Chapter 6
Quantifying Greenhouse Gas Sources and Sinks in Managed Forest Systems

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Acronyms, Chemical Formulae, and Units

BA	Basal area
C	Carbon
CH_4	Methane
cm	Centimeters
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalents
COLE	CarbonOnLineEstimator
CRM	Component ratio method
DBH	Diameter at breast height
DDW	Down dead wood
DOE	Department of Energy
EPA	Environmental Protection Agency
FFE	Fire and Fuels Extension
FIA	Forest Inventory and Analysis
FIADB	Forest Inventory and Analysis Database
FIDO	Forest Inventory Data Online
FOFEM	First Order Fire Effects Model
FVS	Forest Vegetation Simulator model
ft	Feet
g	Gram
GHG	Greenhouse gas
H	Height
ha	Hectare
hp	Horse power
hr	Hour
HW	Hardwood
HWP	Harvested wood products
in	Inches
lbs	Pounds
IPCC	Intergovernmental Panel on Climate Change
m	Meters
mm	Millimeters
Mcf	Thousand cubic feet
N_2O	Nitrous oxide
NO_x	Mono-nitrous oxides
O_2	Oxygen
PW	Pulpwood
SL	Sawlogs
SOC	Soil organic carbon
SSURGO	Soil Survey Geographic database
STATSGO	State Soil Geographic database
SW	Softwood
Tg	Teragrams
UFORE	Urban Forest Effects model
UNFCCC	United Nations Framework Convention on Climate Change
USDA	U.S. Department of Agriculture

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6 Quantifying Greenhouse Gas Sources and Sinks in Managed Forest Systems

This chapter provides guidance for reporting greenhouse gas (GHG) emissions associated with entity-level fluxes from the forestry sector. In particular, it focuses on methods for estimating carbon stocks and stock change from managed forest systems. Section 6.1 provides an overview of the sector. Section 6.2 describes the methods for forest carbon stock accounting. Section 6.3 describes the methods for estimating carbon stocks and stock change from establishing and clearing forest. Section 6.4 describes methods for estimating carbon stocks and stock change from forest management. Section 6.5 describes methods for estimating carbon stocks and stock change from harvested wood products. Section 6.6 describes methods for estimating carbon stocks and stock change from urban forests (i.e., trees outside of forests). Finally, Section 6.7 describes methods for estimating emissions from natural disturbances including forest fires.

6.1 Overview

A summary of proposed methods and models for estimating GHG emissions from managed forest systems is provided in Table 6-1.

Table 6-1: Overview of Managed Forest Systems Sources, Method and Section

Section	Source	Method
6.2.3	Forest Carbon Accounting	Range of options dependent on the size of the entities' forest land including: Forest Vegetation Simulator model with Fire and Fuels Extension (FVS-FFE) (entities that fit the large landowner definition); and default lookup tables (entities fitting the small landowner definition).
6.3.3	Establishing, Re-establishing, and Clearing Forests	Intergovernmental Panel on Climate Change (IPCC) algorithms developed by Aalde et al. (2006). These options use: allometric equations from Jenkins et al. (2003a), or FVS with the Jenkins et al. equations where applicable; and default lookup tables from Smith et al. (2006; GTR NE-343)—default regional values based on forest type and age class developed from FIA data.
6.4.4	Forest Management	Range of options dependent on the size/management intensity/data availability of the entity's forest land including: FVS-FFE with Jenkins (2003a) allometric equations; Default lookup tables of management practice scenarios; and FVS may be used to develop a supporting product providing default lookup tables of carbon stocks over time by region; forest type categories, including species group (e.g., hardwood, softwood, mixed); regeneration (e.g., planted, naturally regenerated); management intensity (e.g., low, moderate, high, very high); and site productivity (e.g., low, high).
6.5.2	Harvested Wood Products	Method uses U.S.-specific harvested wood products (HWPs) tables. The HWPs tables are based on WOODCARB II model used to estimate annual change in carbon stored in products and landfills (Skog, 2008). The entity uses these tables to estimate the average amount of HWP carbon from the current year's harvest that remains stored in end uses and landfills over the next 100 years.
6.6.3	Urban Forests	Range of options depends on data availability of the entity's urban forest land. These options use: i-Tree Eco model (http://www.itreetools.org) to assess carbon from field data on tree populations; and i-Tree Canopy model (http://www.itreetools.org/canopy/index.php) to assess tree cover from aerial images and lookup tables to assess carbon. Quantitative methods are also described for maintenance emissions and altered building energy use and included for information purposes only.

Section	Source	Method
6.7.3	Natural Disturbance—Wildfire and Prescribed Fire	Range of options depends on the data availability of the entity's forest land including: First Order Fire Effects Model (FOFEM) entering measured biomass; and FOFEM model using default values generated by vegetation type. These options use Reinhardt et al. (1997).

6.1.1 Overview of Management Practices and Resulting GHG Emissions

6.1.1.1 Description of Sector

Forestry activities represent significant opportunities to manage GHGs (Caldeira et al., 2004; Pacala and Socolow, 2004). There are many kinds of forestry activities that may be considered by entities as a means to reduce GHGs, such as establishing new forests, agroforestry, improved forest management, and avoided forest clearing. Cost is a major factor guiding decisions about which activities in forestry to pursue (Lewandrowski et al., 2004; Stavins and Richards, 2005; U.S. EPA, 2005). In the annual GHG inventory reported by the U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (EPA), forests and forest products sequester an average of 790 million metric tons carbon dioxide (CO_2) per year on 253 million hectares (ha) of forest land, making it the main land category sequestering carbon (U.S. EPA, 2012b; USDA, 2011). Most of the carbon sequestered (89 percent) is in the forest ecosystem, with the remainder added to the pool of carbon in wood products.

