21.0	2.1	3.8	1.2	2.1	34.4					
15	21.2		30.3	2.5	3.5	1.8	3.0	34.9					
20	33.8		40.0	2.8	3.3	2.4	3.7	35.6					
25	46.6		49.5	3.0	3.2	2.9	4.4	36.4					
30	60.2		57.5	3.2	3.1	3.4	5.0	37.4					
35	76.3		66.6	3.4	3.0	4.0	5.5	38.3					
40	94.3		76.2	3.6	2.9	4.5	6.0	39.3					
45	114.1		86.4	3.8	2.9	5.1	6.4	40.2					
50	0.0	133.0	0.0	0.0	4.2	10.8	6.0	41.1	15.7	0.0	17.9	6.8	53.7
5	0.0		8.1	0.8	4.2	6.7	2.4	41.9	10.1	2.3	19.5	8.5	
10	11.7		21.0	2.1	3.8	4.8	2.4	42.6	7.0	3.5	20.5	9.4	
15	21.2		30.3	2.5	3.5	3.8	3.0	43.2	5.4	4.0	21.0	10.0	
20	33.8		40.0	2.8	3.3	3.5	3.8	43.7	4.6	4.3	21.2	10.4	
25	46.6		49.5	3.0	3.2	3.6	4.4	44.1	4.0	4.4	21.4	10.6	
30	60.2		57.5	3.2	3.1	3.8	5.0	44.4	3.6	4.5	21.5	10.9	
35	76.3		66.6	3.4	3.0	4.2	5.5	44.6	3.3	4.5	21.6	11.1	
40	94.3		76.2	3.6	2.9	4.6	6.0	44.8	3.0	4.6	21.6	11.2	
45	114.1		86.4	3.8	2.9	5.2	6.4	44.9	2.8	4.6	21.7	11.4	
50	0.0	133.0	0.0	0.0	4.2	10.8	6.0	45.0	18.2	4.6	39.6	18.3	53.7

Continued

C22.—Continued

Age	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*ft³/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	1.7	0.0	0.0	13.7					
5	0		3.3	0.3	1.7	0.2	0.5	13.8					
10	167		8.5	0.8	1.5	0.5	0.9	13.9					
15	303		12.3	1.0	1.4	0.7	1.2	14.1					
20	483		16.2	1.1	1.3	1.0	1.5	14.4					
25	666		20.1	1.2	1.3	1.2	1.8	14.7					
30	860		23.3	1.3	1.3	1.4	2.0	15.1					
35	1,091		26.9	1.4	1.2	1.6	2.2	15.5					
40	1,348		30.8	1.5	1.2	1.8	2.4	15.9					
45	1,630		35.0	1.5	1.2	2.1	2.6	16.3					
50	0	1,901	0.0	0.0	1.7	4.4	2.4	16.6	6.3	0.0	7.3	2.8	21.7
5	0		3.3	0.3	1.7	2.7	1.0	16.9	4.1	0.9	7.9	3.4	
10	167		8.5	0.8	1.5	1.9	1.0	17.2	2.8	1.4	8.3	3.8	
15	303		12.3	1.0	1.4	1.5	1.2	17.5	2.2	1.6	8.5	4.1	
20	483		16.2	1.1	1.3	1.4	1.5	17.7	1.9	1.7	8.6	4.2	
25	666		20.1	1.2	1.3	1.5	1.8	17.8	1.6	1.8	8.6	4.3	
30	860		23.3	1.3	1.3	1.5	2.0	18.0	1.5	1.8	8.7	4.4	
35	1,091		26.9	1.4	1.2	1.7	2.2	18.1	1.3	1.8	8.7	4.5	
40	1,348		30.8	1.5	1.2	1.9	2.4	18.1	1.2	1.8	8.8	4.5	
45	1,630		35.0	1.5	1.2	2.1	2.6	18.2	1.1	1.9	8.8	4.6	
50	0	1,901	0.0	0.0	1.7	4.4	2.4	18.2	7.4	1.9	16.0	7.4	21.7

C23.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-pine stands in the Southeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- *m^3/hectare* -------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.2	0.0	0.0	46.1					
5	0.0		7.4	0.6	4.1	0.5	3.1	46.2					
10	13.6		19.6	1.2	3.6	1.2	5.1	46.7					
15	27.8		29.3	1.6	3.5	1.9	6.6	47.4					
20	43.9		39.0	1.9	3.4	2.5	7.7	48.3					
25	59.3		46.8	2.1	3.3	3.0	8.5	49.5					
30	77.2		55.4	2.3	3.2	3.5	9.2	50.7					
35	96.8		64.4	2.5	3.2	4.1	9.8	52.0					
40	117.2		73.4	2.7	3.1	4.7	10.2	53.3					
45	136.4		81.6	2.8	3.1	5.2	10.6	54.6					
50	0.0	154.1	0.0	0.0	4.2	11.3	10.3	55.8	19.5	0.0	17.6	7.2	41.4
5	0.0		7.4	0.6	4.1	9.0	5.8	56.8	13.0	2.6	19.6	9.1	
10	13.6		19.6	1.2	3.6	7.7	5.9	57.8	9.4	3.9	20.8	10.2	
15	27.8		29.3	1.6	3.5	6.7	6.8	58.6	7.6	4.5	21.4	10.9	
20	43.9		39.0	1.9	3.4	6.2	7.7	59.2	6.5	4.8	21.7	11.3	
25	59.3		46.8	2.1	3.3	5.8	8.6	59.8	5.9	5.0	21.9	11.6	
30	77.2		55.4	2.3	3.2	5.6	9.2	60.2	5.3	5.1	22.0	11.9	
35	96.8		64.4	2.5	3.2	5.7	9.8	60.6	4.9	5.2	22.1	12.1	
40	117.2		73.4	2.7	3.1	5.9	10.2	60.8	4.5	5.3	22.2	12.3	
45	136.4		81.6	2.8	3.1	6.1	10.6	61.0	4.2	5.3	22.2	12.5	
50	0.0	154.1	0.0	0.0	4.2	11.3	10.3	61.1	23.5	5.4	39.9	19.9	42.1

Continued

C23.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *ft³/acre* ----------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	1.7	0.0	0.0	18.6					
5	0		3.0	0.3	1.7	0.2	1.2	18.7					
10	195		7.9	0.5	1.5	0.5	2.1	18.9					
15	397		11.9	0.6	1.4	0.8	2.7	19.2					
20	628		15.8	0.8	1.4	1.0	3.1	19.6					
25	848		19.0	0.8	1.3	1.2	3.5	20.0					
30	1,104		22.4	0.9	1.3	1.4	3.7	20.5					
35	1,384		26.1	1.0	1.3	1.7	4.0	21.0					
40	1,675		29.7	1.1	1.3	1.9	4.1	21.6					
45	1,950		33.0	1.1	1.2	2.1	4.3	22.1					
50	0	2,202	0.0	0.0	1.7	4.6	4.2	22.6	7.9	0.0	7.1	2.9	16.8
5	0		3.0	0.3	1.7	3.6	2.4	23.0	5.3	1.0	7.9	3.7	
10	195		7.9	0.5	1.5	3.1	2.4	23.4	3.8	1.6	8.4	4.1	
15	397		11.9	0.6	1.4	2.7	2.7	23.7	3.1	1.8	8.7	4.4	
20	628		15.8	0.8	1.4	2.5	3.1	24.0	2.6	1.9	8.8	4.6	
25	848		19.0	0.8	1.3	2.3	3.5	24.2	2.4	2.0	8.9	4.7	
30	1,104		22.4	0.9	1.3	2.3	3.7	24.4	2.2	2.1	8.9	4.8	
35	1,384		26.1	1.0	1.3	2.3	4.0	24.5	2.0	2.1	8.9	4.9	
40	1,675		29.7	1.1	1.3	2.4	4.1	24.6	1.8	2.1	9.0	5.0	
45	1,950		33.0	1.1	1.2	2.5	4.3	24.7	1.7	2.2	9.0	5.1	
50	0	2,202	0.0	0.0	1.7	4.6	4.2	24.7	9.5	2.2	16.1	8.1	17.0

C24.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for loblolly-shortleaf pine stands in the South Central; volumes are for high-productivity sites (growth rate greater than 120 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- m^3/*hectare* -------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.1	0.0	0.0	31.4					
5	0.0		10.8	0.4	4.1	0.4	3.2	31.5					
10	47.7		34.2	0.9	3.9	1.3	5.5	31.8					
15	146.5		68.7	1.0	3.8	2.7	7.3	32.3					
20	244.8		99.2	1.1	3.7	3.8	8.7	33.0					
25	0.0	315.2	0.0	0.0	4.1	20.4	12.2	33.7	39.7	0.0	27.3	15.0	18.8
5	0.0		10.8	0.4	4.1	15.8	6.5	34.6	27.1	4.9	31.4	18.7	
10	47.7		34.2	0.9	3.9	13.0	6.4	35.5	20.1	7.4	33.8	20.9	
15	146.5		68.7	1.0	3.8	11.5	7.5	36.4	16.4	8.5	34.9	22.2	
20	244.8		99.2	1.1	3.7	10.5	8.7	37.2	14.5	9.1	35.5	23.0	
25	0.0	315.2	0.0	0.0	4.1	20.4	12.2	38.0	52.8	9.4	63.2	38.7	23.8
years	------ ft^3/*acre* --------		------ *tonnes carbon/acre* ------										
0	0		0.0	0.0	1.7	0.0	0.0	12.7					
5	0		4.4	0.2	1.6	0.2	1.3	12.8					
10	682		13.8	0.3	1.6	0.5	2.2	12.9					
15	2,094		27.8	0.4	1.5	1.1	2.9	13.1					
20	3,498		40.1	0.4	1.5	1.6	3.5	13.3					
25	0	4,504	0.0	0.0	1.7	8.2	4.9	13.7	16.1	0.0	11.1	6.1	7.6
5	0		4.4	0.2	1.6	6.4	2.6	14.0	11.0	2.0	12.7	7.6	
10	682		13.8	0.3	1.6	5.2	2.6	14.4	8.1	3.0	13.7	8.4	
15	2,094		27.8	0.4	1.5	4.6	3.0	14.7	6.7	3.4	14.1	9.0	
20	3,498		40.1	0.4	1.5	4.2	3.5	15.1	5.9	3.7	14.4	9.3	
25	0	4,504	0.0	0.0	1.7	8.2	4.9	15.4	21.4	3.8	25.6	15.7	9.6

C25.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-gum-cypress stands in the South Central

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- m^3*/hectare* -----		---- *tonnes carbon/hectare* ----										
0	0.0		0.0	0.0	1.8	0.0	0.0	39.6					
5	0.0		5.4	0.5	2.1	0.3	1.1	39.7					
10	9.8		17.8	1.8	1.8	1.1	2.1	40.1					
15	19.9		28.4	2.8	1.7	1.8	3.0	40.7					
20	32.7		39.3	3.2	1.7	2.5	3.7	41.5					
25	45.4		48.8	3.4	1.6	3.1	4.4	42.5					
30	58.1		57.2	3.5	1.6	3.6	5.0	43.6					
35	73.4		66.9	3.6	1.6	4.2	5.5	44.7					
40	92.2		76.9	3.7	1.6	4.9	6.0	45.8					
45	110.7		86.1	3.7	1.5	5.4	6.4	46.9					
50	0.0	128.1	0.0	0.0	1.8	10.8	6.0	47.9	14.5	0.0	16.0	6.5	57.0
5	0.0		5.4	0.5	2.1	6.5	2.4	48.8	9.4	2.1	17.5	7.9	
10	9.8		17.8	1.8	1.8	4.6	2.4	49.7	6.6	3.2	18.3	8.8	
15	19.9		28.4	2.8	1.7	3.8	3.0	50.3	5.2	3.7	18.8	9.3	
20	32.7		39.3	3.2	1.7	3.6	3.8	50.9	4.4	3.9	19.0	9.7	
25	45.4		48.8	3.4	1.6	3.7	4.4	51.4	3.9	4.0	19.2	9.9	
30	58.1		57.2	3.5	1.6	4.0	5.0	51.8	3.5	4.1	19.3	10.1	
35	73.4		66.9	3.6	1.6	4.4	5.5	52.0	3.2	4.1	19.3	10.3	
40	92.2		76.9	3.7	1.6	5.0	6.0	52.3	2.9	4.2	19.4	10.4	
45	110.7		86.1	3.7	1.5	5.5	6.4	52.4	2.7	4.2	19.4	10.6	
50	0.0	128.1	0.0	0.0	1.8	10.8	6.0	52.5	17.0	4.3	35.5	17.2	57.0

Continued

C25.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *ft³/acre* ---------		------ *tonnes carbon/acre* ------										
0	0		0.0	0.0	0.7	0.0	0.0	16.0					
5	0		2.2	0.2	0.8	0.1	0.5	16.1					
10	140		7.2	0.7	0.7	0.5	0.9	16.2					
15	284		11.5	1.1	0.7	0.7	1.2	16.5					
20	467		15.9	1.3	0.7	1.0	1.5	16.8					
25	649		19.7	1.4	0.7	1.2	1.8	17.2					
30	830		23.1	1.4	0.7	1.5	2.0	17.6					
35	1,049		27.1	1.4	0.6	1.7	2.2	18.1					
40	1,318		31.1	1.5	0.6	2.0	2.4	18.5					
45	1,582		34.9	1.5	0.6	2.2	2.6	19.0					
50	0	1,830	0.0	0.0	0.7	4.4	2.4	19.4	5.9	0.0	6.5	2.6	23.1
5	0		2.2	0.2	0.8	2.6	1.0	19.8	3.8	0.8	7.1	3.2	
10	140		7.2	0.7	0.7	1.9	1.0	20.1	2.7	1.3	7.4	3.6	
15	284		11.5	1.1	0.7	1.5	1.2	20.4	2.1	1.5	7.6	3.8	
20	467		15.9	1.3	0.7	1.5	1.5	20.6	1.8	1.6	7.7	3.9	
25	649		19.7	1.4	0.7	1.5	1.8	20.8	1.6	1.6	7.8	4.0	
30	830		23.1	1.4	0.7	1.6	2.0	20.9	1.4	1.7	7.8	4.1	
35	1,049		27.1	1.4	0.6	1.8	2.2	21.1	1.3	1.7	7.8	4.2	
40	1,318		31.1	1.5	0.6	2.0	2.4	21.1	1.2	1.7	7.9	4.2	
45	1,582		34.9	1.5	0.6	2.2	2.6	21.2	1.1	1.7	7.9	4.3	
50	0	1,830	0.0	0.0	0.7	4.4	2.4	21.3	6.9	1.7	14.4	7.0	23.1

C26.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-hickory stands in the South Central

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.2	0.0	0.0	29.0					
5	0.0		9.7	0.9	4.7	0.6	1.1	29.1					
10	11.7		20.9	1.9	4.0	1.4	2.1	29.4					
15	21.2		30.1	2.1	3.6	2.0	3.0	29.8					
20	33.8		39.5	2.3	3.4	2.6	3.7	30.4					
25	46.6		48.2	2.4	3.3	3.2	4.4	31.1					
30	60.2		56.6	2.6	3.1	3.8	5.0	31.9					
35	76.3		65.6	2.7	3.0	4.4	5.5	32.7					
40	94.3		76.2	2.8	2.9	5.1	6.0	33.5					
45	114.1		85.7	2.9	2.8	5.7	6.4	34.3					
50	0.0	133.0	0.0	0.0	4.2	11.7	6.0	35.1	16.0	0.0	18.9	7.5	49.5
5	0.0		9.7	0.9	4.7	7.3	2.4	35.8	10.0	2.4	20.6	9.2	
10	11.7		20.9	1.9	4.0	5.2	2.4	36.4	6.8	3.6	21.6	10.3	
15	21.2		30.1	2.1	3.6	4.2	3.0	36.9	5.2	4.1	22.1	10.9	
20	33.8		39.5	2.3	3.4	3.9	3.8	37.3	4.4	4.3	22.4	11.2	
25	46.6		48.2	2.4	3.3	3.9	4.4	37.6	3.8	4.4	22.5	11.5	
30	60.2		56.6	2.6	3.1	4.2	5.0	37.9	3.4	4.4	22.7	11.7	
35	76.3		65.6	2.7	3.0	4.6	5.5	38.1	3.1	4.5	22.7	11.9	
40	94.3		76.2	2.8	2.9	5.2	6.0	38.3	2.9	4.5	22.8	12.1	
45	114.1		85.7	2.9	2.8	5.8	6.4	38.4	2.7	4.5	22.8	12.3	
50	0.0	133.0	0.0	0.0	4.2	11.7	6.0	38.5	18.4	4.6	41.8	19.8	49.5

Continued

C26.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*ft³/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	1.7	0.0	0.0	11.7					
5	0		3.9	0.4	1.9	0.3	0.5	11.8					
10	167		8.5	0.8	1.6	0.6	0.9	11.9					
15	303		12.2	0.9	1.5	0.8	1.2	12.1					
20	483		16.0	0.9	1.4	1.1	1.5	12.3					
25	666		19.5	1.0	1.3	1.3	1.8	12.6					
30	860		22.9	1.0	1.3	1.5	2.0	12.9					
35	1,091		26.6	1.1	1.2	1.8	2.2	13.2					
40	1,348		30.8	1.1	1.2	2.0	2.4	13.6					
45	1,630		34.7	1.2	1.2	2.3	2.6	13.9					
50	0	1,901	0.0	0.0	1.7	4.7	2.4	14.2	6.5	0.0	7.6	3.0	20.0
5	0		3.9	0.4	1.9	2.9	1.0	14.5	4.1	1.0	8.3	3.7	
10	167		8.5	0.8	1.6	2.1	1.0	14.7	2.8	1.4	8.8	4.2	
15	303		12.2	0.9	1.5	1.7	1.2	14.9	2.1	1.7	9.0	4.4	
20	483		16.0	0.9	1.4	1.6	1.5	15.1	1.8	1.7	9.1	4.6	
25	666		19.5	1.0	1.3	1.6	1.8	15.2	1.6	1.8	9.1	4.7	
30	860		22.9	1.0	1.3	1.7	2.0	15.3	1.4	1.8	9.2	4.8	
35	1,091		26.6	1.1	1.2	1.9	2.2	15.4	1.3	1.8	9.2	4.8	
40	1,348		30.8	1.1	1.2	2.1	2.4	15.5	1.2	1.8	9.2	4.9	
45	1,630		34.7	1.2	1.2	2.3	2.6	15.5	1.1	1.8	9.2	5.0	
50	0	1,901	0.0	0.0	1.7	4.7	2.4	15.6	7.5	1.9	16.9	8.0	20.0

C27.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-pine stands in the South Central

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.2	0.0	0.0	31.3					
5	0.0		8.7	0.7	4.4	0.6	3.1	31.4					
10	13.6		21.4	1.4	3.7	1.5	5.1	31.7					
15	27.8		31.9	1.7	3.5	2.3	6.6	32.2					
20	43.9		41.8	2.0	3.3	3.0	7.7	32.8					
25	59.3		50.9	2.2	3.2	3.7	8.5	33.6					
30	77.2		59.2	2.5	3.1	4.3	9.2	34.4					
35	96.8		67.9	2.6	3.0	4.9	9.8	35.3					
40	117.2		76.5	2.8	2.9	5.5	10.2	36.2					
45	136.4		84.4	3.0	2.9	6.1	10.6	37.0					
50	0.0	154.1	0.0	0.0	4.2	12.4	10.3	37.9	19.7	0.0	17.4	8.2	42.8
5	0.0		8.7	0.7	4.4	10.0	5.8	38.6	13.2	2.6	19.4	10.1	
10	13.6		21.4	1.4	3.7	8.6	5.9	39.2	9.6	3.9	20.6	11.3	
15	27.8		31.9	1.7	3.5	7.7	6.8	39.8	7.7	4.5	21.2	11.9	
20	43.9		41.8	2.0	3.3	7.1	7.7	40.2	6.7	4.8	21.5	12.4	
25	59.3		50.9	2.2	3.2	6.7	8.6	40.6	6.0	4.9	21.6	12.7	
30	77.2		59.2	2.5	3.1	6.6	9.2	40.9	5.5	5.0	21.8	13.0	
35	96.8		67.9	2.6	3.0	6.7	9.8	41.1	5.1	5.1	21.9	13.2	
40	117.2		76.5	2.8	2.9	6.9	10.2	41.3	4.7	5.2	21.9	13.4	
45	136.4		84.4	3.0	2.9	7.1	10.6	41.4	4.4	5.3	22.0	13.6	
50	0.0	154.1	0.0	0.0	4.2	12.4	10.3	41.5	23.8	5.4	39.4	22.0	43.6

Continued

C27.—Continued

Age	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- ft^3/*acre* ---------		------------------- *tonnes carbon/acre* -------------------										
0	0		0.0	0.0	1.7	0.0	0.0	12.7					
5	0		3.5	0.3	1.8	0.3	1.2	12.7					
10	195		8.6	0.6	1.5	0.6	2.1	12.8					
15	397		12.9	0.7	1.4	0.9	2.7	13.0					
20	628		16.9	0.8	1.3	1.2	3.1	13.3					
25	848		20.6	0.9	1.3	1.5	3.5	13.6					
30	1,104		24.0	1.0	1.2	1.7	3.7	13.9					
35	1,384		27.5	1.1	1.2	2.0	4.0	14.3					
40	1,675		31.0	1.1	1.2	2.2	4.1	14.6					
45	1,950		34.2	1.2	1.2	2.5	4.3	15.0					
50	0	2,202	0.0	0.0	1.7	5.0	4.2	15.3	8.0	0.0	7.0	3.3	17.3
5	0		3.5	0.3	1.8	4.0	2.4	15.6	5.3	1.0	7.9	4.1	
10	195		8.6	0.6	1.5	3.5	2.4	15.9	3.9	1.6	8.3	4.6	
15	397		12.9	0.7	1.4	3.1	2.7	16.1	3.1	1.8	8.6	4.8	
20	628		16.9	0.8	1.3	2.9	3.1	16.3	2.7	1.9	8.7	5.0	
25	848		20.6	0.9	1.3	2.7	3.5	16.4	2.4	2.0	8.8	5.1	
30	1,104		24.0	1.0	1.2	2.7	3.7	16.5	2.2	2.0	8.8	5.3	
35	1,384		27.5	1.1	1.2	2.7	4.0	16.6	2.1	2.1	8.8	5.4	
40	1,675		31.0	1.1	1.2	2.8	4.1	16.7	1.9	2.1	8.9	5.4	
45	1,950		34.2	1.2	1.2	2.9	4.3	16.8	1.8	2.1	8.9	5.5	
50	0	2,202	0.0	0.0	1.7	5.0	4.2	16.8	9.6	2.2	16.0	8.9	17.6

Appendix D

Detailed Information on Development and Use of Tables for Calculating Carbon in Harvested Wood Products (Tables 4 through 9)

This appendix features detailed information on the source of coefficients for Tables 4 through 9. This will help users in adapting carbon calculations to specific needs. Information is organized by the three starting points: primary wood products (Tables D1 through D5), industrial roundwood (principally Tables D6 and D7), and forest ecosystems (principally Tables D8 through D12).

The choice of starting points depends on the available wood products information. For example, a landowner may want to know potential carbon sequestration for a given area of forest. This is addressed by the principally land-based estimate that starts from a measure of trees in a forest, specifically growing-stock volume. Alternatively, a measure of wood removed at harvest, such as logs transported to mills for processing, volume or mass of industrial roundwood, is another starting point. Finally, a starting point with relatively precise information is based on quantities of primary wood products. These latter two starting points can be considered product-based. Data on roundwood and primary products are often available as State-level or regional statistics.

The methods for these three starting points will result in identical core results, if consistent data are available corresponding to the starting points. This is because estimates of the disposition—or fate—of carbon in products over time are based on likely uses and longevity of primary wood products. Thus, the data and assumptions on primary wood products serve as the model for the disposition of carbon over time. These data and assumptions are discussed below in the section on primary wood products. All additional calculations associated with the other two starting points (industrial roundwood or forest ecosystem) are based on linking inputs to the disposition of these primary wood products. If industrial roundwood is the starting point, or input quantity, then the disposition of carbon is calculated by linking carbon in roundwood to the separate primary wood product classifications. Similarly, volume of merchantable wood in forests is linked to quantities of roundwood before calculating the disposition of carbon over time. These links can include some additional output estimates which are not associated with all three starting points, such as the fraction of emitted carbon associated with energy recapture. Data and assumptions used to link the different inputs to a common quantity of harvested wood are presented below in the section on industrial roundwood and the section on forest ecosystem.

Primary Wood Products

Primary wood products are the initial results of processing at mills; examples of primary products include lumber, panels, and paper. These primary products are usually incorporated into end-use products with the long-term disposition of carbon classified as remaining in use, in landfills, or emitted to the atmosphere following burning or decomposition. Calculations are in three parts: 1) converting quantity of primary product to quantity of carbon, 2) determining the fraction of carbon in primary product in use as a function of time since production, and 3) determining the fraction of carbon in primary product in landfills as a function of time since production. These steps correspond to Tables 7, 8, and 9, respectively. Total carbon emissions to the atmosphere for a given year are the difference between the initial quantity of carbon in primary wood products and the sum of carbon in use or in landfills.

Carbon in primary wood products is based on conversion factors in Table 7, which were computed using data in Table D1. Specific carbon content of wood fiber in solid wood products (those in Table D1) is 50 percent, and the carbon content of air dry weight paper is 45 percent. Table D1 includes factors to convert the customary units used for each primary product to a standard mass and volume for calculating carbon mass of the wood fibers.