6.1.1.2 Resulting GHG Emissions

Forests remove carbon from the atmosphere and store it in vegetative tissue such as stems, roots, barks, and leaves. Through photosynthesis, all green vegetation removes CO_2 and releases oxygen (O_2) to the atmosphere. The remaining carbon is used to create plant tissues and store energy. During respiration, carbon-containing compounds are broken down to produce energy, releasing CO_2 in the process. Any remaining carbon is sequestered until the natural decomposition of dead vegetative matter or combustion releases it as CO_2 to the atmosphere. The net carbon stock in forests increases when the amount of carbon withdrawal from the atmosphere during photosynthesis exceeds the release of carbon to the atmosphere during respiration. The net carbon stock decreases when biomass is burned.

Other GHGs, such as nitrous oxide (N_2O) and methane (CH_4), are also exchanged by forest ecosystems. N_2O may be emitted from soils under wet conditions or after nitrogen fertilization; it is also released when biomass is burned. CH_4 is often absorbed by the microbial community in forest soils but may also be emitted by wetland forest soils. When biomass is burned in either a prescribed fire/control burn or in a wildfire, precursor pollutants that can contribute to ozone and other short-lived climate forcers as well as CH_4 are emitted. A wildfire is an unplanned ignition caused by lightning, volcanoes, unauthorized activity, accidental human-caused actions, and escaped prescribed fires. A prescribed fire/control burn is any fire intentionally ignited by management under an approved plan to meet specific objectives.

Some of the carbon in forests is released to the atmosphere after the harvest of timber. However, the amount of the carbon released, and when, depends on the fate of the harvested timber. If the timber is used to make wood products, a portion of the sequestered carbon will remain stored for up to several decades or longer. If the harvested trees are burned and used to produce energy, carbon will be released through combustion but may also prevent carbon emissions that would have been released through the burning of fossil fuels. Such emissions from biomass energy use are typically combusted with higher efficiency as compared to open biomass burning as would occur in a wildfire situation netting lower carbon emissions.

6.1.1.3 Forest Sector Schematic

Figure 6-1 is a simplified representation of the key forest carbon pools, carbon transfers, and GHG fluxes for the forest system. At this time, CO_2 is the main GHG represented comprehensively. Emissions of non-CO_2 GHGs interact with other sectors; at this time, potential fluxes of non-CO_2 GHGs are represented in a general manner on the schematic. The proportion of total system carbon in each pool can vary over time depending on a variety of factors; rates of carbon transfer are also variable.

6.1.1.4 Management Interactions

Forestry practices typically trigger ecosystem responses that change over time. For example, a newly established forest will take up carbon at a low rate initially, and then pass into a period of relatively rapid carbon accumulation. The carbon uptake rate will then typically decline as heterotrophic and autotrophic respiration increase and growth is balanced against mortality in the older forest. From this point in time, standing live tree biomass may not increase, but evidence suggests that carbon may continue to flow into other forest carbon pools until the forest is removed by harvest or a natural disturbance event.

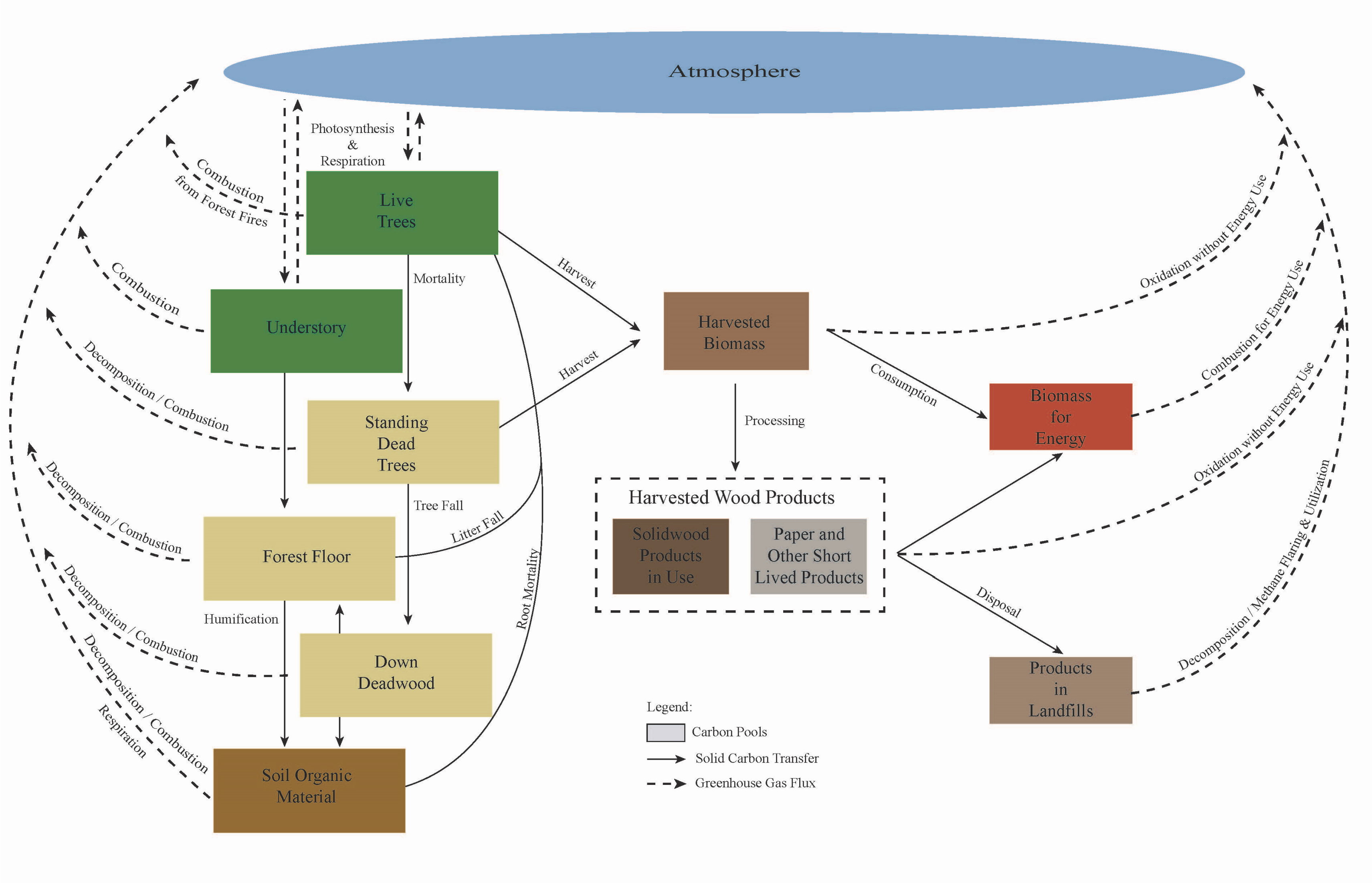
The net effects of management activities on carbon flows in forest ecosystems include changes in many different pools of carbon (such as aboveground biomass, belowground biomass, litter, soil, etc.). Carbon accounting should be comprehensive, addressing the net effects of activities on all carbon flows. Forestry activities cause carbon to move between the various pools and to/from the atmosphere. For example, forest management may be very effective at increasing the accumulation of biomass in commercially valuable forms—that is, in the trunks of commercial tree species. This increased growth may simply result from reducing competition from other types of trees, causing a transfer of carbon uptake from one group of trees to another. Forestry activities can also have effects on forest soils, woody debris, and the amount of carbon in wood products. The net carbon flow effects of any activity will be the sum of all the individual effects on the different carbon pools.

In addition, there may be interactions between biological and physical processes that are affected by forest management treatments or natural disturbances (e.g., changes in albedo during forest regeneration, after wildfires). While these interactions occur, research in this field is in the early stages and such interactions are beyond the scope of this guidance.

6.1.1.5 Risk of Reversals

Carbon that is sequestered in soils, vegetation, or wood products is not necessarily permanently removed from the atmosphere. Forestry activities intended for one purpose may be changed by a different landowner or a change in management objectives. Landowners may change their practices, causing the release of stored carbon, or natural disturbances may cause the loss of stored carbon to the atmosphere. Insect epidemics, drought, or wildfire may happen at any time and may affect all or only a portion of the land area within activity or entity boundaries. Natural disturbances may be rare events, in which case the effects on estimated carbon flows may be small when averaged over large forested areas or long periods of time. Catastrophic disturbances such as wind storms may cause obvious and easily estimated changes in carbon stocks, while in other cases, such as a one-year period of insect defoliation, it may be difficult after a few years to separate the effects of the natural disturbance from other factors. It should be noted that GHG registries generally require entities to calculate carbon stocks and fluxes and generally require entities to conduct an assessment of risk of reversal of projected carbon values. Such assessments generally

Figure 6-1: Schematic of Forest Carbon Pools, Carbon Transfers, and Greenhouse Gas Flux



include risk of natural disturbances such as fire, drought, insect and disease mortality, wind throw (hurricane, tornado, high wind events), as well as financial risks, management risks, and social political risks. These risk assessments are commonly used to generate a value that discounts the projected carbon value of management activities and to provide an "insurance policy" against reversals that may be used to ensure that a program's climate benefits are realized. Many forest management practices can reduce these natural hazard risks (such as fuel hazard reduction, forest thinning for growth or resilience to droughts, climate change, insect or disease agents, and use of prescribed fire to reduce risk of fires). Reducing the risk of reversal through management may lead to reduced emissions, long-term net increase in carbon stocks, and improved results in a risk assessment.

6.1.2 System Boundaries and Temporal Scale

For this report, the nominal system boundaries are the extent of the landowner's property. Estimation methods presented in this section are for the forest sector; however, where the forest sector may interact with the animal agriculture or croplands and grazing lands sectors, these instances are noted and landowners should refer to the relevant sector guidance. A landowner may need to use estimation methods for several sectors to achieve a comprehensive report of GHG sources and sinks for their property, ensuring that double counting does not occur. In addition, if land-use transitions occur within the property, these must be accounted for so that apparent changes in carbon stocks or fluxes are "real" and not the result of an unrecorded transfer from one sector to another. While GHG fluxes will occur across the system boundary, these are generally not estimated except in the instance of harvested wood products (HWPs).