The fractions of primary wood products remaining in use for a given number of years after production in Table 8 were developed by first allocating the primary product to a number of end-uses and then determining the fraction remaining in each end use over time. The allocation of primary products to end uses is presented in Table D2. The fraction remaining in use over time is determined using first-order decay functions and the half-lives presented in Table D3. The fraction of primary products (and thus the fraction of carbon) remaining in use can be calculated by the following:

[Equation D1]

Fraction of carbon in solid wood products remaining in use in year n

$= (\text{fraction used in single family houses}) \times e^{(- n \times \ln(2)/\ \text{half-life for sf houses})}$
$+ (\text{fraction used in multifamily houses}) \times e^{(- n\times\ln(2)/\ \text{half-life for mf houses})}$
$+ (\text{fraction used in mobile homes}) \times e^{(- n\times\ln(2)/\ \text{half-life mobile homes})}$
$+ (\text{fraction used in repair and alteration}) \times e^{(- n\times\ln(2)/\ \text{half-life repair})}$
$+ (\text{fraction used in nonresidential except railroads}) \times e^{(- n\times\ln(2)/\ \text{half-life non res ex rr})}$
$+ (\text{fraction used in railroad ties}) \times e^{(- n\times\ln(2)/\ \text{half-life rr ties})}$
$+ (\text{fraction used in railroad cars}) \times e^{(- n\times\ln(2)/\ \text{half-life rr cars})}$
$+ (\text{fraction used in household furniture}) \times e^{(- n\times\ln(2)/\ \text{half-life hh furn})}$
$+ (\text{fraction used in commercial furniture}) \times e^{(- n\times\ln(2)/\ \text{half-life com furn})}$
$+ (\text{fraction used in other manufacturing}) \times e^{(- n\times\ln(2)/\ \text{half-life oth manf})}$
$+ (\text{fraction used in wood containers}) \times e^{(- n\times\ln(2)/\ \text{half-life wood cont})}$
$+ (\text{fraction used in pallets}) \times e^{(- n\times\ln(2)/\ \text{half-life pallets})}$
$+ (\text{fraction used in dunnage}) \times e^{(- n\times\ln(2)/\ \text{half-life dunnage})}$
$+ (\text{fraction used in other uses}) \times e^{(- n\times\ln(2)/\ \text{half-life other uses})}$
$+ (\text{fraction used in exports}) \times e^{(- n\times\ln(2)/\ \text{half-life exports})}$

[Equation D2]

Fraction of paper products remaining in use in year n

$= e^{(- n\times\ln(2)/\ \text{half-life for paper})}$

The fractions of paper in use, as provided in Table 8, are based on Equation D2 and the assumption that some paper is recycled. To include the effects of recycling in these calculations, the following general assumptions are necessary: an average half-life of paper products, a rate of paper recovery and recycling, and the efficiency of reuse of paper fibers (Skog and Nicholson 1998, Row and Phelps 1996). We use a half-life of 2.6 years, a paper recovery rate of 0.48, and an efficiency of reuse of 0.70.[5]

The difference between a fraction of paper in use calculated by Equation D2 for a particular year and the fraction from the previous year represents the amount of paper discarded during that year.

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[5]Klungness, J. 2005. Personal communication.Chemical Engineer, USDA Forest Service, Forest Products Lab, One Gifford Pinchot Drive, Madison, WI 53726-2398.

We assume that 48 percent of the discarded paper is recycled and 70 percent of the fibers in recycled paper are recovered and incorporated into new paper products. This represents a net recovery of 33.6 percent of fibers from discarded paper. The fraction of these recycled fibers remaining in use in subsequent years also is determined according to Equation D2. This sequence of calculations can be repeated for the fraction of paper discarded each year. Thus, the summed remaining fractions of the original paper and all subsequently recycled fractions are included in Table 8. All these successive calculations pertain to the original paper fibers produced from wood at the beginning of the first year, yet none of the fiber from the original paper production is expected to remain in paper products beyond five rounds of recycling.[5] Therefore, the estimates provided in Table 8 are based on five rounds of recycling, because beyond this point the effects of additional rounds are negligible. Thus, each fiber has the potential to be included in the recycling process up to five times. However, if the fiber is in the 66.4 percent (1- 0.336) of discarded paper that is lost during recycling, there is no potential for additional recycling because it is no longer in the system.

The fractions of primary wood product remaining in landfills for a given number of years after production in Table 9 were developed by determining the fraction discarded to landfills each year and then determining the part of those fractions remaining in landfills over subsequent years. Thus, Table 9 is based on years since production but accounts for both rate of disposal to landfills and cumulative effect of residence times in landfills. Allocation to landfills occurs in two parts: 1) the fraction discarded at year n after production is the difference in the in-use fractions between two successive years from Table 8, that is, fraction at year n minus fraction at year n-1; and 2) the part of the discarded fraction that is placed in landfills is determined by fractions in Table D4 (the fractions for the year 2002). The fraction going to landfills is further divided into nondegradable and degradable pools, which are supplied in Table D5. The nondegradable pool is sequestered permanently. The fraction of the degradable pool remaining in subsequent years is determined by first-order decay, that is, fraction remaining=exp(-years×ln(2)/half-life), and the half-life is shown in Table D5.

Example calculations and applications of selected factors in Tables 7, 8, and 9—disposition from primary wood products

This set of example calculations determines the disposition of carbon in a primary wood product at 3 and 100 years after production. The product for this example is 320,000 ft^2 of ⅜-inch softwood plywood. These calculations are possible with factors from Tables 7, 8, and 9, but this example illustrates the foundation for those factors by using Tables D1 through D5. Note that some of these calculations are spreadsheet-intensive, so we show only enough work to illustrate the basic process.

Specifically, we calculate:

1) Initial quantity of carbon in the primary wood product (Table D1, used to make Table 7)
2) Amount of this carbon in single-family houses at years 3 and 100 (Equation D1 and Tables D2 and D3; this is an applications example)
3) Amount of this carbon in use in all end-use products at years 3 and 100 (Equation D1 and Tables D2 and D3; resulting fractions presented in Table 8)
4) Amount of this carbon in landfills from all end-use products at years 3 and 100 (Tables 8, D4, and D5; resulting fractions presented in Table 9)

Part 1: Initial quantity of carbon, from Table D1:

$320{,}000\ ft^2 \times 31.25\ ft^3/1{,}000\ ft^2 \times 35.0\ lb/ft^2 \times 0.95 = 332{,}500$ lb of wood fiber

332,500 lb × 0.5 × (1 short ton / 2000 lb) = 83.13 tons of carbon

332,500 lb × 0.5 × (1 metric ton / 2204.62 lb) = 75.41 t of carbon

Note this is the only table that includes non-metric units.

Part 2: Amount of softwood plywood carbon in single-family houses at years 3 and 100, from Equation D1 and Tables D2 and D3:

In single-family houses at 3 years

$= 75.41 \times 0.334 \times \exp(-3\times\ln(2)/100) = 24.67$ t

In single-family houses at 100 years

$= 75.41 \times 0.334 \times \exp(-100\times\ln(2)/100) = 12.59$ t

Part 3: Amount of softwood plywood carbon in use in all end-use products at years 3 and 100, from Equation D1 and Tables D2 and D3:

Amount of carbon in use at 3 years (showing the 15 terms from Equation D1)

= 75.41 × (0.327 + 0.032 + 0.029 + 0.227 + 0.087 + 0.000 + 0.001 + 0.043 + 0.047 + 0.070 + 0.006 + 0.018 + 0.000 + 0.008 + 0.036) = 75.41 × 0.930 = 70.1 t

Amount of carbon in use at 100 years (showing the 15 terms from Equation D1)

= 75.41 × (0.167 + 0.012 + 0.000 + 0.024 + 0.032 + 0.000 + 0.000 + 0.005 + 0.005 + 0.000 + 0.000 + 0.000 + 0.000 + 0.000 + 0.000) = 75.41 × 0.245 = 18.5 t

Note that the sum of terms from equation D1 is the fraction remaining in use at the end of a given year. These fractions are calculated and provided in Table 8, for example the fractions 0.930 and 0.245, which are for years 3 and 100, respectively.

Part 4: Amount of carbon in landfills from all end-use products at years 3 and 100, from Tables 8, D4, and D5:

Note that the amount of carbon in landfills at the end of year 3 is a sum from material discarded in each of the years, that is: from year 1, the nondegradable fraction of carbon discarded in year 1 plus the remaining part of the degradable fraction after two years of decay; from year 2, the nondegradable fraction of carbon discarded in year 2 plus the remaining part of the degradable fraction after one year of decay; and from year 3, the carbon discarded to landfills in year 3.

Coefficients from Table 8 are necessary because the amount discarded each year is based on the difference between the amounts in use at the start and end of each year. By multiplying 75.41 by the first four softwood plywood coefficients in Table 8, we obtain in-use stocks of 75.41, 73.60, 71.79, and 70.13 t carbon, which represent the time of processing (the beginning of year 1) and the ends of years 1, 2, and 3, respectively.

Nondegradable fraction from year 1

= (75.41-73.60) × 0.67 × 0.77 = 0.9337 t

Degradable fraction from year 1 remaining at year 3
= (75.41-73.60) × 0.67 × (1-0.77) × exp(-2×ln(2)/14) = 0.2526 t
Nondegradable fraction from year 2
= (73.60-71.79) × 0.67 × 0.77 = 0.9337 t
Degradable fraction from year 2 remaining at year 3
= (73.60-71.79) × 0.67 × (1-0.77) × exp(-1×ln(2)/14) = 0.2654 t
Nondegradable fraction from year 3
= (71.79-70.13) × 0.67 × 0.77 = 0.8559 t
Degradable fraction from year 3 remaining at year 3
= (71.79-70.13) × 0.67 × (1-0.77) × exp(-0×ln(2)/14) = 0.2557 t

Thus, total carbon in landfills at the end of the third year = 3.5 t.

Note that the fraction of softwood plywood in landfills at the end of year 3 in Table 9 can be determined from the previous series of calculations by changing the first factor in each line to represent the relative amount discarded each year rather than the absolute amount. The calculations are:
Nondegradable fraction from year 1
= (1-0.976) × 0.67 × 0.77 = 0.0124
Degradable fraction from year 1 remaining at year 3
= (1-0.976) × 0.67 × (1-0.77) × exp(-2×ln(2)/14) = 0.0034
Nondegradable fraction from year 2
= (0.976-0.952) × 0.67 × 0.77 = 0.0124
Degradable fraction from year 2 remaining at year 3
= (0.976-0.952) × 0.67 × (1-0.77) × exp(-1×ln(2)/14) = 0.0035
Nondegradable fraction from year 3
= (0.952-0.930) × 0.67 × 0.77 = 0.0114
Degradable fraction from year 3 remaining at year 3
= (0.952-0.930) × 0.67 × (1-0.77) × exp(-0×ln(2)/14) = 0.0034

Thus, total fraction in landfills at year the end of the third year = 0.047. The difference between this value and the 0.046 in Table 9 is due to rounding.

Net flux of carbon to landfills at year 3 is the difference between the previous values and similar calculations for year 2, or more simply from Table 9:

75.41 × (0.046 - 0.032) = 1.06 t in year 3

A similar series of calculations can be repeated for year 100, or more simply from Tables 8 and 9: the amount of carbon in landfills at 100 years = 75.41 × 0.400 = 3.2 t, and the flux of carbon in landfills at 100 years = 75.41 × (0.400-0.394)/5 = 0.09 t in year 100.

Industrial Roundwood

Industrial roundwood is basically harvested logs brought to mills for processing. Roundwood, as used here, refers to wood that is processed to primary wood products; it excludes bark or roundwood that is identified as fuelwood. Input values for calculations from this starting point are carbon mass of roundwood logs grouped by categories defined for Table 6. The links between these inputs and the disposition of carbon in primary wood products are the allocation patterns described in Tables D6 and D7.

Carbon mass of industrial roundwood logs is categorized as softwood or hardwood and saw logs or pulpwood. However, if roundwood data are not classified according to type or size of logs, this appendix includes factors for distributing roundwood to appropriate categories according to regional averages. Additionally, roundwood data in the form of volume of wood can be converted to carbon with average values for specific gravity of softwood or hardwood species. These factors are included in Tables 4 or D8. See additional discussion of their use in the section on Forest Ecosystem.

Average disposition patterns of industrial roundwood carbon by region and roundwood category are presented in Table 6. These values were developed from regional average allocation of industrial roundwood to primary wood products in Table D6. Disposition of carbon allocated to primary wood products then follows the patterns described above by Tables 8 and 9, which allocate carbon to in-use or landfill classifications. The balance of carbon originally in roundwood but no longer in use or in landfills is emitted to the atmosphere. The fraction emitted to the atmosphere that occurs with energy recapture is calculated using Table D7 (Birdsey 1996). These fractions for primary products are pooled within regions to allocate industrial roundwood carbon for up to four categories per region. These fractional values are displayed in Table 6, which is the resulting net effect of linking information in Tables D6, 8, 9, and D7.

Example calculations related to constructing and applying Table 6—disposition from industrial roundwood

This example calculates the disposition of carbon in industrial roundwood. We calculate the disposition of carbon at 15 years after harvest and the processing of 10,000 m^3 of hardwood saw logs from a maple-beech-birch forest in the Northeast. The example demonstrates the basic set of calculations used to develop and apply Table 6. It is limited in scope because factorial combinations of year, roundwood categories, and classifications for the disposition of carbon in harvested wood products can require a sequence of many repeated spreadsheet calculations.

We calculate:

1) Carbon mass based on volume of saw logs
2) The allocation of carbon from saw logs at year 15—the allocation values in Table 6
3) The disposition of carbon—apply the allocation factors from Table 6 to carbon mass from step 1

Part 1: The carbon mass of roundwood can be determined using the volume. The product of volume of roundwood and specific gravity (from Tables 4 or D8) is mass; 50 percent of this is carbon mass. Based on specific gravity from Table 4, total carbon for this example is:

$$= 10{,}000 \times 0.518 \times 0.5 = 2{,}590 \text{ t}$$

Part 2: The allocation of industrial roundwood logs to primary wood products according to region and category are provided in Table D6. The fractions of primary products remaining in use or in landfills at a given year are provided in Tables 8 and 9, respectively. The fraction of emitted carbon associated with energy recapture is from Table D7. The calculations for hardwood saw logs from the Northeast at 15 years are:

Fraction of carbon in products in use (summed products from Table D6 and Table 8)
$= (0 \times 0.698) + (0.492 \times 0.456) + (0 \times 0.724) + (0 \times 0.799) + ((0.005 + 0.022) \times 0.647) + (0.038 \times 0.420) + (0.058 \times 0.040)$
$= 0 + 0.224 + 0 + 0 + 0.017 + 0.016 + 0.002 = 0.260$

Fraction of carbon in landfills (summed products from Table D6 and Table 9)
$= (0 \times 0.187) + (0.492 \times 0.334) + (0 \times 0.171) + (0 \times 0.124) + ((0.005 + 0.022) \times 0.218) + (0.038 \times 0.357) + (0.058 \times 0.253)$
$= 0 + 0.164 + 0 + 0 + 0.006 + 0.014 + 0.015 = 0.198$

Fraction of carbon emitted by year 15 (one minus the fractions in use or in landfills)
$= 1 – 0.260 – 0.198 = 0.542$
Fraction of carbon emitted with energy recapture (from Table D7)
$= 0.542 \times 0.6143 \times \exp(-((15/6812)0.5953)) = 0.324$
Fraction of carbon emitted without energy recapture
$= 0.542 – 0.324 = 0.218$

These fractions allocate the disposition of carbon at year 15 after harvest for hardwood saw logs in the Northeast (see Table 6).

Part 3: The application of the factors from Table 6 (calculated in Step 2) to carbon in industrial roundwood (calculated in Step 1) determines the disposition of carbon at year 15, which is:

In use	= 0.260 × 2,590 = 673 t
Landfills	= 0.198 × 2,590 = 513 t
Emitted with energy	= 0.324 × 2,590 = 839 t
Emitted without energy	= 0.218 × 2,590 = 565 t

Forest Ecosystems

Wood in trees in a forest is often characterized according to the total volume of merchantable wood. Merchantable volume can be expressed per unit of forest area; in this case, we use the volume of growing stock of live trees as defined by the USDA Forest Service, Forest Inventory and Analysis Database (FIADB; Alerich and others 2005). Merchantable volume must be linked to amount of roundwood carbon to calculate the expected disposition of carbon in harvested wood products (as described above for industrial roundwood and primary wood products).

A set of regional average factors (Tables D8 through D12) is used for the calculations to transform growing-stock volume to carbon in industrial roundwood, which is then allocated to the expected disposition of carbon in primary wood products. This land-based approach for calculating the disposition of carbon in harvested wood products differs from the previously described product-based approaches in two important respects: the disposition of carbon is expressed as mass per area of forest rather than as an absolute mass, and additional carbon pools must be considered such as ecosystem carbon and carbon removed at harvest but not incorporated into wood products. Calculations can include carbon in roundwood removed as fuelwood as well as carbon in bark on roundwood. Furthermore, estimates of forest carbon at the time of harvest place constraints on quantities harvested. For instance, total carbon mass allocated to harvest, as in Table 3, is calculated from volume but is limited to a portion of live tree biomass.

The starting variable for the forest ecosystem calculation is volume at harvest (for example, 172.1 m^3/ha in Table 3). Carbon in growing-stock volume is allocated to the four categories of roundwood using the factors in Table 4. The first three factors allocate growing stock based on two separate divisions among trees contributing to stand-level growing-stock volume: first, to hardwood or softwood types, and second, to sawtimber diameter- or less-than-sawtimber diameter trees. These factors were developed from the most recent forest inventory data for each State in the FIADB and are summarized according to region and forest type. Data from the FIADB were compiled to reflect types and sizes of trees in stands that are likely to be harvested; thus, trees are classified as growing stock and stands are identified as medium- or large-diameter (Alerich and others 2005). Finally, volumes of wood are converted to carbon mass according to the specific gravity of wood. Values for specific gravity (Jenkins and others 2004) were summarized from the FIADB with the same criteria as the other factors in Table 4. Table D8 contains regional averages for the factors in Table 4. Thus, the product of growing-stock volume and the first, second, and fourth columns of factors (in Tables 4 or D8) is the average dry weight of softwood sawtimber in that growing-stock volume. To convert dry weight to carbon mass, multiply by 0.5.

The next step in the process is to calculate carbon in industrial roundwood from the previously calculated values of carbon in growing-stock volume. The definition of industrial roundwood is the same as elsewhere in this text; as such, it excludes bark and the portion of roundwood identified as fuelwood. Not all roundwood is from growing-stock volume. Similarly, not all of growing-stock volume is removed from the site of harvest as roundwood, some remains as logging residue, for example. Table 5 includes the fraction of growing-stock volume that is removed as roundwood and the ratio of industrial roundwood to growing-stock volume removed as roundwood. These factors are from Johnson (2001) and are also in Tables D9 and D10. The product of carbon in growing-stock volume and these two factors from Table 5 is the mass of carbon in industrial roundwood for each of the roundwood categories.

Fuelwood and bark on roundwood are also carbon pools removed from site at harvest. These are calculated separately because they are not part of the industrial roundwood carbon pool allocated according to Table 6. Fuelwood, as used here, is a portion of total roundwood as defined in Johnson (2001). For the harvest scenario tables (Appendix C), we assume that carbon from these pools is emitted the same year as harvest. Thus, the carbon is added to the two emitted categories at the time of harvest; all of the fuelwood and a portion of the bark on roundwood are emitted with energy capture. Tables 5 and D11 provide ratios of carbon in bark to carbon in wood summarized according to region. The ratios apply to roundwood logs and are based on biomass component equations of Jenkins and others (2003); they are summaries from the FIADB by types and sizes of stem wood and bark in stands that are likely to be harvested (as described above for Table 4). The product of carbon in roundwood and the bark ratio (from Tables 5 or D11) is carbon in bark on roundwood. Fuelwood is estimated from the ratio of fuelwood to growing-stock volume removed as roundwood (Johnson

2001), which is summarized in Tables 5 and D12. Thus, total carbon in fuelwood is the product of carbon in growing-stock volume removed as roundwood, the fuelwood ratio, and one plus the bark ratio.

Ecosystem carbon is removed, emitted, or remains on site at harvest. Thus, total non-soil carbon at the time of harvest in the Appendix C tables (the harvest scenarios) equals the non-soil carbon in the corresponding year of the Appendix B tables (afforestation). Similarly, total non-soil forest ecosystem carbon at the time of harvest in the Appendix C tables (the harvest scenarios) equals the non-soil carbon at age zero of the Appendix A tables (reforestation). The pools of carbon in down dead wood and forest floor at the time of harvest reflect logging residue. These decay over time even as new material accumulates in these pools with stand regrowth (Turner and others 1995, Johnson 2001, Smith and Heath 2002, Smith and others 2004b). The pool of carbon removed at harvest is based on regional average values and calculated as described above. The residual carbon—not on-site or removed—is assigned to the "emitted at harvest" column in Appendix C. While site disturbance associated with harvest likely results in carbon emissions, this pool is also likely to include carbon in wood removed but not classified as roundwood. The use of regional averages to allocate ecosystem and harvested carbon also suggests that values in the final column (in Appendix C) may be larger or smaller, depending on actual forests or harvests. The Appendix C tables are examples of how forest carbon stocks can include carbon in harvested wood; these are not recommendations for rotation length or timing of harvest.

The use of regional fractions or ratios to allocate carbon for a number of forest types within the region has potential for occasional extreme or unrealistic values. That is, the sum of carbon in industrial roundwood, fuelwood, and bark is limited by live tree carbon density. To avoid extreme values, some limits are set for the use of these regional averages. The fuelwood ratios used for calculating the fuelwood components of the harvest scenario tables (Appendix C) are averages by type but not size (that is, columns 3 and 6 in Table D12). We also limit the proportion of live tree carbon allocated to industrial roundwood plus bark to 66 percent, and the limit for total carbon removed (industrial roundwood, bark, and fuelwood) is 78 percent of live tree carbon. These limits are based on generalized tree biomass component equations from Jenkins and others (2003). Calculated values for carbon removed at harvest (such as for Appendix C) seldom exceed these limits, but one of the exceptions is included in the example below.

Example calculations of carbon in harvested wood products for Table 3—disposition from forest ecosystems

This example illustrates the calculations to determine the disposition of carbon in wood products for the harvest scenario tables in Appendix C. We calculate the disposition of carbon at 15 years after harvest from a maple-beech-birch forest in the Northeast (see Table 3). Most of the following example can be completed with factors in Tables 4 through 6 (as opposed to tables in this section), but it is included here because it illustrates the above discussion.

We calculate:

1) Carbon in growing-stock volume according to the industrial roundwood categories (Table 4)
2) Carbon in industrial roundwood from carbon in growing-stock volume removed as roundwood (Table 5)

3) The additional pools of carbon in fuelwood and bark on roundwood, which are assumed emitted with or without energy capture soon after harvest
4) Modifications to totals for industrial roundwood or fuelwood if necessary
5) The disposition of carbon at 15 years after harvest (Table 6)

Part 1: Carbon in growing-stock volume is calculated with the factors in Table 4, which allocates volume to four categories based on wood type and log size. The example growing-stock volume harvested in Table 3 is 172.1 m^3/ha. Three steps are needed to calculate total carbon in growing-stock volume: growing stock is allocated to softwood or hardwood; volumes are partitioned to saw logs and pulpwood; and finally, carbon mass is determined from specific gravity of wood, which is 50 percent carbon by dry weight. Thus, the softwood saw log part of growing stock = (growing-stock volume) × (softwood fraction) × (sawtimber-size fraction) × (softwood specific gravity) × (carbon fraction of wood). The calculated values from growing-stock volume are:

Softwood sawtimber carbon
= 172.1 × 0.132 × 0.604 × 0.369 × 0.5 = 2.53 t/ha
Softwood poletimber carbon
= 172.1 × 0.132 × (1 – 0.604) × 0.369 × 0.5 = 1.66 t/ha
Hardwood sawtimber carbon
= 172.1 × (1 – 0.132) × 0.526 × 0.518 × 0.5 = 20.35 t/ha
Hardwood poletimber carbon
= 172.1 × (1 – 0.132) × (1 – 0.526) × 0.518 × 0.5 = 18.34 t/ha

Total carbon stock in 172.1 m^3/ha of growing-stock volume is 42.88 t/ha.

Part 2: Carbon in roundwood, which excludes bark and fuelwood, is determined from factors in Table 5. The two factors are the fraction of growing-stock volume that is removed as roundwood, and the ratio of total industrial roundwood to growing-stock volume removed as roundwood. The calculated values for industrial roundwood are:

Softwood saw log carbon
= 2.53 × 0.948 × 0.991 = 2.38 t/ha
Softwood pulpwood carbon
= 1.66 × 0. 948 × 3.079 = 4.84 t/ha
Hardwood saw log carbon
= 20.35 × 0.879 × 0.927 = 16.58 t/ha
Hardwood pulpwood carbon
= 18.34 × 0. 879 × 2.177 = 35.09 t/ha

Thus, total carbon in industrial roundwood is 58.90 t/ha.

Part 3: Pools of carbon in bark on roundwood are based on ratios in Table 5; these are also applied to calculate bark on fuelwood. The portion of bark on industrial roundwood allocated to emitted with energy capture is according to coefficient A from Table D7. Carbon in fuelwood is calculated from factors in Table 5. The calculations are:

Softwood saw log bark carbon = 2.38 × 0.182 = 0.43 t/ha
Softwood pulpwood bark carbon = 4.84 × 0. 185 = 0.90 t/ha

Hardwood saw log bark carbon = 16.58 × 0.199 = 3.30 t/ha
Hardwood pulpwood bark carbon = 35.09 × 0. 218 = 7.65 t/ha

Thus, total carbon in bark on industrial roundwood is 12.28 t/ha.

Part of carbon in bark on industrial roundwood emitted with energy capture is
= (0.43 × 0.5582) + (0.90 × 0.6289) + (3.30 × 0.6143) + (7.65 × 0.5272)
= 6.87 t/ha
Part of carbon in bark on industrial roundwood emitted without energy capture is
= 12.28 – 6.87 = 5.41 t/ha

Softwood saw log carbon in fuelwood with bark
= 2.53 × 0.948 × 0.136 × (1 + 0.182) = 0.39 t/ha
Softwood pulpwood carbon in fuelwood with bark
= 1.66 × 0. 948 × 0.136 × (1 + 0.185) = 0.25 t/ha
Hardwood saw log carbon in fuelwood with bark
= 20.35 × 0.879 × 0.547 × (1 + 0.199) = 11.73 t/ha
Hardwood pulpwood carbon in fuelwood with bark
= 18.34 × 0. 879 × 0.547 × (1 + 0.218) = 10.74 t/ha

Thus, total carbon in fuelwood with bark is 23.11 t/ha.