The forest sector presents an accounting challenge related to temporal scale that may not occur in other sectors. While many farms operate on an annual cycle, forestry operations, by their nature, occur over multiple years and decades. While annual estimation and reporting are required, annual measurements of forest carbon pools are not economically feasible, nor are changes in carbon stocks generally detectable within acceptable error levels on an annual basis. This necessitates the use of models and projections to assess the carbon consequences of management practices and evaluate the possible GHG benefits of a change in management practices. Throughout the forest guidance, references will be made to several types of estimates that may be generated. A Type I estimate is the estimate of the carbon stock in the current year (or a recent past year) based on field measurements and other data. To assess the carbon impacts of a practice over time, a necessary step to generate an annual estimate, projections of future carbon stocks must be made. This will be referred to as a Type II estimate and will require the use of lookup tables, simulation models, or other tools. A Type III estimate is used to assess the change in the GHG footprint as a result of a change in management practice. To generate a Type III estimate, a landowner will need to produce Type II estimates for the current practice and the practice under consideration and compare the two. While some landowners may require only an estimate of current carbon stocks (Type I estimate), many will be interested in generating estimates of the rate of carbon storage over time (Type II estimate), which necessitates the use of models to project forest growth. The overall goal of this guidance is to enable a landowner to develop an estimate of their GHG footprint and to assess the potential effects of changes in management practices or land use on this footprint (for forest systems, this will be dominated by carbon). Type II estimates can be generated and compared for the current management scheme and multiple alternatives (which may include a "no action" scenario). Comparing the estimates permits landowners to evaluate the potential impacts of a wide range of possible factors, including foregone growth, land-use change, and changes in management practices.

Generally, entities report annually for the life of a project. Since forests may last indefinitely, there is no biological ending, although events such as land-use change, a natural disturbance, or biome shift from climate change may effectively end the life of a specific forest or forest type. Various programs may impose time limits for reporting, or the entity may choose a project length that is consistent with management objectives. The accounting methods are not affected by project or reporting period length; therefore no specific recommendations are made in this guidance.

6.1.3 Summary of Selected Methods/Models

6.1.3.1 Field Measurements of Carbon Pools and Fluxes

Methods for estimating the key forest carbon pools are well developed and fairly standard. Pools are defined in Section 6.2, although detailed methods are not given. Methods for measuring forest carbon stocks are described in a variety of publications, including the IPCC Good Practice Guidance for Land Use, Land Use Change, and Forestry (IPCC, 2003), Pearson et al. (2007), and Hoover (2008), among others. As the Forest Inventory and Analysis (FIA) program of the USDA Forest Service is the Federal program tasked with providing national-scale estimates of the U.S. forest carbon stocks/flux (Heath et al., 2011), documented inventory procedures from this program (USDA Forest Service, 2010a; 2010b) serve as a basis for many facets of entity level carbon reporting prescribed in this document.

6.1.3.2 Lookup Tables and Regional Estimates

The most comprehensive collection of tables of carbon stock estimates is Smith et al. (2006). Estimation methods are described, and estimates for each carbon pool are provided by forest type for each region of the conterminous United States. The volume includes methods and tables to estimate carbon in HWPs.

6.1.3.3 Models

A variety of models may be used to assist in the estimation of forest carbon stocks and stock changes. Models will be described in more detail in the sections that follow, but for reference purposes, brief summaries of the most commonly used models are provided below. Some of these models are complex and may require a substantial time investment. Interacting with some of these models often requires specialist knowledge or training or both. For such models, an online estimation tool could be developed so that landowners would not need to learn each individual model, but would interact with them through the interface of an estimation tool, while the components operate in the background. While all models have strengths and limitations, the models recommended for use in each section of this report were selected because of their nationwide coverage, history of performance, and suitability for this task.

Forest Vegetation Simulator and Fire and Fuels Extension Carbon Reports. The Forest Vegetation Simulator (FVS) is a national system of growth and yield models, with multiple regional variants, that can be used to simulate growth and yield for U.S. forests. FVS is a stand-level model and can simulate nearly any type of forest management practice. The Fire and Fuels Extension (FFE) to FVS can be used to generate reports of all carbon pools except soil but including HWPs; non CO_2 GHGs are not included.[1] A number of geographic variants are available, each with regionally specific equations and default values.[2]

i-Tree. Two of the tools in i-Tree estimate carbon storage within urban trees, annual carbon sequestration, and carbon emissions avoided through energy conservation due to urban trees. One tool, the Urban Forest Effects (UFORE) model, focuses on an entire urban forest. The other tool,

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[1] See http://www.fs.fed.us/fmsc/fvs/index.shtml

[2] Suggested variants may be found here : http://www.fs.fed.us/fmsc/fvs/whatis/index.shtml

STRATUM, focuses on street tree populations. Tree sample (e.g., from random field plots) or inventory data are required to run the model. Models to estimate future carbon effects based on local field data and user-defined mortality and planting rates have also been developed.[3]

First Order Fire Effect Model. The First Order Fire Effects Model (FOFEM) is a national level model with geographic variants, designed to predict tree mortality, fuel consumption, smoke production, and soil heating caused by prescribed fire or wildfire.[4]

COMSUME. CONSUME is a decision-making tool designed to assist resource managers in planning for prescribed fire and impacts of wildfire. CONSUME predicts fuel consumption, pollutant emissions, and heat release based on fuel loadings, fuel moisture, and other environmental factors.[5] It allows estimation of GHG emissions and consumption from post-harvest and thinning activities.

6.1.4 Sources of Data

Sources of available data that may be appropriate for use in developing estimates of GHG emissions and carbon sequestration vary by carbon pool (or flux). In all cases, field collection of data is possible, and may be the only available approach for those instances where credible default values have not been developed and/or lookup tables are not available; this may be particularly relevant for agroforestry and urban forestry applications. In the case of many of the non-living forest carbon pools, regional default values are available for down dead wood (DDW), forest floor, and standing dead wood through the FIA program, as well as a number of documents developed in support of official U.S. government estimates. All FIA data are available through a number of portals, including the FIA database tools—Forest Inventory Date Online (FIDO) and EVALIDator—and the CarbonOnLineEstimator (COLE),[6] which interacts directly with the FIA database. See Table 6-2 for a partial list of potential data sources.

Currently, values for soil organic carbon (SOC) stocks are drawn from the State Soil Geographic (STATSGO) database, and are of coarse spatial resolution. A limited amount of field-sampled SOC data are also available through the FIA database as part of the Forest Health Monitoring portion of the inventory process. Carbon in live tree biomass is also available from FIA and like other variables can be retrieved at the county level. The FIA sampling design is intended to meet a specified error target at large areas of forest land; so FIA data may not be appropriate for use at smaller spatial scales. Estimates based on a small number of plots may present an unacceptable error level. COLE and EVALIDator provide error estimates for all variables; these values should be carefully considered before the data are used to develop estimates for a particular site.

Data for emissions of other GHGs from forests are not widely available, although estimates and calculation methods are better developed for N_2O than CH_4. The U.S. EPA and IPCC provide estimation methods and emissions factors for both gases from wildfires, and for N_2O from forest fertilization (IPCC, 2006; U.S. EPA, 2011). The U.S. EPA publishes a National Emissions Inventory every three years, which provides estimates for wildfire as well as prescribed fire for criteria pollutants as well as hazardous air pollutants, including some GHG species (U.S. EPA, 2012a).

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[3] See http://www.itreetools.org/

[4] See http://www.firelab.org/science-applications/fire-fuel/111-fofem

[5] See http://www.fs.fed.us/pnw/fera/research/smoke/consume/index.shtml

[6] See http://www.ncasi2.org/COLE/index.html. COLE was developed through USDA Forest Service financial support, but is currently hosted by NCASI.

6.1.5 Organization of Chapter/Roadmap

This chapter provides guidance on estimating carbon sequestration and GHG emissions for the forest sector. In cases where a landowner's holdings involve multiple land uses, guidance for the other sectors should be consulted. In this chapter, attempts to note areas where cross-sector interactions are likely to occur have been made. Wetlands and hydrologically managed soils are important in several sectors, and for this reason guidance for estimating GHG emissions and sequestration from wetland systems is covered in a separate section, outside of the croplands/grazing lands and forest sectors.

The chapter is organized to provide an overview of the elements of forest carbon accounting, including definitions of the key carbon pools and basic methods for their estimation. Next is a section relating to estimation methods in cases where forests have been established, re-established, and/or cleared. The forest management section considers the GHG implications of a variety of commonly employed management practices, and is followed by guidance on the estimation of carbon in HWPs. While agroforestry systems and urban forests may not be considered as traditional forest landscapes, the working group recognizes the importance of trees located outside of forests. Since the most important component in these systems is often the live biomass, urban systems have been included in the forest sector. Agroforestry is a complex topic, combining aspects of forestry, cropland agriculture, and animal agriculture. Since agroforestry is most likely to be practiced on lands primarily used for agriculture, the estimation guidance is provided in the croplands and grazing lands section of the document. It is important to note that agroforestry has many cross-sector linkages, and a complete estimate of the GHG implications of agroforestry practices may necessitate consultation of the forest methods provided here. As noted above, natural disturbance is one of the important risks of reversal in the forest sector, and the final section provides guidance on estimating the impacts from natural disturbance in forested systems.

The remainder of this chapter is organized as follows:

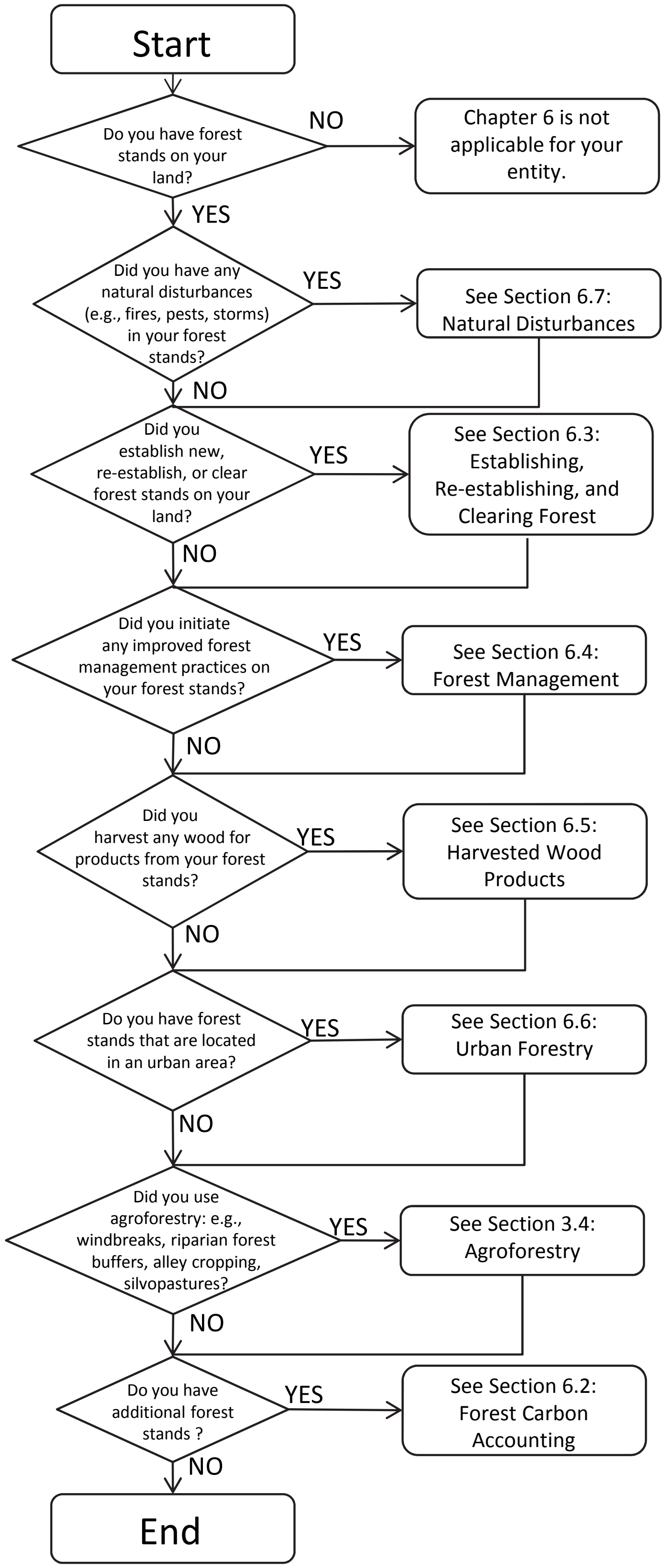
- Section 6.2: Forest Carbon Accounting
- Section 6.3: Establishing, Re-establishing, and Clearing Forest
- Section 6.4: Forest Management
- Section 6.5: Harvested Wood Products
- Section 6.6: Urban Forests
- Section 6.7: Natural Disturbances

Table 6-2 shows internet sites available for information on carbon estimation. Figure 6-2 shows a decision tree for the forest sector showing which forest chapter sections (i.e., source categories) are relevant depending on which forest activities are taking place for an entity.

Table 6-2: Internet Sites Available for Information on C Estimation

Internet site	Organization	Relevant Content
http://fia.fs.fed.us/	USDA Forest Service, Forest Inventory and Analysis	▪ Forest statistics by state, including carbon estimates ▪ Sample plot and tree data ▪ Forest inventory methods and basic definitions
http://www.fhm.fs.fed.us/	USDA Forest Service, Forest Health Monitoring	▪ Forest health status ▪ Regional data on soils and dead wood stocks ▪ Forest health monitoring methods
http://www.usda.gov/oce/climate_change/greenhouse.htm	USDA GHG Inventory	▪ State-by-State forest carbon estimates
http://unfccc.int/ http://www.ipcc.ch/	UNFCCC and IPCC	▪ International guidance on carbon accounting and estimation
http://soildatamart.nrcs.usda.gov/	USDA Natural Resources Conservation Service	▪ Soil Data Mart: access to a variety of soil data
http://www.nrs.fs.fed.us/carbon/tools/	USDA Forest Service, Northern Research Station	▪ Accounting and reporting procedures ▪ Software tools for carbon estimation
http://www.eia.gov/oiaf/1605/gdlins.html	U.S. Energy Information Administration, Voluntary GHG Reporting	▪ Methods and information for calculating sequestration and emissions from forestry; see Part I, Appendix
http://www.epa.gov/climatechange/emissions/usinventoryreport.html	U.S. Environmental Protection Agency	▪ Methods and estimates for GHG emissions and sequestration
http://www.comet2.colostate.edu/	USDA Natural Resources Conservation Service and Colorado State University Natural Resources Ecology Lab	▪ Web-based tool for estimating carbon sequestration and net GHG emissions from soils and biomass for U.S. farms and ranches

Figure 6-2: Decision Tree for Forest Sector Showing Relevant Chapter Sections Depending on Applicable Source Categories



6.2 Forest Carbon Accounting

Methods for Forest Carbon Accounting Utilized in this Guidance

- Range of options dependent on the size of the entities' forest land including:
  - FVS-FFE module (entities that fit the large landowner definition), and
  - Default lookup tables (entities fitting the small landowner definition).
- These options use:
  - Allometric equations from Jenkins et al. (2003a), and
  - Default lookup tables from Smith et al. (2006; GTR NE-343)—default regional values based on forest type and age class developed from FIA data.
- These methods were selected because they provide a range of options dependent on the size of the entities' forest land.

6.2.1 Description of Forest Carbon Accounting

The basic question inherent within the broader context of forest carbon estimation is: "How much carbon is in this forest?" Any discussion of forests or forestry activities in the context of GHGs depends on quantifying forest carbon. Forest ecosystems are generally recognized as significant stocks of carbon, and aggrading, or growing, forests can be strong carbon sinks. Disturbances and forest management influence the size and rates of change of these stocks. It is important to note that forest carbon generally is not measured directly (e.g., collecting forest biomass samples for laboratory determination of carbon content). It is usually quantified indirectly from standard forest inventories and associated carbon models (e.g., litter carbon dependent on forest type and stand age). For live tree pools, forest inventories often only measure limited dimensional attributes (e.g., diameter and height) of individual trees and use biomass component models (e.g., bole and crowns) and wood density values to convert these values into an estimate of total tree biomass. Once an estimate of biomass is attained, a standard carbon conversion constant is applied to produce a carbon stock estimate. Carbon conversions vary slightly, but 50 percent of dry weight is a useful round value applicable to all vegetation and sound wood (IPCC, 2006). For other pools, such as litter layers and soil organic matter, specific carbon content per unit volume depends on decay and composition of the material and is generally less than 50 percent carbon. Given the diversity of estimation procedures and carbon pool definitions, a reasonable selection of methodologies should be available for entities wishing to assess their forest carbon.