Part 4: Limits are placed on values calculated for industrial roundwood and fuelwood where the regional average factors result in extreme values for some forest types (as discussed above). Based on biomass component equations, total carbon in industrial roundwood with bark is limited to 66 percent of live tree carbon density, and the sum of industrial roundwood, fuelwood, and bark is limited to 78 percent. Live tree carbon density at harvest is 113.1 t/ha (from Table B2).

The sum of industrial roundwood and bark is less than 66 percent of live tree carbon
(58.90 + 12.28) / 113.1 = 0.629

However, the sum of industrial roundwood, fuelwood, and bark is greater than 78 percent of live tree carbon
(58.90 + 12.28 + 23.11) / 113.1 = 0.834

Therefore, the seven carbon pools are reduced by the factor 0.78/0.834=0.935
Industrial roundwood softwood saw log = 2.38 × 0. 935 = 2.22 t/ha
Industrial roundwood softwood pulpwood = 4.84 × 0. 935 = 4.53 t/ha
Industrial roundwood hardwood saw log = 16.58 × 0. 935 = 15.50 t/ha
Industrial roundwood hardwood pulpwood = 35.09 × 0. 935 = 32.81 t/ha

Industrial roundwood bark emitted with energy capture = 6.87 × 0. 935 = 6.42 t/ha
Industrial roundwood bark emitted without energy capture = 5.41 × 0. 935 = 5.06 t/ha

Fuelwood with bark = 23.11 × 0. 935 = 21.61 t/ha

These modified values are used in subsequent calculations and are applied to the harvest scenario tables. Such modifications occur infrequently with the tables presented in Appendix C.

Part 5: The four pools of industrial roundwood carbon are each allocated to the four disposition categories for carbon in wood products according to Table 6. Totals are the summed products of industrial roundwood carbon and allocation at year 15. Carbon in fuelwood and bark are one-time additions to the emitted columns (in Appendix C). Thus the disposition of carbon at year 15 is calculated as:

Total industrial roundwood carbon in use
= (2.22 × 0.326) + (4.53 × 0.037) + (15.50 × 0.260) + (32.81 × 0.252) = 13.19 t/ha
Total industrial roundwood carbon in landfills
= (2.22 × 0.126) + (4.53 × 0.128) + (15.50 × 0.198) + (32.81 × 0.127) = 8.10 t/ha
Total industrial roundwood carbon emitted with energy recapture
= (2.22 × 0.296) + (4.53 × 0.497) + (15.50 × 0.324) + (32.81 × 0.310) = 18.10 t/ha
Total industrial roundwood carbon emitted without energy recapture
= (2.22 × 0.252) + (4.53 × 0.338) + (15.50 × 0.218) + (32.81 × 0.311) = 15.67 t/ha

Total carbon emitted with energy recapture is the sum of industrial roundwood, bark, and fuelwood
= 18.10 + 6.42 + 21.61 = 46.13 t/ha

Total carbon emitted without energy recapture is the sum of industrial roundwood and bark
= 15.67 + 5.06 = 20.73 t/ha

These are the carbon density values for the four harvested wood classifications at 15 years after harvest in Table 3 (that is, 13.2, 8.1, 46.1, and 20.7). The differences between values in this example and those in the table are due to rounding subtotals in this example.

Table D1.—Factors to convert solid wood products in customary units to carbon[a]

Solid wood product	Unit	Cubic feet per unit	Pounds/ cubic foot	Fraction of product that is wood fiber	Factor to convert units to tons (2000 lb) carbon	Factor to convert units to tonnes carbon
Softwood lumber/ laminated veneer lumber/ glulam lumber/ I-joists	thousand board feet	59.17	33.0	1.00	0.488	0.443
Hardwood lumber	thousand board feet	83.33	40.5	1.00	0.844	0.765
Softwood plywood	thousand square feet, 3/8-inch basis	31.25	35.0	0.95	0.260	0.236
Oriented strandboard	thousand square feet, 3/8-inch basis	31.25	40.0	0.97	0.303	0.275
Nonstructural panels (average)	thousand square feet, 3/8- inch basis	31.25	--	--	0.319	0.289
Hardwood veneer/ plywood	thousand square feet, 3/8- inch basis	31.25	42.0	0.96	0.315	0.286
Particleboard / Medium density fiberboard	thousand square feet, 3/4-inch basis	62.50	45.0	0.92	0.647	0.587
Hardboard	thousand square feet, 1/8-inch basis	10.42	60.0	0.97	0.152	0.138
Insulation board	thousand square feet, 1/2-inch basis	41.67	23.5	0.99	0.242	0.220
Other industrial products	thousand cubic feet	1.00	33.0	1.00	8.250	7.484

-- = not applicable.

[a]Factors in the last two columns are calculated by multiplying the previous three columns to provide the mass of product in pounds, the fraction of carbon in wood (assumed to be 0.5), and converting mass to tons or tonnes.

Table D2.—Fraction of solid wood product production used for various end uses in the United States, and used for export, 1998

End use	Product				
	Lumber[a]		Structural panels[b]		Non-structural panels[c]
	Softwood	Hardwood	Softwood plywood	Oriented strandboard	
New residential construction					
Single family	0.332	0.039	0.334	0.578	0.130
Multifamily	0.031	0.004	0.033	0.047	0.019
Mobile homes	0.039	0.002	0.035	0.060	0.037
Residential upkeep and improvement	0.253	0.039	0.243	0.164	0.112
New nonresidential construction					
All except railroads	0.079	0.028	0.090	0.071	0.053
Railroad ties	0.001	0.047	0.000	0.000	0.000
Railcar repair	0.000	0.008	0.001	0.000	0.000
Manufacturing					
Household furniture	0.023	0.235	0.046	0.002	0.138
Commercial furniture	0.004	0.048	0.050	0.006	0.218
Other products	0.035	0.095	0.083	0.021	0.094
Shipping					
Wooden containers	0.006	0.008	0.008	0.000	0.005
Pallets	0.037	0.349	0.025	0.001	0.001
Dunnage etc	0.002	0.007	0.000	0.000	0.000
Other uses[d]	0.126	0.007	0.009	0.041	0.139
Total domestic use	0.967	0.917	0.957	0.991	0.946
Export	0.033	0.083	0.043	0.009	0.054

[a]Includes hardwood and softwood dimension and boards, glulam, and lumber I-joist flanges.
[b]Includes softwood plywood, OSB, structural composite lumber, and I-joist webs.
[c]Includes hardwood plywood, particleboard, medium-density fiberboard, hardboard, and insulation board.
[d]Other uses for lumber and panels include: 1) upkeep and improvement of nonresidential structures, 2) roof supports and other construction in mines, 3) made-at-home projects such as furniture, boats, and picnic tables, 4) made-on-the-job products such as advertising and display structures, and 5) any other uses.
Source: Calculated from tables in McKeever (2002).

Table D3.—Half-life for products by end use

End use or product	Half-life
	years
New residential construction	
Single family	100
Multifamily	70
Mobile homes	12
Residential upkeep and improvement	30
New nonresidential construction	
All except railroads	67
Railroad ties	12
Railcar repair	12
Manufacturing	
Household furniture	30
Commercial furniture	30
Other products	12
Shipping	
Wooden containers	6
Pallets	6
Dunnage etc	6
Other uses for lumber and panels	12
Solid wood exports	12
Paper	2.6

Sources: Skog and Nicholson (1998), Row and Phelps (1996), Klungness, J. 2005. Personal communication. Chemical Engineer, USDA Forest Service, Forest Products Lab, One Gifford Pinchot Drive, Madison, WI 53726-2398.

Table D4.—Fraction of discarded wood and paper placed in landfills

Year	Wood to landfills	Paper to landfills	Year (continued)	Wood to landfills	Paper to landfills
1950	0.05	0.05	1977	0.49	0.38
1951	0.06	0.05	1978	0.55	0.43
1952	0.06	0.06	1979	0.62	0.48
1953	0.07	0.06	1980	0.68	0.52
1954	0.07	0.06	1981	0.69	0.53
1955	0.08	0.06	1982	0.71	0.53
1956	0.08	0.07	1983	0.72	0.53
1957	0.09	0.07	1984	0.73	0.54
1958	0.09	0.07	1985	0.74	0.54
1959	0.10	0.07	1986	0.76	0.54
1960	0.11	0.09	1987	0.77	0.54
1961	0.12	0.09	1988	0.78	0.54
1962	0.13	0.10	1989	0.79	0.54
1963	0.13	0.10	1990	0.74	0.54
1964	0.14	0.11	1991	0.79	0.50
1965	0.15	0.11	1992	0.71	0.48
1966	0.17	0.13	1993	0.70	0.48
1967	0.19	0.15	1994	0.70	0.44
1968	0.22	0.17	1995	0.73	0.39
1969	0.24	0.19	1996	0.71	0.37
1970	0.26	0.21	1997	0.69	0.38
1971	0.29	0.23	1998	0.68	0.39
1972	0.32	0.25	1999	0.68	0.39
1973	0.35	0.27	2000	0.67	0.37
1974	0.37	0.29	2001	0.67	0.35
1975	0.40	0.32	2002	0.67	0.34
1976	0.43	0.34			

Source: Freed, R. 2004. Personal communication. Environmental Scientist, ICF Consulting, 9300 Lee Highway, Fairfax, VA 22031.

Table D5.—Nondegradable fraction of wood and paper in landfills and half-life for degradable fraction

Nondegradable fraction in landfills[a]	
wood	0.77
paper	0.44
Half-life of degradable fraction (yr)[b]	14

[a] Source: Freed, R. and C. Mintz. 2003 (29 Aug). Letter to H. Ferland (EPA), K. Skog (USDA), T. Wirth (EPA) and E. Scheehle (EPA). Revised input data for WOODCARB. On file with: Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398

[b] Source: de Silva Alves and others (2000).

Table D6.—Fraction of each classification of industrial roundwood according to category as allocated to primary wood products (based on data from 2002)[a]

Region	Category[b] SW/HW	Category[b] SL/PW	Softwood lumber	Hardwood lumber	Softwood plywood	Hardwood plywood[c]	Oriented strandboard	Non-structural panels	Other industrial products	Wood pulp	Fuel and other emissions
Northeast	SW	SL	0.391	0	0.004	0	0	0.020	0.083	0.072	0.431
		PW	0	0	0	0	0.010	0.016	0	0.487	0.487
	HW	SL	0	0.492	0	0.005	0	0.022	0.038	0.058	0.386
		PW	0	0	0	0	0.293	0.007	0	0.350	0.350
North Central	SW	SL	0.378	0	0	0	0	0.049	0.120	0.084	0.370
		PW	0	0	0	0	0.020	0.009	0	0.486	0.486
	HW	SL	0	0.458	0	0.006	0	0.013	0.044	0.064	0.415
		PW	0	0	0	0	0.361	0.009	0	0.315	0.315
Pacific Northwest, East	SW	All	0.422	0	0.069	0	0	0.001	0.001	0.144	0.363
Pacific Northwest, West	SW	SL	0.455	0	0.089	0	0	0.009	0.073	0.114	0.260
		PW	0	0	0	0	0	0	0	0.500	0.500
	HW	All	0	0.160	0	0.140	0	0.002	0	0.229	0.469
Pacific Southwest	SW	All	0.454	0	0	0	0	0.040	0.036	0.145	0.325
Rocky Mountain	SW	All	0.402	0	0.054	0	0	0.033	0.062	0.153	0.296
Southeast	SW	SL	0.350	0	0.076	0	0	0.027	0.054	0.129	0.364
		PW	0	0	0	0	0.103	0.004	0	0.447	0.447
	HW	SL	0	0.455	0	0.006	0	0.049	0.012	0.087	0.391
		PW	0	0	0	0	0.180	0.002	0	0.409	0.409
South Central	SW	SL	0.324	0	0.130	0	0	0.019	0.023	0.133	0.371
		PW	0	0	0	0	0.135	0.006	0	0.430	0.430
	HW	SL	0	0.434	0	0.023	0	0.025	0.003	0.102	0.413
		PW	0	0	0	0	0.160	0.001	0	0.419	0.419
West[d]	HW	All	0	0.039	0	0.301	0	0.015	0.066	0.147	0.432

[a]Data based on Adams and others (2006).

[b]SW/HW=Softwood/Hardwood, SL/PW=Saw log/Pulpwood. Saw log includes veneer logs.

[c]Hardwood plywood fractions are pooled with nonstructural panels when allocating roundwood to the primary products listed in Tables 8 and 9.

[d]West includes hardwoods in Pacific Northwest, East; Pacific Southwest; Rocky Mountain, North; and Rocky Mountain, South.

Table D7.—Coefficients for estimating fraction of emitted carbon associated with energy recapture with emission for industrial roundwood

Region	Roundwood category[a]		Coefficients[b]		
	SW/HW	SL/PW	a	b	c
Northeast	SW	SL	0.5582	2594	0.6557
		PW	0.6289	3062	0.5432
	HW	SL	0.6143	6812	0.5953
		PW	0.5272	3483	0.5364
North Central	SW	SL	0.6728	2162	0.6550
		PW	0.6284	3494	0.5117
	HW	SL	0.6097	5144	0.6236
		PW	0.5243	3399	0.5451
Pacific Northwest, East	SW	All	0.5421	1144	0.7958
Pacific Northwest, West	SW	SL	0.4823	823	0.8561
		PW	0.7040	2376	0.5184
	HW	All	0.6147	4746	0.6306
Pacific Southwest	SW	All	0.5216	1278	0.8061
Rocky Mountain	SW	All	0.7072	992	0.7353
Southeast	SW	SL	0.7149	1313	0.6051
		PW	0.6179	3630	0.5054
	HW	SL	0.5749	4574	0.5954
		PW	0.5490	3731	0.5025
South Central	SW	SL	0.6136	1264	0.6634
		PW	0.6190	3455	0.5148
	HW	SL	0.5744	4541	0.6070
		PW	0.5449	3239	0.5324
West[c]	HW	All	0.5917	6433	0.6054

[a]Applicable to industrial roundwood without bark or fuelwood, which is classified as: SW/HW=Softwood/Hardwood, SL/PW=Saw log/Pulpwood.

[b]Estimates are calculated according to: fraction =a×exp(-((year/b)^c)), based on proportions in Table 1.7 of Birdsey (1996). We assume that values in the Birdsey (1996) table are that portion of the growing-stock volume harvested and removed from the forest, so that the values are generally accurate when applied to roundwood categories.

[c]West includes hardwoods in Pacific Northwest, East; Pacific Southwest; Rocky Mountain, North; and Rocky Mountain, South.

Table D8.—Average regional factors to calculate carbon in growing-stock volume: softwood fraction, sawtimber-size fraction, and specific gravity[a,b]

Region	Fraction of growing-stock volume that is softwood[c]	Fraction of softwood growing-stock volume that is sawtimber-size[d]	Fraction of hardwood growing-stock volume that is sawtimber-size[d]	Specific gravity[e] of softwoods	Specific gravity[e] of hardwoods
Northeast	0.226	0.647	0.579	0.371	0.518
Northern Lake States	0.292	0.556	0.407	0.360	0.473
Northern Prairie States	0.093	0.622	0.511	0.434	0.537
Pacific Northwest, East	0.980	0.865	0.501	0.396	0.424
Pacific Northwest, West	0.890	0.911	0.538	0.426	0.415
Pacific Southwest	0.829	0.925	0.308	0.399	0.510
Rocky Mountain, North	0.983	0.734	0.442	0.394	0.389
Rocky Mountain, South	0.865	0.742	0.337	0.369	0.353
Southeast	0.423	0.612	0.512	0.462	0.508
South Central	0.358	0.693	0.523	0.463	0.529

[a]These factors correspond to the values in Table 4.

[b]Estimates based on survey data for the conterminous United States from USDA Forest Service, Forest Inventory and Analysis Program's database of forest surveys (FIADB; USDA For. Serv. 2005) and include growing-stock on timberland stands classified as medium- or large-diameter stands. Fractions are based on volumes of growing-stock trees.

[c]To calculate fraction in hardwood, subtract fraction in softwood from 1.

[d]Softwood sawtimber are trees at least 22.9 cm (9 in) d.b.h., hardwood sawtimber is at least 27.9 cm (11 in) d.b.h. To calculate fraction in less-than-sawtimber-size trees, subtract fraction in sawtimber from 1. Trees less than sawtimber-size are at least 12.7 cm (5 in) d.b.h.

[e]Average wood specific gravity is the density of wood divided by the density of water based on wood dry mass associated with green tree volume.

Table D9.—Fraction of growing-stock volume that is removed as roundwood and ratio of volume of logging residue to growing-stock volume by region and wood type[a]

Region[b]	Fraction of growing-stock volume removed as roundwood			Ratio of volume of logging residue to growing-stock volume[c]		
	Softwood	Hardwood	All	Softwood	Hardwood	All
Northeast	0.948	0.879	0.901	0.471	0.602	0.560
North Central	0.931	0.831	0.848	0.384	0.441	0.431
Pacific Coast	0.929	0.947	0.930	0.133	0.081	0.131
Rocky Mountain	0.907	0.755	0.899	0.305	0.246	0.301
South	0.891	0.752	0.840	0.090	0.254	0.149

[a]Values and classifications are based on data in Tables 2.9, 3.9, 4.9, 5.9, and 6.9 of Johnson (2001).

[b]North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

[c]Ratios used as part of estimates of down dead wood following harvest in Appendix A and C.

Table D10.—Ratios of industrial roundwood (without fuelwood) to growing-stock volume that is removed as roundwood by category[a]

Region[c]	Industrial roundwood:growing-stock volume removed as hardwood[b]					
	Softwood			Hardwood		
	Sawtimber-size	Less than sawtimber-size	All	Sawtimber-size	Less than sawtimber-size	All
Northeast	0.991	3.079	1.253	0.927	2.177	1.076
North Central	0.985	1.285	1.077	0.960	1.387	1.071
Pacific Coast	0.965	1.099	1.005	0.721	0.324	0.606
Rocky Mountain	0.994	2.413	1.089	0.832	1.336	0.862
South	0.990	1.246	1.047	0.832	1.191	0.933

[a]Values and classifications are based on data in Tables 2.2, 3.2, 4.2, 5.2, and 6.2 of Johnson (2001).

[b]Ratios are to calculate industrial roundwood (that is, without fuelwood) and are based on volumes. The denominators are portions of growing-stock volume removed as roundwood according to wood type and size. Numerators for "less than sawtimber-size" include poletimber and nongrowing-stock sources. We assume the ratios do not include bark and use these values as a step in determining the allocation of carbon for Table 5 and Appendix C, based on growing stock.

[c]North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

Table D11.—Regional average ratios of carbon in bark to carbon in wood according to wood type and size

Region[b]	Ratio of carbon in bark to carbon in wood[a]					
	Softwood[c]			Hardwood[d]		
	Sawtimber-size[e]	Poletimber-size[e]	All	Sawtimber-size	Poletimber-size	All
Northeast	0.182	0.185	0.183	0.199	0.218	0.205
North Central	0.182	0.185	0.183	0.199	0.218	0.206
Pacific Coast	0.181	0.185	0.181	0.197	0.219	0.203
Rocky Mountain	0.181	0.185	0.182	0.201	0.219	0.210
South	0.182	0.185	0.183	0.198	0.218	0.204

[a]Ratios are calculated from carbon mass based on biomass component equations in Jenkins and others (2003) applied to all live trees identified as growing stock on timberland stands classified as medium- or large-diameter stands in the survey data for the conterminous United States from USDA Forest Service, Forest Inventory and Analysis Program's database of forest surveys (FIADB; USDA For. Serv. 2005, Alerich and others 2005). Note that "sawtimber trees" and "poletimber trees" are not stand-level classifications as used here; these terms apply to individual trees. Carbon mass is calculated for boles from stump to 4-inch top, outside diameter.

[b]North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

[c]Softwood sawtimber-size are trees at least 22.9 cm (9 in) d.b.h., and softwood poletimber-size trees are 12.7 to 22.6 cm (5.0 to 8.9 in) d.b.h.

[d]Hardwood sawtimber-size is at least 27.9 cm (11 in) d.b.h., and hardwood poletimber-size trees are 12.7 to 27.7 cm (5.0 to 10.9 in) d.b.h.

[e]When applying these ratios to roundwood, we assume that ratios based on sawtimber-size trees and ratios based on poletimber-size trees in the forest apply to saw log roundwood and pulpwood roundwood, respectively.

Table D12.—Ratios of total fuelwood (both growing-stock and nongrowing-stock sources) to corresponding portion of growing-stock volume that is removed as roundwood[a]

Region[c]	Fuelwood:growing-stock volume removed as hardwood[b]					
	Softwood			Hardwood		
	Sawtimber-size	Less than sawtimber-size	All	Sawtimber-size	Less than sawtimber-size	All
Northeast	0.009	1.017	0.136	0.073	4.051	0.547
North Central	0.015	0.180	0.066	0.040	1.230	0.348
Pacific Coast	0.035	0.242	0.096	0.279	2.627	0.957
Rocky Mountain	0.006	3.145	0.217	0.168	50.200	3.165
South	0.010	0.049	0.019	0.168	0.644	0.301

[a]Values and classifications are based on data in Tables 2.2, 3.2, 4.2, 5.2, and 6.2 of Johnson (2001).

[b]Ratios are to calculate fuelwood and are based on volumes. The denominators are portions of growing-stock volume removed as roundwood according to size. Numerators for “less than sawtimber-size” include poletimber and nongrowing-stock sources. We assume the ratios do not include bark and use these values as a step in determining the allocation of carbon for Table 5 and Appendix C, based on growing stock.

[c]North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

Download the spreadsheet files at:
http://www.nrs.fs.fed.us/pubs/8192

Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A. 2006. **Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States.** Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 p.

This study presents techniques for calculating average net annual additions to carbon in forests and in forest products. Forest ecosystem carbon yield tables, representing stand-level merchantable volume and carbon pools as a function of stand age, were developed for 51 forest types within 10 regions of the United States. Separate tables were developed for afforestation and reforestation. Because carbon continues to be sequestered in harvested wood, approaches to calculate carbon sequestered in harvested forest products are included. Although these calculations are simple and inexpensive to use, the uncertainty of results obtained by using representative average values may be high relative to other techniques that use site- or project-specific data. The estimates and methods in this report are consistent with guidelines being updated for the U.S. Voluntary Reporting of Greenhouse Gases Program and with guidelines developed by the Intergovernmental Panel on Climate Change. The CD-ROM included with this publication contains a complete set of tables in spreadsheet format.

Keywords: forest carbon sequestration project, harvested wood carbon, carbon yield tables, stock change, voluntary reporting

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The role of benefit transfer in ecosystem service valuation

Article *in* Ecological Economics · March 2014

DOI: 10.1016/j.ecolecon.2014.02.018

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ARTICLE IN PRESS

ECOLEC-04687; No of Pages 8

Ecological Economics xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

The role of benefit transfer in ecosystem service valuation

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ARTICLE INFO

Article history:
Received 1 March 2013
Received in revised form 5 February 2014
Accepted 25 February 2014
Available online xxxx

Keywords:
Benefit transfer
Ecosystem services
Nonmarket
Valuation methods

ABSTRACT

The demand for timely monetary estimates of the economic value of nonmarket ecosystem goods and services has steadily increased over the last few decades. This article describes the use of benefit transfer to generate monetary value estimates of ecosystem services specifically. The article provides guidance for conducting such benefit transfers and summarizes advancements in benefit transfer methods, databases and analysis tools designed to facilitate its application.

Published by Elsevier B.V.

1. Introduction

The articles that make up this special section of Ecological Economics all have one common feature. Either explicitly or implicitly, they address the need for valuing the services provided by the natural environment in order to achieve more informed resource policy decisions. It is not always possible or efficient to conduct an original valuation study for each specific geographic area or service of concern. This article addresses the potential for using benefit transfer to estimate the value of nonmarket environmental goods and services generated by ecosystem processes. We first discuss the growing demand for monetized values of ecosystem services, and the role of benefit transfer in meeting this demand. We then review accepted guidelines for conducting benefit transfers and discuss advancements in transfer methods and modeling techniques. Next, we discuss the role of web-based resources in the valuation of ecosystem services along with recent references that provide in-depth reviews of these resources. Finally, we offer suggestions for improving benefit transfers in the spirit of improving ecosystem service valuation for future project or policy analysis.

2. The Demand for and Supply of Ecosystem Service Valuation Research

Growth in human population or per-capita resource consumption, shifting public preferences, increasing resource scarcity, declining environmental health and many other pressures mean that policymakers across the globe face increasingly complex decisions about natural resource management. Coupled with recent global assessments of the status of ecosystems and the benefits they provide to society (Millennium Ecosystem Assessment, 2005; The Economics of Ecosystems and Biodiversity, 2011; UK National Ecosystem Assessment, 2011), this has led to a rapidly growing demand for information on ecosystem service flows and their economic values. Ecosystem services can be thought of as the aspects of nature utilized (actively or passively) to produce human well-being (Fisher and Turner, 2008).

In the United States in particular, federal agencies have varied widely in their use of ecosystem service values in natural resource management decisions. However, recent guidance from a 2011 report by the President's Council of Advisors on Science and Technology has increased awareness of the importance of these values in federal decision making. The report recommends that federal agencies with responsibilities relating to ecosystems and their services be tasked with using best available techniques to value ecosystem services affected by their decision making and incorporate these results into analyses that inform major planning and management decisions (President's Council of Advisors on Science and Technology, 2011). Environmental damage caused by large oil spills has further highlighted the importance of assessing the lost value of goods and services provided by the natural environment. The Exxon Valdez oil spill of 1989 provided a major turning point for the consideration of non-use economic values in damage assessments. Over two decades later, the Deepwater Horizon oil spill has brought additional attention to valuing services lost from large-scale spills. Given the magnitude and depth of the event, a congressionally mandated report by the National Research Council notes that

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http://dx.doi.org/10.1016/j.ecolecon.2014.02.018
0921-8009/Published by Elsevier B.V.

"an 'ecosystem services approach' may expand the potential to to capture, value, and restore the full breadth of impacts to the ecosystem and the public" (National Research Council, 2012, p. 2). Many federal agencies have released formal guidelines and recommendations for addressing ecosystem services and estimating nonmarket values for use in management decisions (see Murray et al., 2013; Tazik et al., 2013; US EPA, 2009; USDA Forest Service, 2012; USDOI BLM, 2013, for example). Ecosystem service valuation is being incorporated into U.S. state decision making as well through initiatives such as the Genuine Progress Indicator endorsed by the states of Maryland and Vermont, and many private companies are exploring the inclusion of ecosystem service values in business decision making (see World Business Council for Sustainable Development, 2011).

This increased demand for information on ecosystem service flows and values has redoubled the longstanding effort of economists in nonmarket valuation. Economic theory has long recognized that the value humans receive from these services can be comprehensively captured in a Total Economic Value (TEV) framework that distinguishes among two broad value categories: use values, derived by producers and consumers from the direct or indirect use of a resource; and non-use, or passive use, values, derived from simply knowing that a resource exists in a particular condition or is maintained for future generations (Krutilla, 1967). Due to the characteristics of many ecosystem services, their value often is only partially or not at all reflected in market prices. For the last forty years, environmental and resource economists have developed, utilized, and tested methodologies to monetize the benefits provided by goods and services that are not traded in markets. There now exists a large body of research demonstrating the successful application of these methods to value ecosystem services such as recreation, air and water quality, water supply, flood prevention, scenic amenities, and the protection of threatened, endangered or rare species. These advances have led to an understanding that, while many challenges remain, economic valuation methods are capable of providing information that can routinely be used to improve public-sector decision making (National Research Council, 2004; President's Council of Advisors on Science and Technology, 2011). Further, a significant body of literature has emerged describing how economic analysis can be integrated into ecosystem service assessments and ecosystem-based management in particular (Bateman et al., 2011a; Fisher and Turner, 2008; Hanley and Barbier, 2009; Holland et al., 2010). Increased collaboration between ecologists and other natural scientists and economists is contributing to a more comprehensive understanding of the ecosystem service impacts of particular decisions and identifying ecological metrics more amenable to economic valuation, resulting in improved information for policymakers.

However, while great strides have been made in advancing the economic methods and tools used to monetize the contribution ecosystem services make to human welfare, the primary research providing these values has not kept pace with the increase in demand for this information (Bateman et al., 2011a). Some of this shortfall could be reduced by conducting additional original valuation studies in cases where the value of the information generated by such studies outweighs the cost of conducting them. Nevertheless, the reality of constrained planning budgets and timeframes means the long-term and interdisciplinary research often required for original ecosystem service valuation is simply not feasible for most planning and management decisions that affect the natural environment. This has led to the widespread use of secondary data for ecosystem service valuation. Applied carefully, such benefit transfer, which is the focus of the remainder of this article, constitutes a viable option for providing ecosystem service valuation information to policymakers. While benefit transfer has many limitations, it is often the best or only option available to inform the policy process and thus will continue to play a role in the field of ecosystem service valuation.

3. Benefit Transfer as a Method to Estimate Ecosystem Service Values

Benefit transfer is broadly defined as "…the use of existing data or information in settings other than for what it was originally collected" (Rosenberger and Loomis, 2003, p. 445). In the context discussed here, this involves the transfer of original ecosystem service value estimates from an existing 'study site' or multiple study sites to an unstudied 'policy site' with similar characteristics that is being evaluated. Benefit transfer is increasingly being used to meet the demand for increased information on nonmarket ecosystem service values in a manner relevant to the timeframe and budget within which decisions often have to be made. If original valuation is not feasible, the choice is not between a new study and benefit transfer but rather between benefit transfer and qualitative judgment (Smith et al., 2002). Federal agencies such as the U.S. Environmental Protection Agency rarely conduct an original valuation study to assess the ecological benefits of a proposed rule, relying instead on benefit transfer, a trend that is expected to continue due to the various constraints that make primary data collection impractical, especially for rules with short judicial or legislative deadlines (Iovanna and Griffiths, 2006). Indeed, carefully conducted benefit transfers have the potential to provide a reasonable approximation of the value of unstudied resources, especially recognizing that the issue with ecosystem service valuation is not necessarily perfection but usefulness (President's Council of Advisors on Science and Technology, 2011). In cases where greater precision in the welfare estimates would not likely change the main conclusions of the analysis (see Timmons, 2013, for example), such approximate values are adequate to inform policy decisions.

That said, benefit transfers will never take the place of a carefully conducted primary study (Bateman et al., 2011a; National Research Council, 2004). The lower level of validity and reliability of transferred value estimates has led researchers to question the appropriate balance between 'purism' and 'practicality' in empirical ecosystem service research (Bauer and Johnston, 2013), and even led to the development of methods for determining the economic returns to using original valuation research over benefit transfer for policy decisions (e.g., Allen and Loomis, 2008). Further, while a growing body of research is explicitly addressing the tradeoffs stemming from the use of benefit transfers, transfers remain the subject of controversy, due in part to the divergence between transfer practices recommended in the scholarly literature and those applied in policy (Johnston and Rosenberger, 2010) and even academic analysis (Nelson and Kennedy, 2009). This gap needs to be bridged if benefit transfer is to play an increasing role in policy decisions that impact our natural capital. Otherwise, if violation of the basic principles and methodological requirements for valuing ecosystem services through benefit transfer remains widespread, this may ultimately undermine the integration of ecosystem service values into policy making. In other words, the flip side of "some number is better than no number" is that "bad numbers may drive out all numbers." Wildly biased welfare estimates could result in all estimates of ecosystem service values, valid or not, being rejected out of hand. This would cause a serious set-back for an important effort that has brought together ecologists and environmental and natural resource economists, and both disciplines with policymakers. Biased estimates can also lead to badly misguided policy. Of course, this error of commission has to be balanced with the policy consequences of omission of the value of nature's nonmarketed outputs.

The mainstreaming of ecosystem service values into policy decisions thus would benefit from a certain amount of quality control. One approach for instituting such control would be to subject important benefit transfers to an external peer review process much like the U.S. Army Corps of Engineers currently does with its benefit–cost analyses of major (over one hundred million dollar) projects. In addition, the formulation of agency guidelines for benefit transfer

Please cite this article as: Richardson, L., et al., The role of benefit transfer in ecosystem service valuation, Ecol. Econ. (2014), http://dx.doi.org/10.1016/j.ecolecon.2014.02.018

that build on the guidelines and recommendations outlined in the next section would increase the likelihood of achieving more valid and reliable transfers.

3.1. Guidelines for Conducting Benefit Transfer

The process of formally evaluating benefit transfer began with Freeman (1984), who outlined the criteria that the source of the value estimate – the original valuation study – should meet in order to provide a basis for valid transfers. These include being based on adequate data, sound economic method, and correct empirical technique (Freeman, 1984). By 1992, systematic research was being conducted to develop procedures and test the validity of benefit transfers. A special issue on this topic published in the journal *Water Resources Research* in 1992 included many notable articles outlining various aspects of conducting successful transfers. Boyle and Bergstrom (1992) proposed three "ideal criteria" for benefit transfer: 1. the nonmarket commodity valued at the study site and policy site are identical; 2. the populations affected by the nonmarket commodity at the study and policy sites have identical characteristics; and 3. the assignment of property rights at both sites must lead to the same theoretically appropriate welfare measures. These criteria are ideals by which benefit transfers are judged. It is frequently difficult for the analyst to meet all of the criteria set out for an accurate transfer, but the more closely they are met, the more valid the transfer is likely to be.

More recent literature has continued to expand on ways in which original research can facilitate valid benefit transfers, since analysts are often hindered by the original study design or incomplete reporting of results (Loomis and Rosenberger, 2006). Brouwer (2000), for example, outlines a protocol for good practice for conducting primary research, with a focus on stated preference methods, as well as for the transfer of the resulting nonmarket values. Adding to Boyle and Bergstrom's (1992) criteria, Loomis and Rosenberger (2006) offer a number of specific additional suggestions for primary studies to better facilitate transfers, including a full and consistent reporting of information on the current level of environmental quality; using objective, quantitative measures of quality; using consistent definitions and measurements of demographic data; and reporting of average values of study-specific variables.

Additional guidelines that have implications for the transfer of welfare estimates, have continued to emerge. A prominent discussion in the ecosystem service valuation literature focuses on distinguishing between intermediate ecosystem services and final ecosystem services for valuation (Boyd and Banzhaf, 2007; Fisher et al., 2009; Johnston and Russell, 2011). This requires that ecosystem services be defined in benefit-specific terms (Boyd and Banzhaf, 2007). Because an ecological component may represent a final service to one beneficiary (e.g., clean water for drinking) and an intermediate service to a different beneficiary (e.g., clean water for a fish population that supports recreational fishing), only benefits of final services (the drinking water in the first example; the fish in the second) should be counted and aggregated in an ecosystem service analysis to avoid double counting (Boyd and Banzhaf, 2007). Failing to clearly define these relationships can result in biased and inconsistent value estimates (Boyd and Krupnick, 2009; Fisher et al., 2009; Johnston and Russell, 2011). Original valuation studies can facilitate the transfer of ecosystem service values by clearly identifying the beneficiaries – individuals whose welfare is improved by a particular ecosystem service – used in the analysis. This information can be used by the benefit transfer practitioner to identify a welfare estimate based on the same group of beneficiaries being evaluated at the policy site. In addition, consulting with the beneficiaries who have been, or will be, affected by the environmental change, and whose values the researcher or decision-maker is interested in, can help ensure that a primary valuation study or benefit transfer generates socially and politically acceptable results (Brouwer, 2000).

Issues that require particularly close attention when transferring welfare estimates are those of scope, geographic scale, and substitutability. Scope refers to the generally non-constant marginal value of an ecosystem service. Any measure of economic value is tied to a specific context, characterized by a baseline and a particular quantity or quality change. If that value is applied to a change that exceeds that for which it was estimated, the issue of scope arises. For instance, the value that a recreational angler places on the catch of an additional fish on a given trip will depend, among other things, on the number of fish she already caught. Due to diminishing marginal utility, the value of the 10th fish caught on a given fishing trip would be expected to be lower than the value of the 2nd fish caught. As a result, the value of a given resource change cannot simply be estimated by multiplying a value from the literature for a specific resource change by the ratio of the resource changes of the policy and the study sites.

Because ecosystem services are supplied and consumed at various spatial scales, valuation requires close examination of how a particular service flow impacts individuals at different geographical and institutional scales (Escobedo et al., 2011; Hein et al., 2006; Turner et al., 2000). The importance of spatial considerations in benefit transfer has been discussed in recent literature (Bateman et al., 2011a; Johnston and Duke, 2009; Plummer, 2009). Spatial scale affects the relative scarcity and substitutability of service flows. For example, the per-hectare fishery production value of a coral reef cannot simply be multiplied by the total acreage of coral reefs in a country, region or the world to calculate the total fishery production value of the country's, region's or world's coral reefs. The fish harvest lost with the loss of the one local reef may be compensated through increased fish imports from other areas or a switch to other foods. Such substitution possibilities generally decline with increasing spatial scale: the loss of a nation's, region's or the entire world's seafood harvest will have an increasingly non-marginal effect on the relative scarcity and thus will increase the marginal value of a unit of seafood (and thus of the reef) because it will be much harder to substitute for than the loss of one reef. Using the marginal value from a local study as an average value to calculate the total value of a resource thus will lead to large estimation errors and suboptimal natural resource management (Bulte and Van Kooten, 2000).

Transfers of measures of economic value should be based on consideration of the entire original valuation study context to ensure a match with the policy site being evaluated. Lack of attention to context and resulting invalid transfer estimates from inappropriate scaling up of transferred value estimates was a major criticism of the widely cited Costanza et al. (1997) analysis of the value of the world's ecosystems (Bulte and Van Kooten, 2000). As noted by Bockstael et al. (2000), "Values estimated at one scale cannot be expanded by a convenient physical index of area, such as hectares, to another scale…" Consideration of basic economic principles such as diminishing marginal utility and changing relative scarcity and substitutability is critical when transferring welfare estimates. Greater communication between ecologists and economists can prevent some of these errors and help advance the measurement of economic values for nature (Bockstael et al., 2000).

The temporal component of transfers, in terms of the year the original study used for benefit transfer was conducted, also warrants consideration when valuing ecosystem services based on secondary data. At some point, the original study may be too old to reliably transfer value estimates. For instance, if societal preferences for certain recreation activities have changed considerably over time, or societal understanding of an ecosystem service has matured over time, a study conducted thirty years ago, for instance, may not adequately capture associated economic values. In addition, advancements in valuation methodologies may complicate direct convergent validity comparisons of studies conducted at different times (Rosenberger and Johnston, 2009). While the literature does not provide much formal guidance for accounting for temporal effects in benefit transfers, Johnston and Rosenberger (2010) summarize the relevant studies addressing this topic.

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To date, a number of studies have sought to empirically test the validity of transfers, calculating the percentage difference between a transferred estimate of the good or service being valued with an estimate derived from an original study (see Rosenberger and Stanley (2006) for a summary of these studies). As might be expected from past guidelines for a valid transfer (Boyle and Bergstrom, 1992; Desvousges et al., 1992), several of these studies support the hypothesis that the greater the similarity, or correspondence, between the original study site and the policy site of interest, the smaller the expected transfer error (Rosenberger and Phipps, 2007; Rosenberger and Stanley, 2006). However, because site characteristics represent only a portion of the total suite of study context characteristics that affect value estimates, close site correspondence is a necessary, but not sufficient, condition for valid benefit transfers (Brouwer and Spaninks, 1999; Loomis and Rosenberger, 2006; Rosenberger and Stanley, 2006).

An important consideration when transferring welfare estimates for policy analysis is to recognize that valuation based on secondary data is as much an art as it is a science. Benefit transfer often requires professional judgment on the part of the researcher, for example, when screening for existing studies that might provide a basis for valid transfers. As professional judgment is subjective and may be susceptible to pressure to produce value estimates, analysts may want to follow recommendations for conducting economic analysis in a participatory manner with policy decision-makers without politicizing the results (e.g., Smith, 2013). It is important for both practitioners and policymakers to understand the role of benefit transfer and be able to communicate its limitations. Continuing to develop and expand on federal guidelines (such as OMB, 2003; US EPA, 2010; USDOI BLM, 2013) can also help to ensure that benefit transfer is used appropriately in policy decisions.

3.2. Advances in Benefit Transfer Methods and Modeling Techniques

3.2.1. Unit Value Transfers

Historically, most benefit transfers can be characterized as unit value transfers based on one of three approaches. The first approach is to identify a single study in the literature that best matches the characteristics of the policy site based on the transfer criteria outlined previously, and transfer this single point estimate, adjusted for inflation, from the study site to the policy site. For example, to estimate the economic value of a management decision that would result in increased opportunities for trout fishing in northern Colorado, the analyst would search for a previously conducted, methodologically sound study quantifying a consumer surplus value for trout fishing in northern Colorado, adjust the resulting value estimate for inflation, and use that estimate in their analysis.

A second approach is to apply an average value from several studies to the policy site of interest. Transferring a measure of central tendency might be preferable to a single point estimate transfer in two cases. First, if there are multiple studies that meet the criteria for a valid transfer, an average of them may be the most accurate estimate. Second, if there are no studies that meet all the criteria for an ideal benefit transfer, an average value may better reflect the criteria by at least partially canceling out biases in individual studies. Essentially, using an average value would implicitly and non-systematically adjust for differences in context between each of the study sites and the policy site.

Lastly, one could apply administratively approved values, such as the U.S. Forest Service Resources Planning Act values for recreation and other resources, or the U.S. Water Resources Council's unit day values for recreation. These are typically derived from a combination of existing empirical evidence, expert judgment, and political screening (Rosenberger and Loomis, 2003). Unit value transfers for a wide range of ecosystem services have been conducted, though often as one of several transfer approaches used in a study (see Gascoigne et al., 2011; Jenkins et al., 2010; Kroeger and Casey, 2006; Loomis, 2006; Noel et al., 2009).

3.2.2. Benefit Function Transfer

Alternatively to unit values, a demand or willingness to pay (WTP) function can be used for benefit transfers. For example, a WTP function might have been estimated in which WTP depends on the quantity or quality of the ecosystem service provided and socioeconomic characteristics of the population originally surveyed:

$$\text{WTP per household} = B_0 + B_1(Q_{es}) + B_2(\text{Income}) + B_3(\text{Age}),$$

where Q_{es} is the quality or quantity of the ecosystem service being valued and B_0, B_1, B_2, and B_3 represent the regression coefficients. This equation would allow the analyst to tailor the WTP per household to the specific quality or quantity of the ecosystem service (e.g., acres of habitat, number of endangered fish protected) and key socioeconomic characteristics of users at the policy site by inserting the quality or quantity and mean income and age at the policy site into the WTP function. Loomis and Gonzalez-Caban (1998) provide an example of a WTP function that can be used for benefit transfers and discuss its application for policy evaluation. Of course, this method requires finding a WTP function study in the existing literature that at least meets Boyle and Bergstrom's (1992) first criterion for an ideal benefit transfer (i.e., valuing the same ecosystem service) and estimates a function that is free from omitted variable bias and other errors. If such a study exists, it can be tailored to the socioeconomic conditions of the policy site even if they differ from the original study site. Potential drawbacks of applying benefit function transfer are that it requires knowledge of the values of the independent variables for the policy site of interest, and assumes that the statistical relationship between the dependent and independent variables is the same between the study and policy sites (Rosenberger and Loomis, 2003).

3.2.3. Meta-Regression Analysis Function Transfer

Another form of function transfer, which addresses some of the drawbacks of benefit function transfers, is the use of meta-regression analysis functions. This approach systematically accounts for differences in results and explanatory variables in relevant, methodologically sound studies valuing a particular ecosystem service in order to estimate a WTP function for the service. It typically involves: (a) assembling the available studies valuing a particular ecosystem service (e.g., recreational fishing, carbon sequestration, water quality for swimming); (b) coding those studies in terms of WTP per unit, characteristics of the study site (e.g., the quantity or quality of the ecosystem service provided, whether the service was provided on public or private land), methodological attributes of the study (e.g., valuation methodology used, type of value estimated, survey mode, survey response rate, question format), and if available, demographics of the original study populations; and (c) estimating a regression model with WTP per unit (for a particular base year) as the dependent variable and, at a minimum, study site characteristics, methodological attributes, and socioeconomic variables as the independent variables. The impact of various selection effects that may bias the existing stock of knowledge should also be adjusted for if possible (Rosenberger and Johnston, 2009).

To use the meta-regression equation to predict welfare estimates for an unstudied policy site, the analyst inserts the levels of the independent variables that describe the policy site and associated demographics. The methodology variables are often set at the metadata sample mean, but other approaches have been employed as well. Johnston et al. (2006) demonstrate the sensitivity of meta-regression function transfers to the analyst's treatment of methodological attributes. While some meta-regression models are estimated for the specific purpose of performing a function transfer, existing meta-regression equations are available for a wide range of

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ecosystem services, including various recreation activities (Brander et al., 2007; Johnston et al., 2006; Neher et al., 2013; Rosenberger and Loomis, 2001; Smith and Kaoru, 1990; Walsh et al., 1992; Zandersen and Tol, 2009), threatened and endangered species (Loomis and White, 1996; Richardson and Loomis, 2009), services provided by wetlands (Brander et al., 2006; Brouwer et al., 1999; Woodward and Wui, 2001), water quality (Boyle et al., 1994; Johnston et al., 2005; Moeltner et al., 2007), and morbidity related to air quality (Vassanadumrongdee et al., 2004). Nelson and Kennedy (2009) provide a summary and assessment of 140 meta-analyses of environmental and resource values, as well as a discussion of the use of meta-analytic methods for benefit transfer.

Support for the higher accuracy of benefit transfer using pooled data models, such as a meta-regression function, over other approaches has been well-documented over the years (Loomis and Rosenberger, 2006; Moeltner et al., 2007; Piper and Martin, 2001; Rosenberger and Loomis, 2000a; VandenBerg et al., 2001). In the absence of an existing study that exactly matches the policy context, applying a meta-analytic transfer generally is the preferred approach because it allows construction of a context-specific value estimate for the policy site that draws on empirically derived relationships between independent and dependent variables from large numbers of observations. Particular characteristics of a study become less problematic because meta-regression functions can explicitly account for any statistically significant effect of variables such as study year, valuation methodology, or publication outlet, on value estimates. Function transfers have generally been found to be more accurate or at least no less accurate than unit value transfers because differences between the study and policy sites are explicitly accounted for (Loomis, 1992; Rosenberger and Stanley, 2006), and their use is recommended in federal guidelines for benefit transfers (OMB, 2003). They are not however, an undisputed solution to concerns regarding the validity and reliability of transfers. Recent findings suggest that, perhaps not surprisingly, the degree of correspondence between the study site and policy site has a large effect on the improved accuracy of a function transfer over a unit value transfer. In general, a unit value transfer may be more appropriate for transfers if study and policy site contexts are very similar, whereas function transfers generally may yield lower errors for transfers between less similar sites (Bateman et al., 2011b).

Over the years, advances in modeling techniques have helped improve function transfer-based welfare estimates. For instance, many studies now highlight the importance of addressing common issues associated with meta-regression models, such as correlation across observations from the same study or author, primary data heterogeneity and heteroskedasticity (Bateman and Jones, 2003; Johnston et al., 2006; Neher et al., 2013; Nelson and Kennedy, 2009; Rosenberger and Loomis, 2000b). Bayesian approaches can further address econometric challenges that arise when estimating meta-regression models using a classical estimation framework. Two of the most prominent challenges are the difference in the available set of regressors across included studies (i.e., the "N vs. K" dilemma), and the treatment of methodological explanatory variables when using the meta-function for welfare predictions (Moeltner et al., 2007).

Recent findings suggest that meta-regression analysis may provide an effective tool for detecting and correcting for selection biases within benefit transfers, such as those that arise when the existing literature is not an unbiased sample of empirical evidence (Rosenberger and Johnston, 2009). The transfer of spatially explicit value functions has been recommended as a potentially more flexible and sophisticated approach to function transfer than meta-analyses in that the former can be used to estimate unit values as well as the quantity change that they are applied to (Bateman et al., 2011a). For instance, a travel cost model that includes spatially variable factors such as river location and quality, substitutes, complements, as well as the density and socioeconomic characteristics of the population, can be transferred to estimate both the number and value of visits to a policy site of interest (Bateman et al., 2011a).

3.3. The Role of Web-Based Resources in Benefit Transfer

Many researchers have suggested the development of a repository of valuation studies, surveys, and raw data to facilitate benefit transfers (e.g., Boyle and Bergstrom, 1992; Loomis and Rosenberger, 2006). Federal entities in the United States, including the U.S. Water Resources Council and the U.S. Forest Service, began compiling databases of administratively approved recreation values in the late 1970s and early 1980s, driven in part by mandates for formal cost–benefit analyses of large federal programs. Since then, databases and analysis tools based on existing welfare estimates have grown in both size and capabilities (see Loomis, 2005; Loomis et al., 2008; http://recvaluation.forestry.oregonstate.edu/; https://www.evri.ca/Global/Splash.aspx; http://www.marineecosystemservices.org/explore). The Bureau of Land Management's (BLM) Socioeconomics Program is currently partnering with economists at the U.S. Geological Survey, Colorado State University, and Oregon State University to conduct case studies aimed at documenting the process of using existing data to quantify nonmarket values associated with BLM managed lands. As part of this work, a web-based Toolkit intended to facilitate benefit transfers (Loomis et al., 2008) will be updated and expanded for possible use in BLM planning and project assessments.

As valuation databases and analysis tools continue to be developed and expanded on, formal reviews can help improve their usefulness. For instance, Morrison (2001) outlines criteria that would be beneficial to include in a nonmarket valuation database, and reviews several existing databases based on meeting these criteria. One finding is that valuation databases could be improved by including more information about the validity and precision of value estimates (Morrison, 2001). McComb et al. (2006) also review several databases and recommend conducting periodic user surveys, incorporating input obtained from workshops and other sources of communication, as well as more collaboration among various efforts. A comprehensive review of the EVRI database and website resulted in several recommendations to ensure that it continues to serve evolving user needs (Johnston and Thomassin, 2009). While valuation databases have increased the accessibility of ecosystem service valuation for policy analysis, they are often best viewed as a starting point. Their role is partly to alert analysts to existing studies that might be suitable for benefit transfer, rather than as a replacement for more rigorous benefit transfers that require the analyst to evaluate the suitability of the original studies and search for additional studies not in the database (Johnston and Thomassin, 2009; Morrison, 2001). As noted by Johnston and Thomassin (2009, p. 36), "Whether in benefit transfer or cost–benefit analysis, valuation databases cannot substitute for practitioner expertise." Along these lines, websites that house valuation databases and analysis tools should include caveats regarding their appropriate use, as well as protocols for benefit transfer and references to the growing body of research surrounding the topic.

Spatial mapping tools are another category of web-based resources increasingly being used for ecosystem service valuations. Software packages[1] such as InVEST (Integrated Valuation of Environmental Services and Tradeoffs; Tallis et al., 2011), ARIES (Artificial Intelligence for Ecosystem Services; Bagstad et al., 2012), or the proprietary NAIS™ (Natural Assets Information System; based on Troy and Wilson, 2006) generate spatially-explicit, Geographic Information System-based estimates of ecosystem service flows. While these tools principally are intended to bring a spatial component to the valuation of ecosystem services and provide the physical units needed for such valuation, some of them offer the option of combining the estimated flows with

[1] Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

unit value estimates contained within the packages themselves. While this is user-friendly, three important limitations generally apply to these packages. First, the flow estimates generated by several of those packages often represent ecosystem function rather than service flows, raising concerns about the unaccounted-for attenuation of flows between the site at which they are produced and the actual location of beneficiaries at which the ecosystem function output produced by the site interacts with a related human demand to produce an actual service (Kroeger, 2013). A second and consequential concern resulting from the quantification of functions rather than services is the potential for a mismatch between the physical flow units estimated by the models (e.g., tons of reduced sediment runoff of a property per year) and the values from the literature with which those flow units are multiplied—after all, those values in all cases result from studies of a particular service that yields a specific benefit (á la Boyd and Banzhaf, 2007) in the respective studied context (e.g., tons of avoided silt deposition in a hydropower reservoir per year; tons of sediment avoided in the filtration system of a water treatment plant). Finally, the general concern regarding simplistic benefit transfer in situations characterized by a mismatch between study and policy site contexts applies, given that these software packages generally apply transfer of unadjusted unit values that do not take into account issues of spatial scale, substitutes and complements and relative scarcity or diminishing marginal utility. However, it must be pointed out that improvements in the valuation components of several of these tools are ongoing. Nonetheless, their primary use should be to generate first-cut, order-of-magnitude value estimates, which still have useful policy applications in some instances. The U.S. Department of Defense has funded a three-year pilot study applying InVEST as a means to quantity, map, and value ecosystem services on military lands.