A major attribute of carbon "accounting" is to explicitly document and define accounting procedures such that forest carbon reports are comparable across ownerships and forest ecosystems. Absolute quantities of carbon, or carbon mass, are not only a function of a specific forest but also dependent on how pools are defined and how the mass of carbon within the pool is estimated. For example, both remotely sensed images and ground-based tree measurements can provide separate estimates of the same forest. These two techniques are unlikely to provide identical estimates due to methodological differences, including the fact that each approach may define different populations of interest and thus account for different sets of trees. Identifying and resolving such issues is an objective of forest carbon research. Not all forest carbon assessments or management plans need to encompass all carbon (or GHGs) pools if the carbon is properly identified. Measuring the current state of a forest's carbon stocks and recent changes is a part of developing a baseline, which can then be used for additional analysis. A baseline of past carbon stocks and change can be constructed and used with modeling to determine projections of likely future carbon. Similarly, a baseline is necessary for analysis of alternate management options to evaluate potential for sequestration/emission. The technical specifications of baselines (e.g., starting year and included stock categories) are often a social/political decision, and are beyond the purview of this document. However, to standardize forest carbon accounting options for the purpose of entity reporting (e.g., woodland owners), this document will propose a single set of forest carbon pool definitions. The specific recommendations included here are intended to direct landowners to tools and data sources specially developed for quantifying forest carbon. Note that these listed processes are not intended to exclude alternative data summaries that may be available to entities. Details are discussed below in the discussion of the respective forest carbon pools, but the general options listed in decreasing accuracy (and cost) include the following:

(1) Measure/sample your forest and estimate carbon from these data (reduce sample data so as to then apply available biomass equations or other carbon conversion factors);

(2) Characterize your forest according to classifications (i.e., lookup tables) based on stand or site attributes derived from records in the nation's forest inventory database (FIADB) (Woodall et al., 2010; Woudenberg et al., 2010); or

(3) Use associated models (FIDO, COLE, etc.), which base your forest's carbon estimates on representative data sampled by others with critical dependent user variable input (e.g., stand age).

Note that the above three options are not necessarily mutually exclusive. For example, FIADB data or similar models (Option 2) are based on permanent inventory plot sampling and carbon conversion (Option 1), and lookup tables (Option 3) are based on the FIADB (Option 2). The recommended forest carbon inventory options involve tradeoffs in costs and level of information unique to the entities' forest land.

The process of obtaining forest carbon estimates depends on circumstances unique to each entity, but mostly depends on the intended audience and the resources available for forest inventory. For this guidance, a two-tier system is in place. The goal is to be as inclusive as possible while not creating a measurement burden. Smaller holdings that are not actively managed are unlikely to be inventoried; a two-tier approach permits owners of such holdings to estimate their footprint and the potential changes from changes in practices applied without incurring the costs of measurement. Smaller landowners who have inventory data or who wish to acquire it should use the tools and protocols described for large landowners.

Landowner size classes are defined as follows:

Landowners who hold 200 or more acres (80.9 hectares [ha]) of forest land should follow the methods for large landowners. Also, landowners who hold less than 200 acres (80.9 ha) of forest land should follow the methods for large landowners if three or more of the following are true:

- Landowner owns or manages more than 50 forested acres (20.2 ha)
- Landowner's forest is certified
- Landowner has developed a forest management plan
- Landowner's forested property has a history of timber harvesting
- Landowner participates in State forest tax abatement programs

Landowners not meeting the definition of large landowner should follow the methods for small landowners.

Recommended methods depend on forest landowner size. Small landowners may use generalized lookup tables based on region, forest type, and age class to estimate carbon stocks. Large landowners should collect standard forest inventory data and use the FVS-FFE module with Jenkins et al. (2003a) allometric equations. It should be noted that FVS and the FFE are large and complicated models; any tool that implements these methods will require development of a simplified user interface that interacts with FVS and FFE.