As the demand for estimates of the value of the benefits people obtain from nature grows and policymakers continue to face constraints in the timeframes and budgets available for planning and management, valuation databases, software programs, and other web-based tools aimed at supporting ecosystem service valuation will continue to play a role in benefit transfers for environmental decision making. It bears reiterating that analysts and policymakers should have a clear understanding of both the capabilities and limitations of these web-based resources. Formal reviews like that of Bagstad et al. (2013) of the applicability of, and differences in the recommendations generated by different ecosystem service tools for environmental decision making, are critical to the informed use of these web-based systems. In addition, workshops focused on benefit transfer and valuation databases can also help stimulate important discussion and identify appropriate uses of these tools in policy decisions. Consortiums of tool users and developers, such as the Coastal–Marine Ecosystem-Based Management Tools Network (EBM Tools Network; www.ebmtools.org), can also serve as a catalyst for research aimed at improving the long-term funding and continued development of these tools (Curtice et al., 2012).

4. The Future of Benefit Transfer in Ecosystem Service Valuation

Benefit transfer has been widely practiced for several decades now. The motivation driving its use, namely, to supply information on ecosystem service values for use in policy decisions, is only growing. Given that economic analyses must be available in a timely manner to be policy-relevant, and often face budget constraints that prevent original study, the existing stock of welfare estimates will continue to be drawn on for valuation studies for new policy sites. Considerable advancements in benefit transfer methodologies and modeling techniques have been achieved since formal evaluation of benefit transfer began nearly three decades ago. Still, there remains a disconnect between transfer practices recommended in the scholarly literature and those applied in the policy realm (Johnston and Rosenberger, 2010). The need for timely information on ecosystem service values needs to be balanced with adherence to protocols that reduce the error in the information generated. Analysts conducting ecosystem service valuations based on secondary data can increase the validity and credibility of value estimates by following the guidelines and recommendations in the literature on performing transfers, some of which have been summarized here. While this may reduce the number of applications, it is likely to increase their accuracy (Plummer, 2009). In addition, practitioners can test whether their estimates comply with basic economic principles, in particular those related to scope (diminishing marginal utility) and substitutability as related to spatial scale.

Emerging valuation databases and software programs can help facilitate transfers for policy analysis, but should be used with caution and should not be viewed as a substitute for the expertise required to generate valid ecosystem service value estimates. Developers of these tools should provide explicit caveats about their use and should reference best-practice guidelines that incorporate methodological advancements in benefit transfer. Surveying current and potential database users, as well as consultation with benefit transfer experts, can help to guide database improvements (Johnston and Thomassin, 2009). In addition, much like the testing that has taken place to measure benefit transfer errors, there is a need to test the relative error associated with using secondary data approaches based on these databases and tools against primary valuation study applications. This offers an important research opportunity to learn more about the trade-offs between ecosystem valuation transfer based on these databases and original valuation studies.

Comprehensive valuation databases allow identification of research gaps and thus can help increase the efficiency with which scarce funds are used for original ecosystem service valuation research. Agencies should strategically choose to fund a set of original studies whose purpose is to fill priority gaps in the literature for use in benefit transfer. Ultimately, the most effective way to reduce transfer errors is to build a better collection of primary ecosystem service valuation studies that lend themselves to benefit transfer (Plummer, 2009). In addition, some of the limitations related to the use of benefit transfer in decision making could be addressed through greater interactions between researchers and policy analysts (Johnston and Rosenberger, 2010). Formal agency guidelines for the use of benefit transfers can provide a starting point for these interactions.

Both analysts and policymakers should be aware that careless benefit transfers can result in highly biased welfare estimates that may jeopardize the continued opportunity for ecologists and economists to make progress on integrating natural resource values into decision making. Frequent use of highly flawed welfare estimates in the policy process may affect the policy relevance of the whole field, which would have adverse consequences for society's well-being by undermining improved natural resource policy making. This risk can be avoided if guidelines and recommendations for benefit transfer for ecosystem service valuation are followed, allowing benefit transfer to continue to make an increasingly important contribution to natural resource management.

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Please cite this article as: Richardson, L., et al., The role of benefit transfer in ecosystem service valuation, Ecol. Econ. (2014), http://dx.doi.org/10.1016/j.ecolecon.2014.02.018

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Please cite this article as: Richardson, L., et al., The role of benefit transfer in ecosystem service valuation, Ecol. Econ. (2014), http://dx.doi.org/10.1016/j.ecolecon.2014.02.018

Quantifying the value of non-timber ecosystem services from Georgia's private forests

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Final Report submitted to the
Georgia Forestry Foundation
January 2011

Acknowledgments

Research for this report was supported by a grant from the Georgia Forestry Foundation, with contributions from:

American Forest Foundation
Georgia Conservancy
Georgia Farm Bureau
Georgia Forestry Commission
Georgia Forestry Foundation
Georgia Power Company
Georgia-Pacific Foundation
Georgia Tree Farm Program
National Alliance of Forest Owners
Plum Creek Timber Company
Rayonier Foundation
Smith, Gambrell & Russell
Superior Pine Products Company
Sustainable Forestry Initiative-SIC
Sutherland Asbill & Brennan LLP
Tall Timbers Research Station & Land Conservancy
Trust for Public Land
The Langdale Company
The Nature Conservancy-Georgia
Wells Real Estate Funds
Weyerhaeuser Foundation

Executive Summary

Georgia's forests provide essential ecosystem services like water filtration, carbon storage, wildlife habitat, recreational opportunities and scenic beauty. However, because no market exists in which to trade many of these services, it is difficult to quantify the benefits they provide. Ecosystem services are those things that nature provides that are of direct benefit to humans. The purpose of the research summarized in this report is to provide an estimate of the value of ecosystem services provided by private forests in Georgia.

We outline a four-step process for estimating the public ecosystem service benefits of private forests in Georgia: 1) Identify the geographic, ecological and economic scope of the study; 2) Create a landscape classification system based on forest characteristics which predict significant differences in the flow and value of ecosystem services; 3) Use the best available data to estimate average per-acre values for each unique combination of forest characteristics and each ecosystem service identified; 4) Calculate the total ecosystem service value.

Identify the geographic, ecological and economic scope of the study

The scope of our study is limited to the 22 million acres of privately-owned forestland in Georgia. Based on a review of the literature, we identified eight types of ecosystem services forests provide:

1. **Timber and forest product provision:** Forests provide raw materials for many uses.
2. **Recreation:** Forests provide a potential place for recreation.
3. **Gas and climate regulation:** Forests contribute to the general maintenance of a habitable planet by regulating carbon, ozone, and other chemicals in the atmosphere.
4. **Water quantity and quality:** Forests capture, store, and filter water mitigating damage from floods, droughts, and pollution.
5. **Soil formation and stability:** Forest vegetation stabilizes soil and prevents erosion.
6. **Pollination:** Forests provide habitat for important pollinator species who naturally perpetuate plants and crops.
7. **Habitat/refugia:** Forests provide living space to wild plants and animals.
8. **Aesthetic, cultural and passive use:** Forests provide scenic value and many people have a positive existence value for forestland.

We are interested only in those ecosystem services that provide external benefits, or benefits to people besides the landowner or land user. Because of this, we do not consider the value of timber and forest products provision or recreation. We do consider the value of the other six ecosystem services listed above.

Create a landscape classification system based on forest characteristics

The value of ecosystem services provided by a particular acre of forestland depends on the quantity and quality of the ecosystem functions and services provided, and the magnitude, preferences, and demographic characteristics of the population receiving those services, typically the nearby population. For large scale valuation projects such as this one, it is not possible to consider each parcel of forestland separately. Instead, we develop a landscape classification system that identifies forestlands that are likely to have similar per-acre values of ecosystem services. We then estimate the value of an average acre of forests in each unique category and apply this value to all acres in that category.

We considered seven different forest characteristics expected to create differences in the flow and/or value of ecosystem services: **forest type, riparian status, rare species abundance, scenic visibility, public land buffer, development class, and geographic region**. Some of these characteristics affect the quantity or quality of ecosystem services provided. For example, an acre of forestland in a riparian area has a much greater impact on water quality and quantity than an acre of non-riparian forest. The per-acre value of riparian forests will be higher because of this difference in the underlying ecosystem functions. Other characteristics primarily affect the value of the service provided. For example, an acre of forestland in an urban area will have a greater aesthetic value than one in a rural area simply because more people are around to see it.

Based on our application of these seven characteristics, there are 864 possible combinations of characteristics that might describe Georgia's private forests. These characteristics describe much of the important variation in ecosystem service flow and value. In applying this classification scheme, we move from an intractable problem (trying to evaluate each of the 22 million acres of private forests separately) to a complex, but manageable one. For a given combination of forest characteristics (eg., mixed forests in North Georgia, riparian, high wildlife, non-roadside, non-public buffer, and urban), we assume each acre of forest with those characteristics produces an identical flow of ecosystem service value. However, forests with different characteristics can have different per-acre values. This is an improvement over most previous studies of this type that allow for just a few different types of forests (and often consider all forest acres as identical).

Not all forest characteristics are equally represented by Georgia's private forests. For example, there are no private forests in Georgia that are characterized as riparian, with low species abundance, are visible from a highway, buffer public land, and are in an urban area of south Georgia. Of the 864 potential classifications of forests, 65 include no private forestland in Georgia, and an additional 547 classifications describe fewer than 1000 acres each. In contrast, over 12% of all forests in Georgia fall in a single classification (rural, south Georgia, evergreen, not riparian, not roadside, not public buffer, low wildlife).

Use the best available data to estimate average per-acre values

We take a two-pronged approach to estimating per-acre ecosystem service values. We developed a stated choice survey to collect original data to estimate aesthetic and non-use values of our study area. Relative to other ecosystem services, these values are most dependent on the tastes and preferences of the local population and therefore the most problematic for value transfer. For the other five ecosystem services of interest we relied on value transfer methods.

For the value transfer component, we considered each ecosystem service individually. We began with a preliminary estimate of the per-acre value based on the values reported in a similar study in New Jersey (Liu et al. 2010). We then carefully considered the sources used to generate that value. We removed some source estimates, reevaluated others to better apply to Georgia, and considered other original studies that might be included. From this process, we estimate the average per-acre value of each service by forest characteristics and also identify areas of much needed research. Table 1 summarizes the value estimates for the five ecosystem services considered for value transfer.

Table 1. Summary of ecosystem service values for value transfer.

Ecosystem Service	$/acre/year in 2009 US$
Gas and climate regulation:	$28 - $381 depending on forest characteristics
Water regulation and supply:	$0 - $8,196 depending on forest characteristics
Soil formation:	No data available
Pollination:	$0 - $184 depending on forest characteristics
Habitat/refugia:	$0 - $251 depending on forest characteristics

To estimate aesthetic and non-use values, we conducted a mail survey of the general population of Georgia during summer and fall 2010. The survey contained background information on forests and ecosystem services and asked respondents about their familiarity with Georgia's forests, recreation activities, general questions about the environment, preferences for public regulation of forested land, and sociodemographic characteristics. In addition, each respondent was asked four questions as part of the stated choice experiment. In these questions, the respondent was invited to participate in a hypothetical referendum. They were told that a referendum was up for vote that would affect the future of Georgia's private forests. They were presented with two alternative futures in each question. By varying the attributes of the alternatives, we are able to estimate an individual's marginal willingness to pay (WTP) for an increase in different types of forestland. When aggregated to the population of Georgia, the aesthetic and non-use value of additional forested acres ranges from $52/year to $4,642/year depending on the characteristics and location of the land. We found that respondents expressed positive values for forest land across the state, but not surprisingly had higher values for forestland in their area. Also, respondents were willing to pay a premium to protect forests important for wildlife and water.

In addition to the questions related to the choice experiment, the survey gathered data on respondents' experiences with forestland in Georgia, general attitudes about forests and the forest industry, and basic demographic data. Respondents from different regions have different rates of forest ownership and different rates of participation in different forest-related recreation. A majority of respondents reported that the beauty of the landscape in their area has changed over the years due to tree cutting and have concerns or apprehensions about the way forests in Georgia are being managed.

Only 45% of respondents agreed with the statement "I trust Georgia's forest owners to maintain healthy forests in the long term." When asked if they agree that there are enough checks and balances in place to ensure responsible forest management in Georgia, 24% of respondents agreed, 45% were neutral, and 27% disagreed. Only 28% of respondents felt that private forest owners have the right to do as they please with their forests regardless of what it does to the environment. 58% said private property rights should be limited if necessary to protect the environment but 68% said that the landowner should be paid for any economic loss accrued when prevented from cutting on his land because of government regulations. Just over half of respondents would support programs that provided incentives for forest landowners to voluntarily comply with environmental regulations.

Calculate the total ecosystem service value

Based on our analysis, we estimate that the total value of these six ecosystem services provided by Georgia's 22 million acres of private forests is over $37.6 billion per year. Per-acre values range from $264 to $13,442 depending on the forest characteristics. Higher per acre values generally come from forested wetlands or riparian forests in urban areas while lower per-acre values come from non-wetland forests in rural areas. This represents a lower bound of the public value of private forests for several reasons. The value of some ecosystem services, such as erosion control and ground water recharge could not be explicitly included in our final estimates because there was not enough information available to estimate their value or because the benefits occur on a relatively small scale and could not be incorporated at the state-level. Other technical aspects of the analysis were conducted in a way to insure a conservative estimate.

It is also important to remember that we estimate only one component of the Total Economic Value of private forests in Georgia. We estimate the indirect use and non-use values of the forests. These are components of value that do not require ownership of or access to the land. Two significant components of the total value that are not included are the value of timber and forest products and recreation. Other research has estimated the impacts of these industries on Georgia's economy. Because economic impacts and economic benefits are different things, we cannot add these values together. Economic impacts consider the revenue generated from market activity and trace this revenue through the economy. Economic benefits are the difference between what consumers would be willing to pay for something and what they have to pay. However, when considered together, this body of research provides an overall view of the importance of forestland to the people of Georgia.

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Part 1: Overview

Project Motivation

In addition to timber and other marketable wood products, Georgia's forests provide essential ecosystem services like water filtration, carbon storage, wildlife habitat, recreational opportunities and scenic beauty. The loss of forestland can lead to risks to human health, accelerated climate change, increased watershed disruption, loss of water quality, and loss of biodiversity (Pearce 2001). However, because no market exists in which to trade many of these services, landowners have little incentive to consider their value when making land use decisions. Recently, market-based mechanisms (such as the carbon registry or nutrient trading programs) have been proposed and/or designed in order to provide the landowner with greater incentives to leave land in forest production. Landowners who only consider the timber value of land in forest production will be more likely to choose non-forest land use options, such as development, which provide more benefits *to the landowner*. This means fewer acres in forest production, reduced importance of the region in global forest markets, and loss of benefits to society from reduced flows of ecosystem services. Efficient land use decisions must take into account the total economic value of each land use option, including market and non-market, use and non-use, values. If the total economic value of forested land, including the value associated with timber production *and* the other ecosystem services provided, is compared to the total economic value of alternative land uses, it is likely that more land would remain in forest production, ensuring sustainable flows of essential forest ecosystem services. We cannot address this problem without knowing the total economic value of forested land, including the value of all non-market forest ecosystem services.

Though the forest land use decision clearly indicates a failure of the market to lead to an efficient solution, historically, forest regulations and tax policies have not addressed this problem. One reason for this oversight is that the value of these other ecosystem services is difficult to quantify, even if the physical nature of the service is well-understood. While carbon markets and water quality trading markets may eventually help us quantify the value of these services, most of these institutions are still in the proposal or early development stage. Also, values of other forest benefits (*e.g.*, scenic beauty, habitat for endangered species) are less easily captured in market-like settings. As a result, it is difficult to incorporate these values into public decision-making in a meaningful way. At the same time, important decisions are being made today that will significantly impact the amount of land that remains in forest cover in the near future. **The primary objective of the research summarized in this report was to fill this knowledge gap by using best available methods to quantify the benefits Georgia's private forests provide to non-forest owners.**

Defining ecosystem services

While sometimes unrecognized by humans, ecosystem services are a vital component of the ecology and economy of the world. The idea of ecosystem services has become an organizing principle for much recent research in both ecology and economics, and also appeals to land managers and landowners who are trying to make efficient decisions related to their land (Brown et al. 2007). As the field has developed, the definition of ecosystem services has evolved and several lists and organizational frameworks for evaluating ecosystem services have been developed (Costanza et al. 1997; de Groot et al. 2002; Daily 1997; MEA 2005; Brown et al. 2007; Boyd and Banzhaf 2006; Wallace 2007; Fisher and Turner 2008). In an early writing on the topic, Daily (1997) described ecosystem services as the "conditions and processes through which natural ecosystem, and the species that make them up, sustain and fulfill human life". The

Millennium Assessment (MEA 2005) defines ecosystem services as the benefits people obtain from ecosystems and divides these services in to four categories: supporting, regulating, provisioning, and cultural services. Brown et al. (2007) distinguish between ecosystem structure, ecosystem processes, and ecosystem goods and services. Ecosystem structure includes the physical and biological components of the ecosystem itself, such as the quantity of water in a reservoir, the soil characteristics, or the density of trees. Ecosystem processes (also called ecosystem functions) are the things that link the components of structure. For example, water supply and wildlife growth are ecosystem functions that depend on the underlying ecosystem structure. Ecosystem processes support the production of ecosystem goods and services. Fisher and Turner (2008) distinguish between intermediate and final ecosystem services and their benefits. The human benefits flow from the final services, which are produced by intermediate services. In some cases, what is considered an intermediate service by Turner et al. is identified as an ecosystem process in Brown et al., and might be a regulating service in the Millennium Assessment.

A distinction can also be made between ecosystem goods and ecosystem services (Daily 1997; Brown et al. 2007). Ecosystem goods are the tangible products of nature, such as timber, minerals, water, and wildlife. Ecosystem goods are better recognized for their contribution to our "natural wealth". Ecosystem services are less recognized aspects of nature's services and in most cases refer to improvements in the condition or location of things of value. Daily referred to ecosystem services as the "actual life-support functions, such as cleansing, recycling, and renewal, …[which] confer many intangible aesthetic and cultural benefits as well (Daily 1997)".

The common thread of the ecosystem service literature is that any delineation, taxonomy, or classification system needs to be flexible and the most appropriate approach for evaluating (and valuing) ecosystem services depends on the needs and purpose of the project. This is not to imply that anything goes, but only to recognize that the distinction between these dichotomies (ecosystem process vs. ecosystem service, intermediate vs. final service, ecosystem good vs. ecosystem service) depends on the context of the problem at hand. Any attempt to evaluate ecosystem services must consider these issues if only to determine the scope of the project. For our purposes, we define **ecosystem services as the things nature provides that are of direct benefit to humans**. We recognize that these ecosystem services are dependent on underlying ecosystem structure and function that may or may not be recognized by society. We acknowledge the distinction between ecosystem goods and ecosystem services, but for brevity, in this report we will refer to these collectively as ecosystem services.

We identified eight broad classifications of ecosystem services provided by forestland in Georgia: timber and forest product provision, recreation, gas and climate regulation, water quantity and quality, soil formation and stability, pollination, habitat refugium, and aesthetic, cultural and non-use values. These ecosystem services are described in Table 2. However, because our objective is to estimate the public benefits of forestland, our estimated benefits do not include the value of timber and fiber provision or recreation.

Defining and measuring economic value

Now that we have defined ecosystem services, we turn to the concept of economic value. Economic value is a measure of the contribution something makes toward human wellbeing (Brown et al. 2007). This is an instrumental type of value, in that something is value because it is a means to an end, in this case, because it brings utility, or happiness, to someone. Ecologists sometimes consider nature to have intrinsic value, or a value independent of any human preference, or even knowledge (Freeman 2003). In this project, we are only interested in the economic value of ecosystem services, but that is not as limiting as it might seem. Economists acknowledge several components that together comprise the Total Economic Value (TEV) of something.

Table 2. Description of ecosystem services.

Ecosystem Service	**General Description**	**Consideration for our analysis**
Timber and forest products provision	Raw materials extracted from forests *Used to produce lumber, engineered wood, fuelwood, landscape products, ornamental products, and edible products (fruits and nuts) (Harper et al. 2009)*	Not considered in our analysis. *The benefits of this service are typically shared between the landowner and the consumer of the product.*
Recreation	Potential place for recreation *Georgia has relatively little public land, so private forests play a large role in providing recreational opportunities (Notman et al. 2006)*	Not considered in our analysis. *The benefits of this service are generally enjoyed by the recreational user and require access to the land.*
Gas and climate regulation	General maintenance of a habitable planet *Regulating CO_2, O_2, O_3 (ozone) and SO_x levels in order to prevent disease and maintain clean, breathable air and a favorable climate (de Groot et al. 2002).*	Partially estimated with value transfer. *Due to limited data, our estimates are dominated by climate regulation and the value of carbon storage. Other particulate regulation is partially considered only for urban forests.*
Water quantity and quality	Capture, storage, and filtration of water *Forests mitigate damage from floods and droughts and naturally filter water which is essential for agricultural, municipal, and industrial uses and serves as an intermediate service for other ecosystem services such as recreation and habitat. (Krieger 2001).*	Partially estimated with value transfer. *Our estimates capture some aspects of flood damage, pollution regulation, water supply for surface water. Due to limited data, some important but localized benefits, such as groundwater recharge in south Georgia, are not included in final estimates.*
Soil formation and stability	Forest vegetation stabilizes soil and prevents erosion. *Helps prevent damaged roads and structures, filled ditches and reservoirs, reduced water quality, and reduced fish populations (Krieger 2001).*	Not included in the final estimates. *These services provide relatively localized benefits and could not be incorporated at the statewide spatial scale considered here.*
Pollination	Provide habitat for important pollinator species *Most plant species, including crops, require pollination. As pollinating species are threatened with habitat loss, often costly artificial pollination is required to maintain healthy systems and crops. (de Groot et al. 2002)*	Partially estimated with value transfer. *Available data is limited and our estimate is likely a lower bound.*
Habitat/refugia	Provide living space to wild plants and animals *Both for resident and migratory, game and non-game species; maintain biologic and genetic diversity that provides natural pest and disease control (de Groot et al. 2002).*	Partially estimated with value transfer. *Our estimates include benefits of threatened and endangered species and overall biodiversity. We do not consider the value of habitat in the maintenance of game species habitat as this is a value to the user.*
Aesthetic, cultural and passive use	Scenic, existence, and/or bequest value *People often value the aesthetic quality of forests scenery and attach value to knowing that forests exist now and will continue to exist in the future (Krieger 2001).*	Estimated from survey data.

There are two main components of TEV: use value and non-use (or passive use) value. Use value captures the benefits received by using the resource either directly or indirectly. Examples of direct use include consumptive uses, like timber harvesting or water withdrawal, and non-consumptive uses like bird watching or boating. Direct use requires direct contact with the resource. Many ecosystem services provide indirect use value as well, which do not require direct contact with the resource. For example water and air quality-related services impact the quality of the ecosystem and thus our quality of life, but we do not have to directly interact with the forest to receive these indirect use benefits.

Economic theory and data show that the Total Economic Value of many environmental goods is greater than their use value. This additional benefit is known as non-use, or passive use, value. For example, a person might value knowing that an endangered species exists, even if it has no use value, meaning the person isn't likely to view or otherwise interact with the species, even indirectly. This type of non-use value is known as existence value because it stems from knowing something exists. Another common source of non-use value is bequest value, or the value of knowing a resource will continue to exist for future generations.

We are interested in estimating the indirect use value and non-use value components of the Total Economic Value of ecosystem services from Georgia's private forests. There are several methods used to estimate economic value. These methods differ in terms of the data used, the components of TEV that are considered, whose values are included, and the value metric estimated. Economic theory says that the value of a good to an individual is the difference between what the person would be willing to pay to have the good, and the cost of producing that good. This is also called the total surplus. Unfortunately, total surplus is difficult to measure because we rarely observe someone's willingness to pay (WTP) for something, only what they have to pay. For many ecosystem services, they don't have to pay anything. But just because something is free, does not mean it has zero value. Because of the difficulty with measuring WTP, some valuation methods estimate other related concepts, such as what is actually paid, which is considered a lower bound estimate on true WTP. A more complete discussion of economic value and valuation measures can be found in Brown et al. (2007), Champ et al. (2003), Fisher and Turner (2008) and other sources. We describe these aspects of six general approaches in Table 3.

Table 3. Description of valuation approaches.

Market valuation

- Estimates based on market exchange of the ecosystem good
- *Example:* Observing price fluctuations and demand and supply of timber traded at market values to estimate the demand and willingness to pay (WTP) for timber
- *Data required:* Observations of individual and firm decisions in markets for goods or services
- *Component of value:* Use value only
- *Individuals considered:* Market participants only
- *Value metric:* Can be used to measure WTP with enough data, but typically uses price as a marginal value, which is an underestimate of total WTP
- *Other comments:* Most ecosystem services aren't traded in markets, so this approach can't be used.

Production function

- The value of a non-market resource is estimated based on its contribution as an input to the production of a market good.
- *Example:* Estimating the value of irrigation water as an input for crop production, even if the farmer does not pay a market price for the water.
- *Data requirements:* Data on input and production decisions, market data for the output
- *Component of value:* Indirect use only
- *Individual considered:* Producer
- *Value metric:* Producer's surplus, which is an underestimate of willingness to pay (WTP)
- *Other comments:* Requires the output good to be competitively priced. This approach is often used to value ecosystem goods, but not ecosystem services.

Replacement Cost

- Considers the cost of replacing the ecosystem service with a substitute
- *Example:* Estimating the water filtration services of a wetland by estimating the cost of building a waste water treatment facility to replace these services.
- *Data requirements:* Costs, no observation of decision making required
- *Components of value:* Use value only
- *Individual considered:* Users
- *Value metric:* This is a measure of cost, not value
- *Other comments:* This is a frequent approach for ecosystem service valuation, even thought it is not a measure of true economic value.

Revealed Preference

- Considers individuals' decisions in related markets to infer the value of a non-market good.
- *Example:* There are three primary revealed preference methods
  - **Hedonic Property**: Differences in housing values are used to infer the value of a non-market good. For example, housing prices bordering urban forests may be higher reflecting the buyer's WTP for scenic views.
  - **Travel Cost**: Decisions about where to recreate are used to infer the value of a non-market good. For example, an angler willing to travel further to get to an area with better water quality (and better fishing), is revealing a higher WTP for improved water quality.
  - **Defensive Behavior**: Individuals' actions to avoid damage are used to infer the value of a non-market good. For example, purchasing bottled water to avoid perceived health damages from poor quality drinking water reveals a positive WTP for improved drinking water.
  - **Damage Cost**: Individuals' WTP to avoid damage from pollution or floods must be higher than the cost of dealing with these damages. For example, WTP to for flood protection is at least as high as the direct and indirect cost of repairing flood damage.
- *Data requirements:* Observations of individual decisions (e.g., housing sales, recreation decisions, defensive behavior, damages, etc)
- *Components of value:* Use value only
- *Individual considered:* Depend on the method. The Hedonic Property Method only captures the benefits to homeowners, the Travel Cost Method only captures the benefits to recreational users, etc.
- *Value metric:* Damage Cost Method measures cost, not WTP; The others measure WTP
- *Other comments:* Data requirements are often overwhelming and only a subset of the population is considered.

Stated Preference

- Ask people carefully designed questions to get them to state their willingness to pay (WTP) for a change in environmental quality
- *Example:* A mail survey asking residents how they would vote in a hypothetical referendum that would increase property taxes to provide improved water quality in their area
- *Data requirements:* Survey data
- *Components of value:* Use and non-use value
- *Individual considered:* Depends on the survey sample
- *Value metric:* WTP
- *Other comments:* This is the only approach that can capture non-use values, but these estimates are sensitive to the survey instrument and the population surveyed.

Benefits Transfer (or Value Transfer)

- Adapt value estimates from previous studies to a different context.
- *Example:* Using the results of previous replacement cost, production function, revealed preference, and stated preference studies to estimate the ecosystem service value of Georgia's forests.
- *Data requirements:* Estimates of non-market values from previous studies
- *Components of value:* Depends on the previous studies considered
- *Individual considered:* Depends on the previous studies considered
- *Value metric:* Depends on the previous studies considered
- *Other comments:* There are several approaches to benefit transfer requiring varying levels of adjustment to the transferred values. Benefits transfer is considered a second best option, as error is introduced in the transfer, but it is commonly used due to significant time and cost savings. The results are limited by the availability and applicability of previous studies.

Overview of project methodology

The best approach to valuing ecosystem services depends on the scale of the study area, data availability, time and budget constraints. For this project, we are interested in a statewide analysis of ecosystem services and determined that an approach similar to the spatially explicit value transfer approach described in Troy and Wilson (2006) and used by others conducting similar research (e.g., Liu et al. 2010) to be a useful starting spot. Adapting their approach, we outlined a four-step process for estimating the public ecosystem service benefits of private forests in Georgia:

1. Identify the geographic, ecological and economic scope of the study;

2. Create a landscape classification system based on forest characteristics which predict significant differences in the flow and value of ecosystem services;

3. Use the best available data to estimate average per-acre values for each unique combination of forest characteristics and each ecosystem service identified;

4. Calculate the total ecosystem service value.

These steps are briefly described here, while detailed methods and results for Steps 2, 3, and 4 are found in the next three parts of this report.

Step 1: Identify the geographic, ecological and economic scope of the study

We are interested in the ecosystem services provided by privately-owned forestland in Georgia. In addition, we are interested only in those ecosystem services that provide external benefits, or benefits that are enjoyed by individuals that do not own or use the forestland and therefore have limited or no influence on land-use decisions. Because of this, we are not considering the value of timber and forest product provision or recreation. Timber and other forest products provide value to those who use them, but this value is captured in the market exchange of these products. The value of this service is generally a private value shared by the landowner and the consumer. Other research adequately captures the importance of the timber industry in Georgia (e.g., Riall 2010). Similarly, recreation benefits are an important aspect of the benefits provided by forests (GFC 2008), but they are largely private benefits enjoyed by users of the resource – someone with access to the land. It is likely that many private forests provide recreational opportunities to the public, but our research is focused on those services that do not require land access.

Step 2: Create a landscape classification system based on forest characteristics which predict significant differences in the flow and value of ecosystem services.

There are over 22 million acres of forestland in Georgia and each acre is different. Georgia's forests are ecologically diverse, and are located in areas that are very socially diverse, meaning each acre of forest could have a unique value. For example, forests in riparian areas provide greater water quantity and quality benefits than forests farther from surface water. Similarly, urban forests are expected to provide greater benefits per acre when compared to rural forests, given their relative scarcity. However, it is not feasible to identify the value of each individual acre of forest on such a large scale. Instead, we created a landscape classification system that divides the state's private forests into categories based on geographic, ecological, and demographic characteristics. While there may be significant differences in ecosystem service flows and values across categories, within each category forests are relatively homogenous and it is more reasonable to consider an average value per acre.

Step 3: Use the best available data to estimate average per-acre values for each landscape classification and each ecosystem service identified.

As described above, there are many different approaches for estimating the magnitude of environmental benefits, including market valuation, stated preference approaches, revealed preference approaches, and benefits transfer. The preferred approach depends on the type of resource being valued and whose values are being considered. Because values are resource, location, and population specific, it is always preferred to estimate values from data specific to the resource, location and population. However this is not always possible given time and budget constraints. We took two approaches in this project. First, we used value transfer methods to apply results of previous research to estimate preliminary per-acre values for most of the ecosystem services considered. This process and these values are reported in Part 3 of this report. Some ecosystem services, such as water quantity and quality, climate regulation and soil stabilization, are unrelated to the ownership classification of the land. Because of this, existing studies that consider the value of these benefits for either public (most commonly) or private (like our study is) forest lands are relevant to our current research. The primary determinants of the magnitude of these services are the biophysical properties of the forest ecosystem. However, the aesthetic and passive use value of forest land is much more sensitive to the preferences and values of the population and the ownership characteristics of the forest. For example, we would not expect the existence value of privately owned forests to be as large as that of national forests due to the expectations and assumptions people make about the management of these two types of forests. Because of this, value transfer is less reliable for these types of values. To address this, we collected original stated preference data specific to Georgia's private forests and used this data to estimate non-use benefits. Part 4 of this report describes the survey component the project and presents the results of this estimation

Step 4: Calculate the total ecosystem service value

The total ecosystem service value is estimated by multiplying the per-acre dollar value estimates for each landscape classification category by the number of forested acres of that type.

Part 2: Landscape Classification

There are over 22 million acres of privately-owned forestland in Georgia. The value of ecosystem services provided by a particular acre of forestland depends on the quantity and quality of the ecosystem functions and services provided, and the magnitude, preferences, and demographic characteristics of the population receiving those services, typically the nearby population. For large scale valuation projects such as this one, it is not possible to consider each parcel of forestland separately. Instead, we develop a landscape classification system that identifies forestlands that are likely to have similar per-acre values of ecosystem services. We then estimate the value of an average acre of forests in each unique category and apply this value to all acres in that category.

We considered seven different characteristics of forests expected to create differences in the flow and/or value of ecosystem services: **forest type, riparian status, rare species abundance, scenic visibility, public land buffer, development class, and geographic region**. Some of these characteristics primarily affect the quantity or quality of ecosystem services provided. For example, an acre of forestland in a riparian area has a much greater impact on water quality and quantity than an acre of non-riparian forest. The per-acre value of riparian forests will be higher because of this difference in the underlying ecosystem function. Other characteristics primarily affect the value of the service provided. For example, an acre of forestland in an urban area will have a greater aesthetic value than one in a rural area partly because more people are around to see it.

Forest Type

Forest Type refers to the dominant ecology of a parcel. Using 2005 Georgia Land Use Trends data, we identified four categories of **Forest Type: Deciduous, Evergreen, Mixed, and Forested Wetland.** Forest Type could affect the quantity and quality of ecosystem services provided, particularly those related to gas and climate regulation, water quality and quantity, recreation, and scenic beauty. Table 4 shows the relative abundance of each forest type in the state. A map of the forest types is shown in Figure 1. Distribution of Forest Type in Georgia.

Table 4. Private forest area by Forest Type.

Forest Type	Acres	Percent of all private forests
Deciduous	5,457,653	25%
Evergreen	11,929,870	54%
Mixed	1,124,921	5%
Forested Wetlands	3,592,174	16%
Total	22,104,618	100%

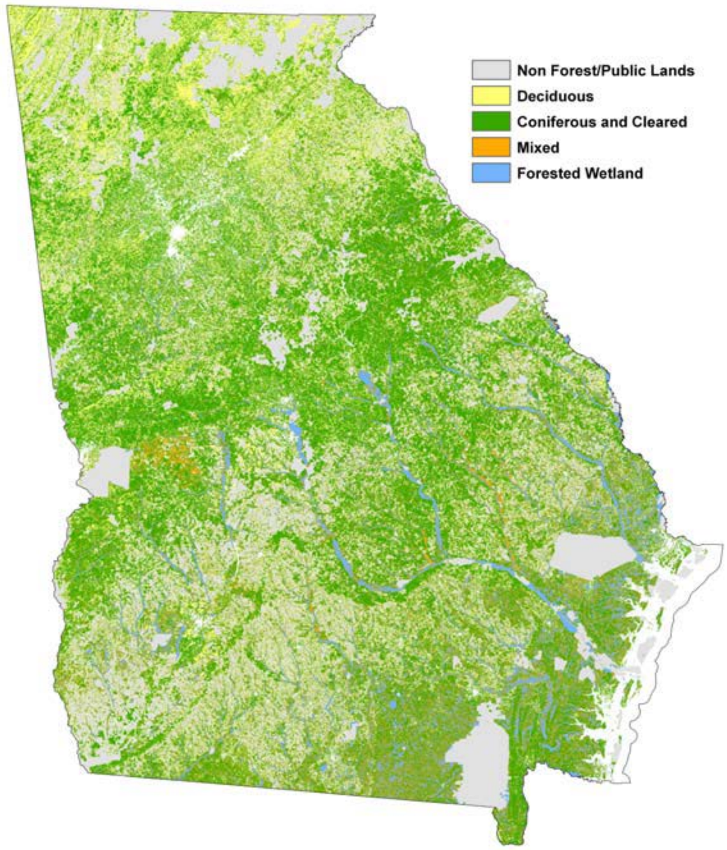

Figure 1. Distribution of Forest Type in Georgia.

Riparian Status

Forests have different impacts on water quantity and quality depending on their position within a watershed. Using DLG Hydrography data, we identified two categories of **Riparian Status: Riparian and Not Riparian**. Riparian includes forests within a 30 m buffer of open and moving water. Note that some areas of south Georgia are particularly important areas of groundwater recharge affecting water supply in Georgia and other states. Due to data limitations this is not considered in our current statewide analysis but should be considered on a localized basis.

Table 5. Private forest area by Riparian Status.

Riparian	Acres	Percent of all private forests
Riparian	3,652,037	17%
Non-riparian	18,452,582	83%
Total	22,104,618	100%

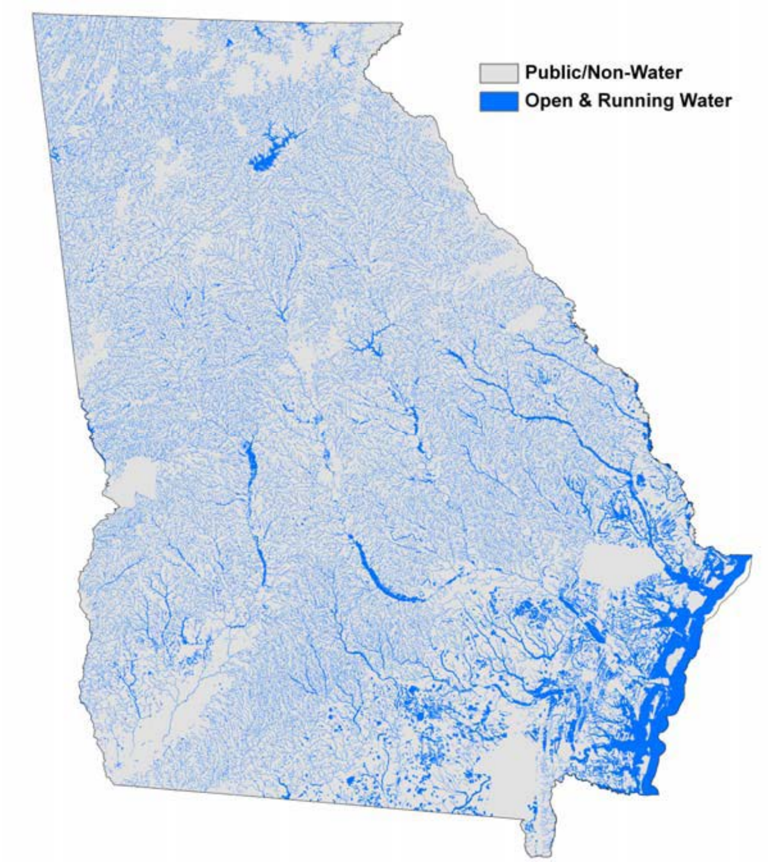

Figure 2. Distribution of Riparian Forests in Georgia.

Rare Species Abundance

Rare Species Abundance refers to the importance of a particular parcel in providing habitat for key species. We used Rare Species Records to identify three categories of **Rare Species Abundance: Low, Medium, and High**, based on the number of rare, threatened, and endangered species (plant and animal) found in an area. Low includes areas with 0 - 5 species (none to few), Medium includes areas with 6 – 11 species (some), and High includes areas with more than 11 species (many). Rare Species Abundance is expected to affect the quantity and quality of wildlife habitat ecosystem services provided by a parcel, thus affecting its per-acre value.

We make three important notes regarding our representation of this forest attribute. First, the data used considers only species of particular conservation concern because they are rare, threatened, or endangered. Species that have cultural, recreational, or other values to human populations, but are not threatened or endangered, are not considered in these counts. Second, of all the data used, Rare Species Records use the coarsest spatial resolution, meaning that data is aggregated over larger areas. Finally, the cutoff points separating the three categories were conservatively selected by the research team. Because areas with higher Rare Species Abundance generate higher per-acre ecosystem service values, the stricter the definition of High Rare Species Abundance, the more confident we can be that our final estimates are a lower-bound on the true estimates. We were aiming for most of the private forestland to be included in the Low category, with roughly 30% in the Middle and only the top 10% in High. The discrete nature of the species count data did not allow these exact proportions, though as Table 6 shows, the final classification is very close to our original goal. Figure 3 shows the location of these categories across the state.

Table 6. Private forest area by Rare Species Abundance.

Wildlife Abundance	Number of Threatened and Endangered Species	Acres	Percent of all private forests
Low	0 – 5	14,173,252	64%
Middle	6 – 11	6,367,531	29%
High	More than 11	1,563,835	7%
Total		22,104,618	100%

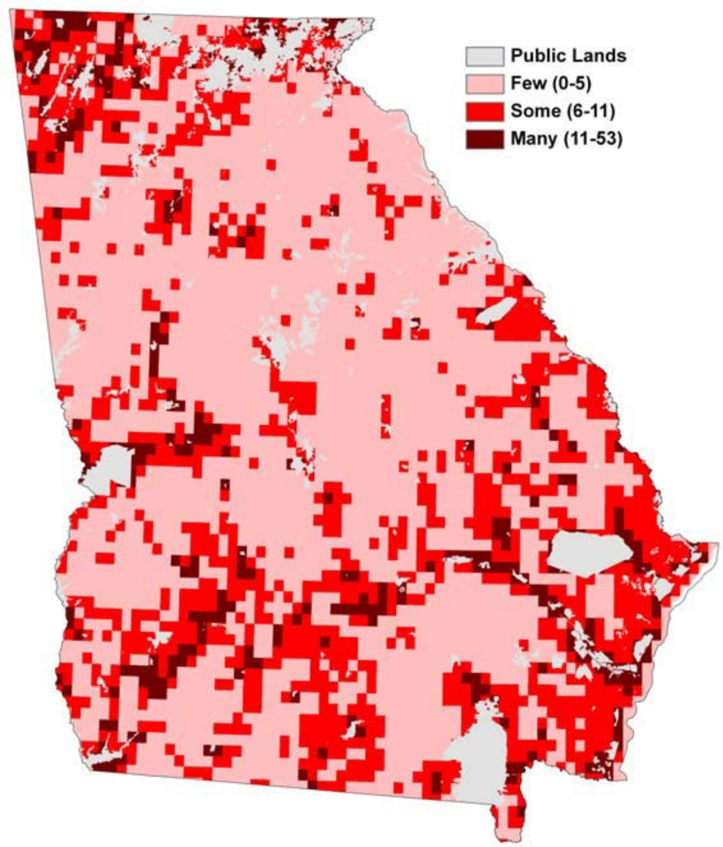

Figure 3. Distribution of Rare Species Abundance in Georgia.

Scenic Visibility

While the public does not necessarily have access to private forests for recreation, some forestland is more visible than others. Scenic visibility is expected to affect the quantity and quality of ecosystem services related to aesthetic value. For our study area, the most obvious predictor of visibility is proximity to major roads. Using data from the Georgia Department of Transportation, we identified two categories of **Scenic Visibility: Roadside and Not Roadside**. Roadside land includes land within a 30 m buffer of Interstates, ramps, State, and County Roads. This is a conservative classification, as it is likely that at least some forests greater than 30 m from the highway is visible to the public and might affect aesthetic values.

Table 7. Private forest area by Scenic Visibility.

Scenic Visibility	Acres	Percent of all private forests
Roadside	1,257,343	6%
Not roadside	20,847,275	94%
Total	22,104,618	100%

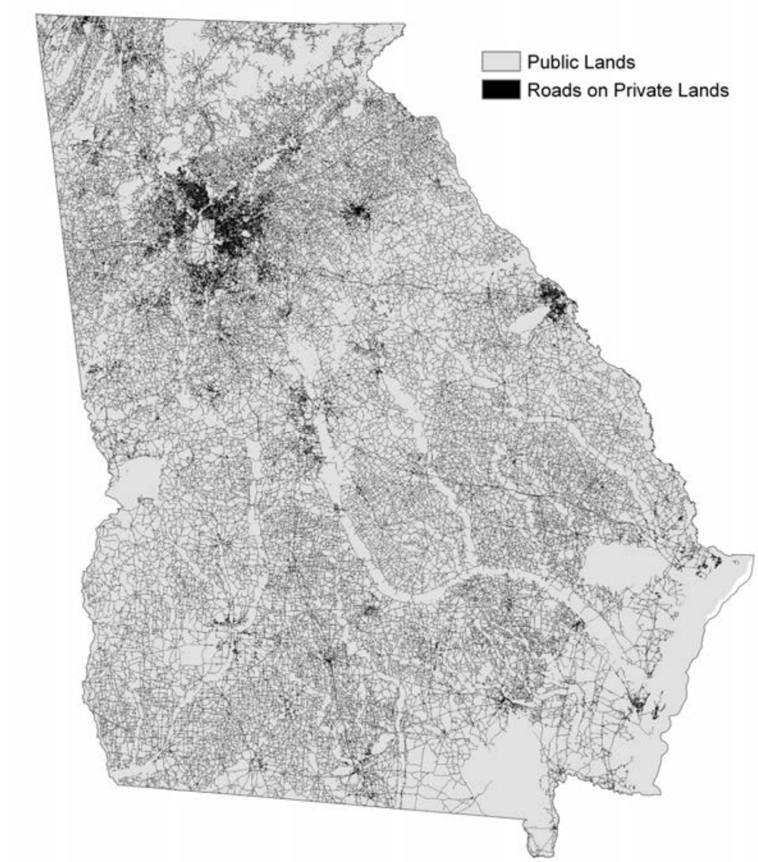

Figure 4. Distribution of roadside forests in Georgia.

Public Land Buffer

It is well documented that the market value of private land is higher for land adjacent to public protected areas such as National Forests, State Parks, and other areas. This price premium is due to the fact that private landowners enjoy private benefits for being adjacent to protected areas. While this is one component of the value of ecosystem services, it is not one that is relevant to our current research because it is a private good. However, it is possible that private land surrounding public land provides some value beyond that captured by the private market. For example, the buffer zone might be more visible to the public if they are accessing the public land for recreation. Also, the buffer zone might protect the public land from encroachment or development pressure, thus affecting the quality or quantity of wildlife or water related ecosystem services. In this way, private land that abuts public land provides an important buffer and might generate greater quantity and/or quality of ecosystem services than other types of private forest land. For that reason, we identify two categories of **Public Land Buffer: Public**

Buffer and Not Public Buffer. The Public Buffer includes private forestland that is within a 90 m buffer of public land.

Table 8. Private forest area by Public Land Buffer.

Public Land Buffer	Acres	Percent of all private forests
Public land buffer	248,687	1%
Not public land buffer	21,855,932	99%
Total	22,104,618	100%

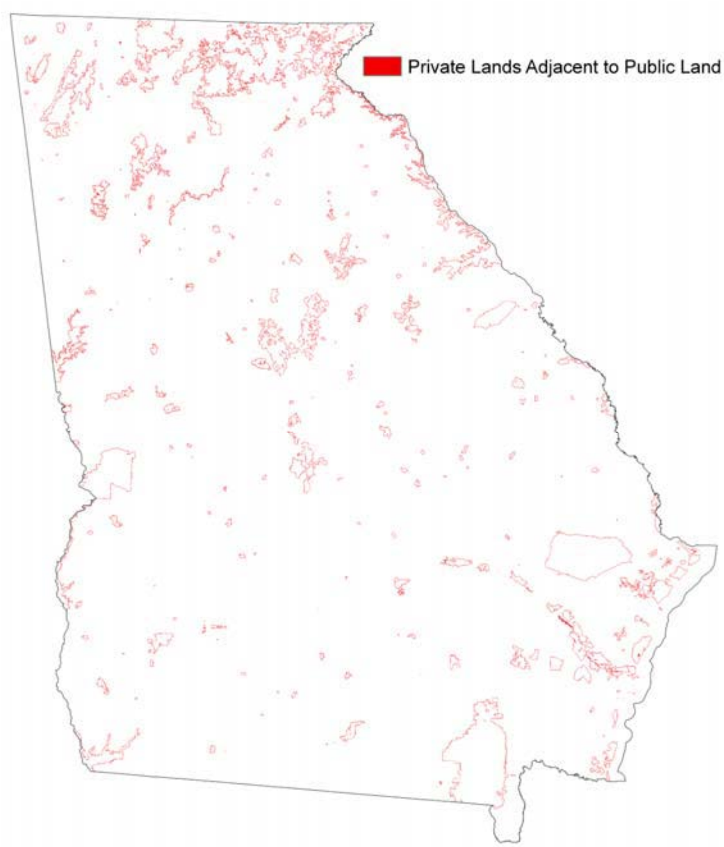

Figure 5. Distribution of forests buffering private land in Georgia.

Development Status

Development Status refers to housing density of an area. While the five forest characteristics already described (Forest Type, Riparian Status, Rare Species Abundance, Scenic Visibility, and Public Buffer) are expected to primarily affect the quantity (or quality) of ecosystem services provided by a representative acre of forest, Development Status affects the "price" component of our value estimates. We suggest three ways in which housing density might affect per-acre values of ecosystem services. First, the benefits of many forest ecosystem services, including pollution control, aesthetics, and non-use value are often estimated as a per-person value and then aggregated to the population receiving these benefits, often the "nearby" population. The more people living nearby, the greater the aggregate benefit to society. Second, basic economic theory suggests that the marginal value of a resource increases as the quantity of resource available decreases. Often called the "scarcity effect" in some of the value transfer literature, this implies that forests in urban areas, where forest are more scarce, provide greater value per acre than in rural areas where forested areas are relatively more common. Third, people living in rural areas might have very different tastes and preference than people living in urban areas. To address these issues, we use data from Wildlands-Urban Interface and Census tracts to identify three categories of **Development Status: Urban, Suburban, and Rural**.

Table 9. Private forest area by Development Status.

Development status	Housing density	Acres	Percent of all private forests
Urban	More than 120 units/km^2	355,571	2%
Suburban	25 – 120 units/km^2	1,352,967	6%
Rural	Less than 25 units/km^2	20,396,080	92%
Total		22,104,618	100%

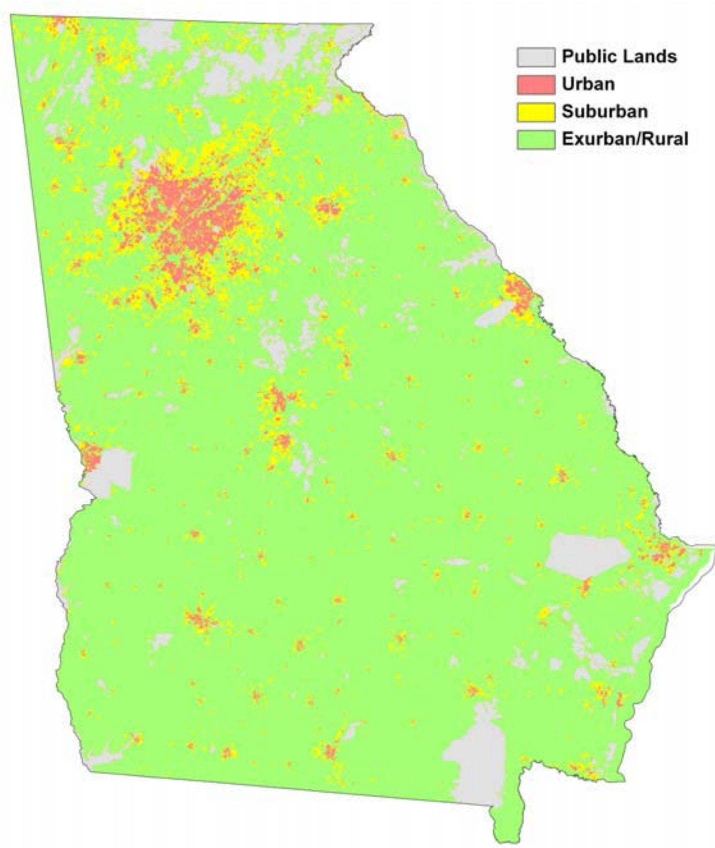

Figure 6. Distribution of Development Status in Georgia.

Geographic Region

In addition to Development Status, we considered Geographic Region as one characteristic of the social aspects of forest ecosystems. We divided the state into three **Geographic Regions: North Georgia, Middle Georgia, and South Georgia**, based on counties. These regions are based on an aggregation of the Survey Units considered by the Forest Inventory Analysis (Harper et al. 2009). Table 10 shows the FIA survey units and counties that correspond to each of our three regions. Differences in attitudes and preferences of the population across regions could affect the per-acre value of ecosystem services, particularly scenic and non-use values.

Table 10. Counties by Geographic Region.

Region	Corresponding FIA Unit	Counties
North Georgia	North and North Central Survey Units	Banks, Barrow, Bartow, Carroll, Catoosa, Chattooga, Cherokee, Clarke, Clayton, Cobb, Coweta, Dade, Dawson, DeKalb, Douglas, Elbert, Fannin, Fayette, Floyd, Forsyth, Franklin, Fulton, Gilmer, Gordon, Gwinnett, Habersham, Hall, Haralson, Hart, Heard, Henry, Jackson, Lumpkin, Madison, Meriwether, Murray, Newton, Oconee, Oglethorpe, Paulding, Pickens, Polk, Rabun, Rockdale, Spalding, Stephens, Towns, Troup, Union, Walker, Walton, White, Whitfield
Middle Georgia	Central Survey Unit	Baldwin, Bibb, Bleckley, Burke, Butts, Calhoun, Chattahoochee, Clay, Columbia, Crawford, Dougherty, Glascock, Greene, Hancock, Harris, Houston, Jasper, Jefferson, Jones, Lamar, Lee, Lincoln, Macon, Marion, McDuffie, Monroe, Morgan, Muscogee, Peach, Pike, Pulaski, Putnam, Quitman, Randolph, Richmond, Schley, Stewart, Sumter, Talbot, Taliaferro, Taylor, Terrell, Twiggs, Upson, Warren, Washington, Webster, Wilkes, Wilkinson
South Georgia	Southwest and Southeast Survey Units	Appling, Atkinson, Bacon, Baker, Ben Hill, Berrien, Brantley, Brooks, Bryan, Bulloch, Camden, Candler, Charlton, Chatham, Clinch, Coffee, Colquitt, Cook, Crisp, Decatur, Dodge, Dooly, Early, Echols, Effingham, Emanuel, Evans, Glynn, Grady, Irwin, Jeff Davis, Jenkins, Johnson, Lanier, Laurens, Liberty, Long, Lowndes, McIntosh, Miller, Mitchell, Montgomery, Pierce, Screven, Seminole, Tattnall, Telfair, Thomas, Tift, Toombs, Treutlen, Turner, Ware, Wayne, Wheeler, Wilcox, Worth

Table 11. Private forest area by Geographic Region.

Geographic Region	Population (2009 US Census)	Acres	Percent of all private forests
North Georgia	6,696,788 (68%)	5,793,381	26%
Middle Georgia	1,556,849 (16%)	6,826,896	31%
South Georgia	1,575,574 (16%)	9,484,341	43%
Total	9,685,744	22,104,618	100%

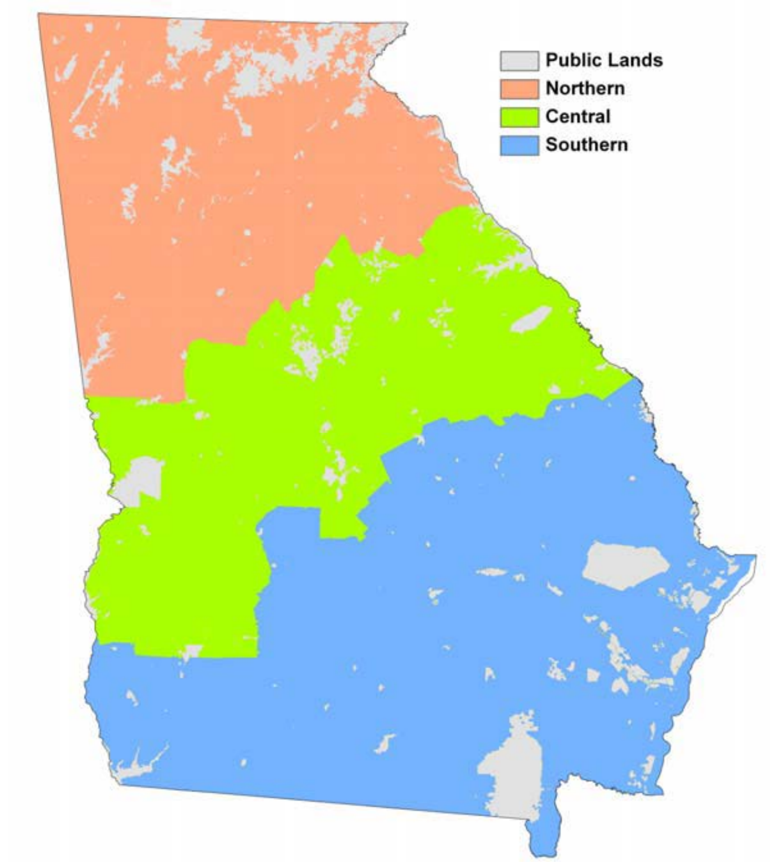

Figure 7. Geographic Regions.

Summary of Landscape Classification

Geospatial data layers were obtained through the Georgia GIS clearinghouse (http://www.gis.state.ga.us/) and projected into a common coordinate system (UTM NAD83 Zone 17). Vector layers were processed to select the appropriate attribute values and converted to raster layers at 30m cell resolution. Table 12 summarizes the data source, relevant attributes, and processing notes for the eight data layers used. Combining the forest and public/private data layers, we identified 22,104,618 acres of privately-owned forestland in Georgia. This represents almost 60% of the total land area in the state. Considering the scale of the analysis, this is almost identical to the estimate of 24.2 million acres reported in the Forest Inventory Analysis (Harper et al. 2009), supporting the accuracy of our analysis.

Based on the seven forest characteristics identified above, we identified 864 possible combinations of characteristics that might describe Georgia's private forests. These characteristics define much of the important variation in ecosystem service flow and value. In applying this classification scheme, we move from an intractable problem (trying to evaluate each of the 22 million acres of private forests separately) to a complex, but manageable one. For a given combination of forest characteristics (eg., mixed forests in North Georgia, riparian, high wildlife, non-roadside, non-public buffer, and urban), we assume each acre of forest with those characteristics produces an identical flow of ecosystem service value. However, forests with different characteristics can have different per-acre values. This is an improvement over most previous studies of this type that allow for just a few different types of forests (and often consider all forest acres as identical).

Not all classes are equally represented by Georgia's private forests. For example, there are no private forests in Georgia that are characterized as riparian, with low species abundance, are visible from a highway, buffer public land, and are in an urban area of south Georgia. Of the 864 potential classes of forests, 65 include no private forestland in Georgia, and an additional 547 classes describe fewer than 1000 acres each. In contrast, over 12% of all forests in Georgia fall in a single class (rural, south Georgia, evergreen, not riparian, not roadside, not public buffer, low wildlife).

Table 12. Summary of GIS Data Sources

Layer	Source, Date & Scale	Attributes	Processing
Private/ Public Land	Georgia Gap Stewardship layer, NARSAL, 2003, 1:24,000	Owner_code	All federal, state, county, DNR, and DOD_COE lands coded as Public, all other lands within state boundaries coded as Private; converted to 30m raster
	Georgia Department of Natural Resources (DNR) lands, 2009, 1:24,000	Owner_code	
	Department of Defense, Army Corps of Engineers (DOD_COE) lands; Georgia Natural Heritage Program, 2005, 1:24,000	Owner_code	
Forest Type	2005 GLUT (Georgia Land Use Trends), NARSAL, 2005 1: 100,000	Deciduous (41), Coniferous (42) and regenerating (31), Mixed (43), Forested Wetland (91)	
Riparian Status	DLG hydrography polygons and lines, 1996, 1:100,000	Major1	Converted to 30m raster, included 30 m (1 pixel) adjacent to water
Rare Species Abundance (Rare Species Records)	USGS 1:24,000 quarter quad	Showing number of spp (animal, plant) that are in that quad that are of conservation concern (R, T, E)0-5: Low; 6-11: Medium; >11: High	Converted to 30m raster
Scenic Visibility (Major Roads)	Georgia DOT, 1996, 1:100,000	Type = interstate, ramp, state highway, collector-distributor, county roads	Converted to 30m raster
Public Land Buffer		90 m (3 pixels) surrounding all public lands	
Development Status	Wildlands-Urban Interface, 2000 Census Blocks, 1:24,000	HDEN00 = housing density per km2 in 2000	1) Urban (>120 units per km2), 2)suburban (25-120 units/km2), 3) rural - exurban put into rural (<25 units/km2); converted to 30m raster
GA Regions	Georgia Counties		Converted to 30m raster

Part 3: Value Transfer

The third step of our approach is to use best available methods to estimate average per-acre values for each category of forestland identified by a unique combination of characteristics. In general, the best available approach is through a combination of methods that rely on data specific to the study area and research question. This might be done in a piece-wise manner, estimating separate values for each ecosystem service provided, using the appropriate methods from those described in Part 1 of this report. Time and budget constraints often limit our ability to collect original data for all aspects of ecosystem services. An alternative approach is to use value transfer methods to apply estimates from previous studies to the current study. Value transfer is inferior to original data collection, but is a common and acceptable alternative (Liu et al. 2010).

We take a two-pronged approach to estimating per-acre ecosystem service values. We developed a stated choice survey to collect original data to estimate aesthetic and non-use values of our study area. Relative to other ecosystem services, these values are most dependent on the tastes and preferences of the local population and therefore the most problematic for value transfer. For the other ecosystem services of interest which are relatively less dependent on the tastes and preferences of the local population, we relied on transferred values. This part of the report describes the value transfer procedures and results, while Part 4 describes the survey methods used to estimate aesthetic and non-use values.

General Value Transfer Protocol

Consistent with the standard practice for value transfer, we considered only published, peer-reviewed literature in our search. Our initial review of the literature identified two general types of studies that we might consider: those with original analysis and those that conduct value transfer and synthesize other reports. The study most similar to ours is that by Liu et al. (2010) who estimated the ecosystem service values of New Jersey's different ecosystems. This paper considers a similar geographic region to Georgia and provides per-acre value estimates broken down by ecosystem service. Other examples of this type of study are Costanza et al. (1997) and Troy and Wilson (2006).

For each ecosystem service considered, we began with a preliminary estimate of the per-acre value based on the values reported in Liu et al. (2010). We then carefully considered the sources used to generate that value. We removed some source estimates, reestimated others to better apply to the population and area of Georgia, and considered other original studies identified that were relevant. These original studies were identified though the ENVI and EconLit databases. From this process, we estimate the average per-acre value of each service by forest characteristics and also identify areas of much needed research. Table 13 summarizes these values. Appendix A provides a list of all studies used in our value transfer analysis. The remainder of Part 3 provides details of this analysis.

Table 13. Summary of Value Transfer Analysis

Ecosystem Service	$/acre/year in 2009 US$
Gas and climate regulation: These estimates are based primarily on studies looking at carbon storage and avoided climate change damages. The studies of urban forest values also consider other pollutants.	$381 for urban forests $28 for other
Water regulation and supply: Includes flood damage protection, water quality improvements, and impacts on water supply	$8,196 for urban and suburban forested wetland $4,635 for rural forested wetland $1,728 for riparian, non-wetland $7 for non-riparian, non-wetland urban $0 for non-riparian, non-wetland rural and suburban (due to lack of available data)
Soil formation: While some information is available, it is very case specific and not reliably applied to our project	No data available
Pollination: This estimate is based on a single study from Sweden.	$184 for non-wetland forests $0 for wetland forests (due to lack of available data)
Habitat/refugia: These estimates are based on studies using stated value methods, with most looking at biodiversity in general in relatively diverse areas.	$251 for evergreen forests in Middle and South Georgia with middle or high rare species abundance; $223 for other forests with middle and high rare species abundance; $28 for evergreen forests in Middle and South Georgia with low rare species abundance; $0 for other low rare species abundance
Aesthetic and Non-use value	Will come from survey data

Gas and climate regulation

Liu et al. (2010) report per-acre values of $60/year for forest areas and $336/year for urban greenspace (both in 2004 US$). The value for forests is based on 31 point estimates from 14 different published papers. Most of these sources use marginal product estimation, estimating the value of carbon stored as the net present value of avoided damage and other social costs in the future. These estimates are highly sensitive to the discounting model applied to future social costs (Atkinson and Gundimeda 2006). Our review of additional recent literature in this area found a wide range of estimates of the value of carbon stored, typically presented as a value per metric ton of carbon ($/tC). In their discussion of this previous work, Atkinson and Gundimeda (2006) suggest that estimates based on "first-generation" climate damage models (such as Fankhauser 1994) are often over-estimates. Atkinson and Gundimeda conclude that a value of $21/tC is a reasonable estimate of the social cost of carbon, and consider a range from $5/tC to $42/tC to be reasonable bounds on the possible range (all adjusted to 2009 US$).

The 2008 Georgia Forest Inventory and Analysis (USDA FS 2008) estimates Georgia's private forest land contains 426,496,939 tC, or approximately 19 tC/acre. Applying Atkinson and Gundimeda's estimated value of $21/tC, we estimate the value of carbon stored in Georgia's private forests is $404/acre (2009 US$), or $28/acre/year assuming a 7% discount rate. We apply this value to all non-urban forests.

An alternative approach to estimating the social value of carbon is to look at the trading price from existing carbon markets. For example, while it was in operation, the Chicago Climate Exchange (CCX) posted a mean price of $2.1 per metric ton of CO_2, with a historic range of $0.05 to $7.4/t$CO_2$. (1 tC ≈ 3.664 t$CO_2$). However, the closure of the CCX and the voluntary nature of all trading on that market limit the reliability of these values as estimates of the true social cost.

While carbon storage dominates the literature in this area, forests provide additional gas and climate benefits beyond carbon storage. This is most often illustrated in the literature on urban green spaces, where these other benefits are relatively more important do to the larger human health issues and relative scarcity of green space. Liu et al. (2010) base their value for urban green space on three estimates from two different studies. Our review of these sources and an additional paper by McPherson et al. (1997), indicate that the Liu et al. estimates are the most reasonable given the available data. Adjusted to 2009$, we apply a value of $381/acre/year to urban forests for gas and climate regulation.

Water regulation and supply

Liu et al. (2010) reports separate values for water regulation, disturbance regulation (i.e., flood control), and water supply. The combined value for water regulation and supply reported in their study is $8,118 for freshwater wetlands, $2,009 for riparian buffer, and $9 for forests (all in 2004 US$). We consider each landcover type in turn.

Wetlands

Liu et al. base their value for wetlands on seven estimates from six separate studies. However, several of those estimates are not applicable to our study. For example, two of the studies consider the water quality benefits to recreation users which is outside the scope of our study. Also, some of the estimates are applicable only to certain types of wetlands. For example, an estimate of the value of flood protection from Thibodeau and Ostro (1981) is based on analysis of damage estimates from urban and suburban areas. We did not find it was reasonable to transfer these values to rural forests where flood damage costs are typically lower due to less built infrastructure. Table 14 summarizes the results of our review, adjusted to 2009 US$. We apply these values to all Rural and non-Rural forested wetlands.

Table 14. Value per acre, per year of wetland forests

Service component	Rural Wetlands	Urban and Suburban Wetlands
Flood Control		$4,717 (1)
Pollution Treatment	$3,479 (1)	$3,479 (1)
Water Supply	$1,157 (2)	
Total	$4,636 (3)	$8,196 (2)

Numbers in parenthesis are the number of estimates our values are based on.

Riparian Buffer

Liu et al. base their estimates for flood protection and water supply from the riparian buffer on 11 estimates from eight separate studies. We found only four of these estimates applicable to our study. Others were either based on travel-cost estimates of recreation users, or specific to a very localized area, such as a specific estuary in California that was not reasonably transferable to all riparian forests in Georgia. The mean value of these four estimates, adjusted to 2009 US$ is $1,728/acre/year. We apply this value to all non-wetland, riparian forests.

Other Forests

Liu et al. report an estimate of water supply value of other forests of $9/acre, however this is based on a travel cost study and not applicable to our current interests. They also report a separate estimate of $6/acre for water regulation from urban green space based on a single study that is applicable to our study. Adjusted to 2009 US$, we apply an estimate of $7/acre for non-wetland, non-riparian urban forests, and $0/acre for non-wetland, non-riparian non-urban forests. We are severely constrained by the available data in this area and consider these estimates to be conservative. Clearly, riparian and wetland forests are likely to have a greater impact on water quantity and quality, we expect that all forest land contributes to these areas in some way. Without additional data, we cannot include them explicitly in our analysis.

Soil formation

Forest vegetation stabilizes soil and prevents erosion. Unfortunately, our review of the peer-reviewed literature provided no estimates of the value of this service that would be transferable to our study. We considered both the summary analyses of Liu et al. (2010), Costanza et al. (1997), and Troy and Wilson (2006), and our search of more recent literature. This doesn't mean the value is zero. Soil erosion fills ditches and reservoirs, damages roads, and threatens water quality and fish habitat. Removing this sediment or otherwise abating the damage can be very expensive. Forestlands prevent society from having to pay these costs. Krieger's (2001) review of this literature indicated the costs of dealing with sedimentation range of values from $1.94/ton of sediment in the Little Tennessee River Basin in the southeastern U.S. to $5.5 million/year in the Willamette Valley of Oregon. However, since these estimates are very site specific we can not reasonably convert them to average $/acre/year values. As such, our estimate of the value/acre of ecosystem services is a lower bound estimate. When considering ecosystem services of smaller scale projects, it is important to consider the impact of forests, particularly riparian forests, on soil formation.

Pollination

Liu et al. (2010) identify one estimate of the pollination value of forests and we were unable to find additional estimates in the more recent literature. This estimate is based on upland forests and so we apply the value, $184/acre/year (2009 US$), only to non-wetland forests.

Habitat/refugia

Liu et al. (2010) report forest habitat/refugia values of $923/acre/year (2004 US$) based on 8 estimates from 5 separate studies. All of these studies were based on CV estimates. Unfortunately, none of the estimates identified by Liu et al. are appropriate for transfer to our study due to differences in the population surveyed (e.g., European populations might have very different preferences for natural resource management) and the ecosystem of interest (e.g., one study looked at an area of mixed grassland, forests, and range, rather than just forestland).

Our broader search of the literature identified three other relevant studies. Two related to biodiversity in the Pacific Northwest (Garber-Yonts et al. 2004; Xu et al. 2003) and one related to red-cockaded woodpecker habitat in Mississippi (Grado et al. 2009). Garber-Yonts et al. and Xu et al. both use stated choice experiments to estimate the value of improved biodiversity levels in the Pacific Northwest. They report their estimates in terms of mean $/household for residents of the region. Xu et al. estimate separate values for urban and rural households. To transfer these values to our study, we first adjust for differences in the size of the forested area (8 – 8.4

million acres in the Pacific Northwest, 22.1 million acres in Georgia) and the population of Georgia (assuming 18% of Georgia population is rural (USDA ERS 2010)). The results of this transfer suggest values of $322 and $123/acre/year from the Xu et al. and Garber-Yonts et al. studies, respectively. The original intent of these two studies was to estimate the value of improved biodiversity. In our current study, we are interested in the stock value of current habitat. To be conservative in this transfer, we apply the full estimated value of $223/acre/year only to forest land identified as Mid and High Rare Species Abundance.

In addition to the two general biodiversity studies, we identified one study specific to an important endangered species found in some portions of Georgia. Grado et al. (2009) estimate the opportunity cost of managing for red-cockaded woodpecker (RCW) habitat on nonindustrial private forests in Mississippi to range from $7 to $42/acre/year depending on the quality of the habitat for the RCW. We apply an average of these values ($28/acre/year) to evergreen forests in Middle and South Georgia, the primary potential habitat of the RCW. A summary of our wildlife/refugia values is given in Table 15. Note that we consider these to be lower bounds on the true estimates as the estimates do not consider all aspects of habitat value. We expect every acre to provide some positive value for this ecosystem service, however we are constrained by the available data and prefer to underestimate the true value than overestimate.

Table 15. Summary of wildlife/refugia values. ($/acre/year 2009 US$)

	Evergreen forests in middle and south GA	Other forest types
Low Rare Species Abundance	28	0
Middle and High Rare Species Abundance	251	223

Aesthetic and non-use value

While there are many estimates of the aesthetic and non-use value of different types of forests, most are estimated in conjunction with the recreation values, which we do not include in our analysis because these are use values which require access to the land. This is outside the scope of our current project. We did find some studies looking specifically at aesthetic values of pine plantations in the southeast (e.g., Gan et al. 2000; Buhyoff et al. 1986; Young and Wesner 2003). These studies primarily rely on interviews and surveys using pictures of different viewsheds and consider the effect of management activities such as thinning or clear cutting on self-reports of aesthetic value and do not generally involve an economic tradeoff. Because our forest type data is aggregated to general forest type (evergreen vs. deciduous), we could not reasonably transfer the results to our study. For this reason, we rely on data from our stated choice to estimate the aesthetic and non-use values. This process is described in Part 4 of this report.

Summary and Discussion of Value Transfer Protocol

As the above discussion illustrates, all forests are not equal. That is, they do not necessarily produce the same flow of ecosystem service values. Per-acre values range from $212 to $8,800/year depending of the characteristics of the forest. Because of this variation in per-acre value, it is not always clear *a priori* which class of forest produces the greatest value of ecosystem services. Table 16 through Table 18 present the number of acres, the average per-acre value, and the total value of each combination of forest characteristics. As the tables show, despite the fact that forested wetlands comprise only 16% of all private forestland in Georgia, they provide 66% of the value of the ecosystem services considered so far (not including

Aesthetic and Non-use). This reflects the vital role wetlands play in the maintenance of healthy watersheds.

Table 16. Estimated values for Evergreen Forests by forest characteristics, without aesthetic.

Rare Species Abundance	Riparian Status	Development Status	Region	Acres	$/acre/year	Total Value ($/year)
Low Rare Species Abundance	not riparian	urban	N	83,878	572	47,978,216
			M & S	21,244	600	12,746,400
		suburban & rural	N	1,372,430	212	290,955,160
			M & S	5,725,491	240	1,374,117,840
	riparian	urban	N	9,139	2,293	20,955,727
			M & S	2,092	2,321	4,855,532
		suburban & rural	N	96,252	1,940	186,728,880
			M & S	526,922	1,968	1,036,982,496
Mid and High Rare Species Abundance	not riparian	urban	N	30,328	795	24,110,760
			M & S	35,344	823	29,088,112
		suburban & rural	N	512,626	435	222,992,310
			M & S	3,114,401	463	1,441,967,663
	riparian	urban	N	3,142	2,516	7,905,272
			M & S	4,321	2,544	10,992,624
		suburban & rural	N	43,031	2,163	93,076,053
			M & S	349,229	2,191	765,160,739
All Evergreen Forests				**11,929,870**		**5,570,613,784**

Table 17. Estimated values for Deciduous and Mixed Forests without aesthetic.

Rare Species Abundance	Riparian Status	Development Status	Acres	$/acre/year	Total Value ($/year)
Low Rare Species Abundance	not riparian	urban	75,801	572	43,358,172
		S & R	3,690,483	212	782,382,396
	riparian	urban	13,467	2,293	30,879,831
		S & R	507,407	1,940	984,369,580
Mid and High Rare Species Abundance	not riparian	urban	44,409	795	35,305,155
		S & R	1,975,879	435	859,507,365
	riparian	urban	7,021	2,516	17,664,836
		S & R	268,106	2,163	579,913,278
All Deciduous and Mixed Forests			**6,582,573**		**3,333,380,613**

Table 18. Estimated values for Forested Wetlands by forest characteristic, without aesthetic.

Rare Species Abundance	Riparian Status	Development Status	Acres	$/acre/year	Total Value ($/year)
Low Rare Species Abundance	not riparian	urban	7,176	8,577	61,548,552
		suburban	33,059	8,224	271,877,216
		rural	971,481	4,663	4,530,015,903
	riparian	urban	6,918	8,577	59,335,686
		suburban	28,952	8,224	238,101,248
		rural	1,001,060	4,663	4,667,942,780
Mid and High Rare Species Abundance	not riparian	urban	6,938	8,800	61,054,400
		suburban	27,639	8,447	233,466,633
		rural	723,975	4,886	3,537,341,850
	riparian	urban	4,354	8,800	38,315,200
		suburban	23,194	8,447	195,919,718
		rural	757,428	4,886	3,700,793,208
All Forested Wetlands			**3,592,174**		**17,595,712,394**

In addition to the value estimates presented, this section of the analysis identifies several areas where additional research is needed, either to better understand the ecological production of an ecosystem service, the economic value of that service, or to create links between these two areas. Where we were unable to find information, we were forced to apply a value of $0/acre. This leads to a conservative estimate of the total value of the forested land but in certain locations where these other values are significant, this omission could have important policy implications.

Part 4: Stated Choice

Value transfer for aesthetic, cultural, and non-use values is more problematic because these values depend on both the characteristics of the resource itself and the tastes and preferences of the population. Instead, we base our estimates of aesthetic and non-use values on analysis of data collected specifically for this study using a stated choice approach. This section describes the survey instrument and administration, presents summary data from the survey, and provides the estimated aesthetic and non-use value of Georgia's private forests.

Survey Design and Administration

We conducted a mail survey of the general population of Georgia during summer and fall 2010. The survey contained background information on forests and ecosystem services and asked respondents about their familiarity with Georgia's forests, recreation activities, general questions about the environment, preferences for public regulation of forested land, and sociodemographic characteristics. In addition, each respondent was asked four questions as part of the stated choice experiment. In these questions, the respondents were invited to participate in a hypothetical referendum. They were told that a referendum was up for vote that would affect the future of Georgia's private forests. They were presented with two alternative futures in each question. Each alternative was described in terms of the gain or loss of forest area in each of the three Geographic Regions in the state. In addition, each region was assigned one of four possible Public Priorities: Wildlife, Scenic Views, Water Quality and Quantity, or No Public Priority. If a Public Priority was identified for a particular region, that meant that future land use planning would place higher priority on protecting forested land that was most important for that goal (e.g., if Scenic Views is a priority, forests along roads would be considered a greater conservation priority than other forests). The survey emphasized that we were only considering private forest land, and that private landowners would still have decision-making authority regarding their land. Regardless of their selection, respondents would not have access to additional forestland in the future. An example of a stated choice section of the survey is provided in Appendix B.

The basic premise of conjoint analysis is that while each question is a "simple" comparison between two or more alternatives, by asking many different questions with different combinations of attributes for each option, the analyst can apply standard discrete-choice modeling techniques to estimate the marginal value of the various attributes. In our survey, each alternative (or a possible future state of Georgia's forests) was defined by seven different attributes: Forested Acres and Public Priority in each of the three Geographic Regions (6 attributes total), plus the cost of the option to the household in terms of estimated increase in the price of wood products, taxes, utilities, and other expenses. The six regional attributes were allowed to take on one of four possible values (called attribute levels in the conjoint literature), and the cost attribute was assigned one of eight values. Table 19 summarizes the attributes and attribute levels used in our survey.

With six 4-level attributes and one 8-level attribute, there are 32,768 ($= 4^6 \cdot 8^1$) possible combinations of attributes, or alternatives. Our survey presented a choice between two alternatives creating over 1 billion possible questions. (This would be a full factorial design). Because it isn't possible to ask this many questions, the conjoint analysis literature provides guidance in identifying which subset of these questions should be asked in order to most efficiently estimate the model of interest (these subsets are known as fractional factorial designs; see Louviere, Henshcher and Swait (2000) for an introduction to experimental design). We used the software program NGENE to create an orthogonal main-effects experimental design that required only 32 different choice questions (64 distinct profiles). These 32 questions were blocked into 8 groups so that each survey respondent was asked four different choice questions. As a result, there were 8 different versions of the survey instrument. These versions were identical except for the stated choice questions themselves.

Table 19. Attributes and levels for stated choice experiment.

Attribute	Levels
North Georgia Acres	-2%, no change, +2%,+5%
North Georgia Priority	Wildlife, Scenic, Water, No Priority
Middle Georgia Acres	-2%, no change, +2%,+5%
Middle Georgia Priority	Wildlife, Scenic, Water, No Priority
South Georgia Acres	-2%, no change, +2%,+5%
South Georgia Priority	Wildlife, Scenic, Water, No Priority
Cost (per year to household)	$0, $10, $25, $50, $75, $100, $200, $500

A sample of 3100 names and addresses was purchased from Survey Sampling, Inc. A pretest subsample of 100 was randomly selected from the purchased list. The pretest group was mailed a preliminary version of the survey. Some questions were revised based on the pretest responses. The final sample of 3000 was stratified by Geographic Region, so that 1000 surveys were sent to each of the three regions: North, Middle, and South Georgia. This was done to provide adequate coverage outside the metro Atlanta area. Within each region, each recipient was randomly assigned one of the eight versions of the survey so that each version was stratified by region as well. Following a modified Dillman method (Dillman 2006), we made three contacts: the initial mailing including cover letter and survey, a follow-up thank you/reminder postcard to everyone, and a third mailing to non-respondents including another copy of the survey. A fourth contact (third survey mailing) was not done because the effect of the second mailing was minimal.

Table 20 shows the sample size, non-deliverables and response rate by Geographic Region. Overall, the response rate was 28%. We found no significant difference in response rate across regions, or across the eight versions of the survey.

Table 20. Response Rate by Region.

Region	Mailed	Undeliverable	Returned	Response Rate
North Georgia	1000	72	270	29%
Middle Georgia	1000	88	262	29%
South Georgia	1000	72	248	27%

Summary of Survey Data

In addition to the questions related to the choice experiment, the survey gathered data on respondents' experiences with forestland in Georgia, general attitudes about forests and the forest industry, and basic demographic data. Table 21 and Table 22 describe the respondents and their experience with Georgia's forests. Respondents from the three regions are similar in age and gender composition, but respondents from middle and south Georgia are more likely to be from rural areas, and report slightly lower median education and income levels. In addition, respondents from the different regions have different rates of forest ownership and different rates of participation in different forest-related recreation. These differences support our decision to estimate different WTP values for residents in the three different regions.

Table 21. Sociodemographic characteristics of the survey respondents by Region.

Characteristic	North Georgia	Middle Georgia	South Georgia
Mean Age	55 years	57 years	55 years
Percent female	36%	36%	36%
Development Status of "area where respondent grew up"	44% Rural 40% Suburban 16% Urban	56% Rural 33% Suburban 11% Urban	65% Rural 23% Suburban 11% Urban
Median education level	Bachelor's degree completed	Some college or tech school	Some college or tech school
Median income category	$60,000 to $69,999	$50,000 to $59,999	$50,000 to $59,999

Table 22. Experience with Georgia's forests by Region.

	North Georgia	Middle Georgia	South Georgia
% who own at least 1 acre of land with some tree cover in Georgia	36% (median 2 acres)	38% (median 3 acres)	44% (median 5 acres)
% of landowners who carry our regular thinning, pruning, or planting	10%	14%	17%
Visited public forests in past 12 months	60%	47%	49%
Not visited any forests in past 12 months	27%	37%	36%
Often hunt in Georgia	8%	21%	23%
Often hike, bike or camp in Georgia	24%	16%	20%
Often bird or wildlife watch in Georgia	19%	18%	18%
Often fish in Georgia	14%	18%	31%
Often swim or boat in Georgia	14%	19%	26%
Often drive through large forested areas	42%	45%	48%

Overall, respondents reported changes in the landscape in their area. 63% of respondents feel the beauty of the landscape in their area has changed over the years due to tree cutting. 34% of respondents thought the area devoted to pine forests in their local area is decreasing, and 40% reported the area devoted to hardwood forests is decreasing. These rates are much lower than those reported in a 1997 telephone survey of Georgia residents in which 54% thought pine coverage was decreasing and 63% thought hardwood forests were decreasing (Harrison, Newman and Macheski 1997). In addition, 65% of respondents have concerns or apprehensions about the way forests in Georgia are being managed. The most frequently identified concern is loss of wildlife habitat (47% of all respondents).

Respondents were mixed in their view of private property rights. Only 45% of respondents agreed with the statement "I trust Georgia's forest owners to maintain healthy forests in the long term." When asked if they agree that there are enough checks and balances in place to ensure responsible forest management in Georgia, 24% of respondents agreed, 45% were neutral, and 27% disagreed. Only 28% of respondents felt that private forest owners have the right to do as they please with their forests regardless of what it does to the environment. 58% said private property rights should be limited if necessary to protect the environment but 68% said that the landowner should be paid for any economic loss accrued when prevented from cutting on his land because of government regulations.

When asked about different types of compensation programs, only 41% would support a program that required forest landowners to comply with regulations designed to provide benefits for the public. But 55% would support a program that provided tax-funded incentives for forest landowners to voluntary comply with such regulations and 58% would support a non-tax funded incentive.

Aesthetic and Non-Use Value Estimates

The economic theory underlying the stated choice method is the Random Utility Model (RUM), where utility is assumed to consist of two components, so that utility individual *i* receives by choosing (or consuming) alternative *j*, is given by

$$U_{ij} = V_{ij}(x_j;\beta) + \varepsilon_{ij}$$

where V_{ij} is the deterministic portion of utility based on a vector of alternative specific attributes X_j and preference parameters β; and ε_{ij} is the random component of utility, known to the respondent but unobservable by the analyst. Faced with a choice between two (or more) alternatives, the respondent chooses alternative *j* if and only if the utility of doing so is greater than the utility of any other option in their choice set. Assuming ε_i is a randomly distributed across alternatives with a Gumbel distribution with scale parameter equal to 1, we can model the probability of choosing alternative *j* with a standard multinomial logit model (MNL), so that

$$\begin{aligned}\Pr\left(\text{choosing alternative } J \mid \text{choice set } C\right) &= \Pr\left(U_j > U_k; k \in C, k \neq j\right) \\ &= \Pr\left(V_j + \varepsilon_j > V_k + \varepsilon_k; k \in C, k \neq j\right) \\ &= \frac{e^{V_j}}{\sum_{k \in C} e^{V_k}}\end{aligned}$$

For our data, we are interested in the marginal value of an acre of forested land and how this value depends on the characteristics of the forest. We model the deterministic part of utility as follows

$$\begin{aligned}V_j = {} & \beta_1 AreaNG_j + \beta_2 AreaMG_j + \beta_3 AreaSG_j \\ & + \beta_4 WildNG_j * AreaNG_j + \beta_5 WaterNG_j * AreaNG_j + \beta_6 RoadNG_j * AreaNG_j \\ & + \beta_7 WildMG_j * AreaMG_j + \beta_8 WaterMG_j * AreaMG_j + \beta_9 RoadMG_j * AreaMG_j \\ & + \beta_{10} WildSG_j * AreaSG_j + \beta_{11} WaterSG_j * AreaSG_j + \beta_{12} RoadSG_j * AreaSG_j \\ & + \beta_y Cost_j\end{aligned}$$

where the variables *AreaNG*, *AreaMG*, and *AreaSG* are the percent change in forestland in North, Middle, and South Georgia, respectively, and the Public Priority for each region is effects-coded into three variables per region as described in Table 23.

Table 23. MNL variable names and descriptions.

Variable name	Description
AreaNG, *AreaMG*, *AreaSG*	Percent change in forest land in North, Middle, and South Georgia respectively
WildNG, *WildMG*, *WildSG*	= 1 if wildlife is the regional priority = -1 if there is no regional priority = 0 otherwise
WaterNG, *WaterMG*, *WaterSG*	= 1 if water is the regional priority = -1 if there is no regional priority = 0 otherwise
RoadNG, *RoadMG*, *RoadSG*	= 1 if scenic roads are the regional priority = -1 if there is no regional priority = 0 otherwise

Using this specification and variable coding scheme, an individual's marginal willingness to pay (WTP) for a 1% increase in forest area can be estimated from the coefficients. For example, individual *i*'s marginal WTP for a 1% increase in forestland in North Georgia with priority on wildlife protection is simply

$$\text{marginal WTP}_{\text{i}}(\text{north GA, wildlife}) = \frac{\beta_1 + \beta_4}{\beta_y}$$

where the coefficient on the cost variable, β_y, is the marginal utility of income. The use of effects coding with No Priority as the baseline, means that under no public priority, individual *i*'s marginal WTP for forestland in North Georgia is given by

$$\text{marginal WTP}_{\text{i}}(\text{north GA, no priority}) = \frac{\beta_1 - \beta_4 - \beta_5 - \beta_6}{\beta_y}$$

Because we expect individual tastes and preferences related to forest benefits to vary by region, we estimated separate MNL models for individuals living in each geographic region. All regressions were run using Limdep 9.0 and NLOGIT 4.0.

Table 24. Individual Marginal WTP by region and priority.

Geographic Region where forestland is added	Priority	Marginal WTP for individual living in North GA ($/year)	Marginal WTP for individual living in Middle GA ($/year)	Marginal WTP for individual living in South GA ($/year)
North GA	No Priority	15	0	0
	Wildlife	39	0	0
	Water	50	26	31
	Roads	17	10	16
Middle GA	No Priority	11	19	7
	Wildlife	35	30	7
	Water	35	16	6
	Roads	25	30	12
South GA	No Priority	6	3	0
	Wildlife	0	26	33
	Water	14	10	30
	Roads	0	6	3

Table 24 shows the marginal WTP for different priorities for individuals living in each region. Each column represents an "average" person living in north, middle or south Georgia. For example, we estimate that an individual living in north GA would be willing to pay $15/year for an increase in forestland in north GA, but only $11/year for an increase in middle GA and only $6/year for an increase in south GA. We make two important observations from this table. First, individuals report a positive WTP for forestland across the state, but do have a higher WTP for forestland in their own geographic region. Second, people generally pay a premium for water and wildlife priorities. The effect of prioritizing forested roads was less clear.

The values given in Table 24 are $/household/year for a 1% increase in area. To incorporate this information into our larger analysis, we need to convert these values to $/acre/year. We do this in three steps. First, divide each value by the number of acres represented by a 1% increase in forested area for that region to get $/household/acre/year. Then, multiply by the estimated number of households in the region based on 2009 census population estimates and the 2000 census estimate of 2.65 persons per household in Georgia. Finally, sum the value of land from residents of all regions.

Table 25 reports the estimated value of forestland to the residents of Georgia based on forest characteristics. To be as conservative as possible in our estimates, we assumed a Wildlife Priority would only apply to forests included in the High Rare Species category, which is just 7% of all forested land. The per-acre values range from $52/year to $4,642/year depending on the forest characteristics. The total aesthetic and non-use value of Georgia's private forests to the residents of Georgia is almost $11.2 billion/year.

Table 25. Aesthetic and non-use value estimates.

Region	Characteristics	$/acre/year	Acres	Value ($/year)
North Georgia	Riparian	642	4,336,704	2,782,690,720
	Road-buffer	1,695	347,053	588,153,579
	High Wildlife	4,642	708,310	3,287,634,733
	Other	1,882	401,315	755,283,923
Middle Georgia	Riparian	314	5,365,262	1,686,716,322
	Road-buffer	617	278,900	172,207,936
	High Wildlife	481	846,600	407,601,487
	Other	577	336,134	193,850,627
South Georgia	Riparian	54	6,416,865	347,061,827
	Road-buffer	371	855,451	317,690,719
	High Wildlife	342	1,825,377	624,866,608
	Other	52	386,649	20,255,257
		TOTAL	**22,104,618**	**11,184,013,738**

Part 5: Final Results and Discussion

Final Estimates

There are 22.1 million acres of privately owned forestland in Georgia. Our analysis estimates that the value of ecosystem services provided by this land to the public is over $37.6 billion per year. Table 26 breaks this value down by ecosystem service.

Table 26. Total value by ecosystem service.

Ecosystem Service	Total Value ($/year)
Gas and Climate Regulation	744,446,192
Water Regulation and Supply	20,306,463,460
Soil Formation	N/A
Pollination	3,406,289,512
Habitat/refugia	2,042,507,627
Aesthetic and non-use	11,184,013,738
Total	**37,683,720,529**

The value of a particular acre of forest ranges from $264 to $13,442/acre annually. Higher per acre values generally come from forested wetlands or riparian forests in urban areas while lower per-acre values come from non-wetland forests in rural areas. Table 27. Impact of Forest Characteristics on Ecosystem Services summarizes our findings on how forest characteristics impact different ecosystem services.

Table 27. Impact of Forest Characteristics on Ecosystem Services

<table>
<tr><th></th><th>Gas and Climate regulation</th><th>Water regulation and supply</th><th>Soil formation</th><th>Pollination</th><th>Habitat/refugia</th><th>Aesthetic and Non-use</th></tr>
<tr><th>Forest Type</th><td>X</td><td>X</td><td rowspan="7">No Values Available</td><td>X</td><td>X</td><td></td></tr>
<tr><th>Rare Species Abundance</th><td></td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><th>Riparian Status</th><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><th>Scenic Visibility</th><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><th>Public Land Buffer</th><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Development Status</th><td>X</td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><th>Geographic Region</th><td></td><td></td><td></td><td>X</td><td>X</td></tr>
</table>

An “X” indicates the per acre value of that ecosystem service will depend on the forest characteristic indicated.

Our analysis highlights the need for additional work in this area. There are significant gaps in our knowledge of both the impact of forest cover on the production of ecosystem services, and how these services are valued in the state. We were most constrained in our analysis by the lack of information related to non-carbon air quality services, soil formation and stability, and pollination.   In developing future research related to forest ecosystem services, it will be important to take an interdisciplinary approach. A major challenge to this type of work is that the outputs of the ecological models (typically the results of ecosystem processes) rarely match up with the inputs to the valuation models (the ecosystem services). Natural scientists and economists must work together to address this issue.

Significant steps were taken to minimize potential error throughout all aspects of the research. However, due to the complexity of the analysis, there are several potential sources of error in the process. The most likely possible sources of error are measurement error in the creation of the GIS data layers, which we minimized by using standard data sets; estimation error in the original studies used in the value transfer, minimized by using only peer reviewed, published papers; error introduced in the transfer of values to our study, though every effort was made to be as conservative as possible in this process; and error due to sample selection bias in the stated choice survey, though our response rate is typical for this type of study.

These values in context

These estimates should be considered a lower bound estimate of the public value of private forests for three primary reasons. First, we faced significant data limitations in the value transfer part of our project. The value of some ecosystem services could not be explicitly included in our final estimates because there was not enough information available to estimate their value (for example, values of non-endangered but culturally valuable species), or because the benefits occur on a relatively small scale and could not be incorporated at the state-level (for example, values of erosion control and ground water recharge), and habitat for non-endangered, but culturally valuable species. Second, our assignment of forest characteristics is quite conservative. For example, only a 30m riparian buffer was considered and only 7% of all forests were considered High Rare Species Abundance. And third, our assignment of per-acre values was conservative. We applied values only to similar forest types so as not to overestimate values on dissimilar parcels. For example, the estimate of flood damage avoidance services from wetlands was only applied to urban and suburban forests, where flood damage is highest.

Not only should our estimates be considered a lower bound on the public value of private forests, they are only one component of the Total Economic Value of private forests in Georgia. We estimate the indirect use and non-use values of the forests. These are components of value that do not require ownership of or access to the land. Direct use value was not considered in our analysis. Two significant components of the direct use value of Georgia's forests are the value of timber and forest products and recreation. Other research estimates that the economic impact of forest products manufacturing in Georgia is approximately $27 billion per year and the industry related activity employs over 118,000 people (Riall 2010). The other component of direct use value that is significant is the recreation value. We did not consider recreation values because recreation requires access to the land and not all private land allows access. However, private forests play an important role in providing outdoor recreation opportunities in Georgia. Georgia has the most non-resident hunters of any state and these sportsmen spend $1.8 billion/year in the state. The economic impact of angling in Georgia is over $1.5 billion per year (GFC 2008).

As tempting as it is, it would be incorrect to add these estimates of the impact of the forest industry and forest recreation to our estimates of the non-timber benefits. The Total Economic Value of Georgia's private forests includes the direct use value, the indirect use value, and the non-use value. Our research estimates the indirect use value and non-use value to be approximately $37.6 billion/year. The direct use value includes the value of timber and forest products provision and recreation. However, economic impact and economic value measure two different things. The economic impact estimates we identify from the existing literature ($27 billion/year for forest products industry and $1.8 billion/year for recreation) trace the revenue generated by these industries through the state economy. They are not estimates of the total surplus, or total willingness to pay, for these services and so we cannot add them to the indirect use and non-use value we estimated. However, the magnitude of the economic impacts is an indication of how important the forest industry or forest recreation is to the state's economy in terms of revenue and job creation. Georgia's private forests provide the raw materials and location necessary to maintain these activities and best management practices help to ensure the sustainable harvest of this resource. So while we can't simply add the impact of forest recreation and the forest industry to our estimate of the indirect use and non-use values of Georgia's forests, when viewed together this body of research provides an overall view of the importance of forestland to the people of Georgia.

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Appendix B: Example stated choice questions.

This is the stated choice section from one version of the survey. There were eight versions of the survey, each with four different stated choice questions.

Section C: Tradeoffs Among Forest Benefits

This section will ask you a series of questions to better understand how you would make decisions regarding our forest resources.

The four questions in this section will ask you to compare alternative futures for Georgia's privately owned forests. For these questions, consider the possibility that you are voting in a referendum to create a program in which forest landowners might voluntarily participate. This program would provide financial incentives to forest landowner who manage their forestland in particular ways. This program would affect the acres of forested land in the state and possibly identify certain forest characteristics that would be of public priority. The public priority may be one or more of the following characteristics:

Wildlife:	Prioritize management of forests to provide the greatest impact on wildlife.
Scenic Beauty:	Prioritize management of forests along roads and highways in order to provide the best scenic vistas.
Water:	Prioritize management of forests near rivers, streams, and lakes in order to have the the greatest impact on water quantity and quality downstream.
No public priority:	The program does not identify a specific forest attribute as a public priority

In addition to the effect on the acres and attributes of private forests, the incentive program may impose a cost to your household. This cost would be realized through some combination of higher prices for wood products, water, energy, or other products. Remember, that **this is money that your household would not have available for other purposes**. The cost of each alternative is listed in the alternative description. These questions ask you to compare the program attributes and cost and decide which program you would vote for.

IMPORTANT: PLEASE READ

- While the alternatives we are posing are hypothetical choices, please consider them as if you were actually voting in such a referendum.
- Remember that we are referring only to **privately-owned forests**. The private owners have their own private objectives for managing their land. **The alternatives we are presenting would not take the place of these private objectives.**
- None of the alternatives would increase public access to private forests. **The purpose of our study is to identify the value of private forested land to the public.**
- Remember, there are no "right" answers to these questions; we are interested in what you think.

C1. Suppose Georgia residents were voting on a referendum that would result in one of these two alternative futures for Georgia's private forests. No other alternatives are being voted on, and one of these two alternatives WILL BE adopted. Compare the two alternatives and indicate which alternative you prefer.

Alternative A

Region 1: North Georgia
Acres of forested land: - 2%
Public priority: Scenic Beauty

Region 2: Middle Georgia
Acres of forested land: - 2%
Public priority: Scenic Beauty

Region 3: South Georgia
Acres of forested land: no change
Public priority: Water

Cost to your household
in higher prices for wood products, water, energy, or other utilities: **$100 per year**

Alternative B

Region 1: North Georgia
Acres of forested land: - 2%
No public priority

Region 2: Middle Georgia
Acres of forested land: no change
Public priority: Scenic Beauty

Region 3: South Georgia
Acres of forested land: + 2%
Public priority: Wildlife

Cost to your household
in higher prices for wood products, water, energy, or other utilities: **$500 per year**

Which alternative do you prefer?

I prefer....

☐ **Alternative A**

☐ **Alternative B**

C2. Suppose Georgia residents were voting on a referendum that would result in one of these two alternative futures for Georgia's private forests. No other alternatives are being voted on, and one of these two alternatives WILL BE adopted. Compare the two alternatives and indicate which alternative you prefer.

Alternative A

Region 1: North Georgia
Acres of forested land: no change
Public priority: Wildlife

Region 2: Middle Georgia
Acres of forested land: + 5%
Public priority: Wildlife

Region 3: South Georgia
Acres of forested land: + 2%
Public priority: Water

Cost to your household
in higher prices for wood products, water, energy, or other utilities: **$75 per year**

Alternative B

Region 1: North Georgia
Acres of forested land: + 2%
No public priority

Region 2: Middle Georgia
Acres of forested land: + 5%
Public priority: Scenic Beauty

Region 3: South Georgia
Acres of forested land: no change
Public priority: Water

Cost to your household
in higher prices for wood products, water, energy, or other utilities: **$25 per year**

Which alternative do you prefer?

I prefer....

☐ **Alternative A**

☐ **Alternative B**

C3. Suppose Georgia residents were voting on a referendum that would result in one of these two alternative futures for Georgia's private forests. No other alternatives are being voted on, and one of these two alternatives WILL BE adopted. Compare the two alternatives and indicate which alternative you prefer.

Alternative A

Region 1: North Georgia
Acres of forested land: + 5%
No public priority

Region 2: Middle Georgia
Acres of forested land: + 5%
No public priority

Region 3: South Georgia
Acres of forested land: + 2%
Public priority: Wildlife

Cost to your household
in higher prices for wood products, water, energy, or other utilities: **$25 per year**

Alternative B

Region 1: North Georgia
Acres of forested land: + 5%
Public priority: Scenic Beauty

Region 2: Middle Georgia
Acres of forested land: + 2%
No public priority

Region 3: South Georgia
Acres of forested land: no change
Public priority: Water

Cost to your household
in higher prices for wood products, water, energy, or other utilities: **$0 per year**

Which alternative do you prefer?

I prefer....

- ☐ **Alternative A**
- ☐ **Alternative B**

C4. Suppose Georgia residents were voting on a referendum that would result in one of these two alternative futures for Georgia's private forests. No other alternatives are being voted on, and one of these two alternatives WILL BE adopted. Compare the two alternatives and indicate which alternative you prefer.

Alternative A

Region 1: North Georgia
Acres of forested land: + 2%
Public priority: Water

Region 2: Middle Georgia
Acres of forested land: - 2%
Public priority: Water

Region 3: South Georgia
Acres of forested land: no change
Public priority: Wildlife

Cost to your household
in higher prices for wood products, water, energy, or other utilities: **$50 per year**

Which alternative do you prefer?

I prefer....

☐ **Alternative A**

☐ **Alternative B**

Alternative B

Region 1: North Georgia
Acres of forested land: no change
No public priority

Region 2: Middle Georgia
Acres of forested land: - 2%
Public priority: Scenic Beauty

Region 3: South Georgia
Acres of forested land: + 5%
Public priority: Scenic Beauty

Cost to your household
in higher prices for wood products, water, energy, or other utilities: **$0 per year**