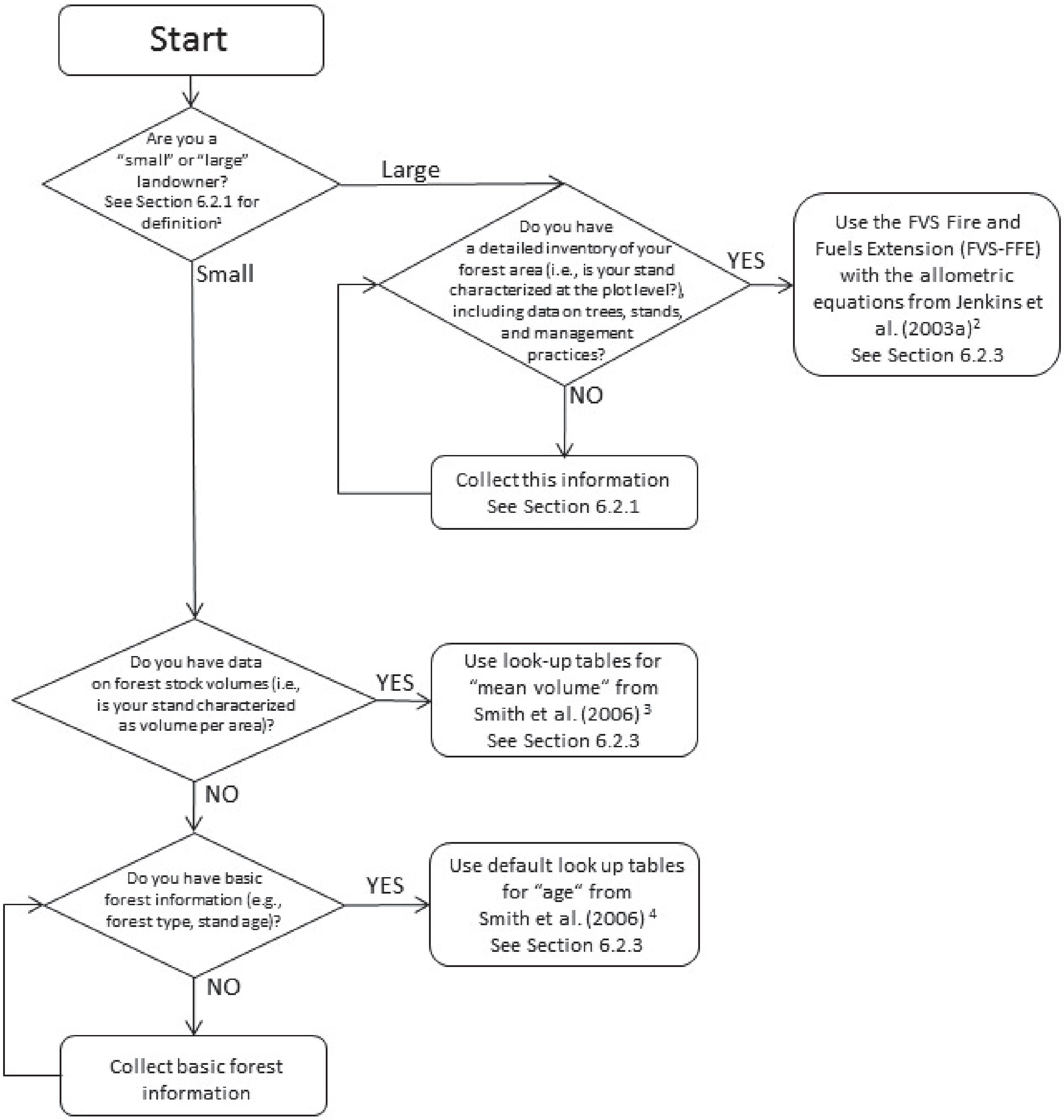
At this time, the Jenkins et al. (2003a) equations are specified since they are nationally consistent. Future development is likely to include the implementation of a more recent FIA biomass estimation method in FVS, enabling the production of estimates that match the official U.S. forest carbon estimates. While local volume or biomass equations may be more accurate for a given location, use of such equations will result in additional inconsistencies in results, so no other equations are approved for use at this time under this methodology.

Although carbon reporting beyond that of the entity level (e.g., major timberland owner or national forest) may use refined measurement protocols, expanded carbon pool definitions, and/or ancillary data (e.g., remotely sensed imagery), the proposed pools and inventory methodologies in this document serve as a starting point. Classification of carbon estimates within multi-tiered systems, and links to models to project future change under alternate scenarios are addressed at the end of Section 6.2.

To facilitate accounting, forest carbon is typically classified into a few discrete pools, which should be comprehensive (all organic carbon) with no gaps and no overlap. The purpose of establishing these separate pools, or bins, of forest carbon is twofold: (1) to align appropriate data with ecosystem/product components (e.g., tree inventories and live tree carbon pool), or alternatively to identify gaps; and (2) as a part of the accounting process, not all reported stock or change necessarily needs to include all of the carbon pools, but what is included must be unambiguously identified. Note that the carbon pools (or bins or classifications) focus on carbon from phytomass. Strictly speaking, total carbon stocks within a forest include a non-plant (not originating from the plant kingdom) percentage, but such pools are not defined because this is generally an insignificant proportion. Exceptions are the forest floor and soil pools, which include decomposers and soil fauna. A sometimes significant amount of carbon is removed from forests as wood is harvested and used in wood products. Some of that carbon remains sequestered for long periods of time, depending on the products. Thus, harvested wood should be included in forest carbon estimates.

Figure 6-3 is a decision tree for the forest carbon accounting source category showing which carbon accounting assumptions (e.g., simulation models, allometric equations, biomass expansion factors, lookup tables) are recommended for an entity depending on the type of activity data available. However, it should be noted that for national reporting—i.e., the annual GHG inventory reported by USDA and U.S. EPA—where individual tree measurements from FIA's inventory plots are available, the component ratio method (CRM) for estimating biomass (Woodall et al., 2011) is currently used. Again, future development will likely bring these methods into alignment.

Figure 6-3: Decision Tree for Forest Carbon Accounting Showing Methods Appropriate for Estimating Forest Carbon Stocks



[1] Small landowners (as defined in Section 6.2.1) may use generalized lookup tables based on region, forest type, and age class to estimate carbon stocks. Large landowners should collect standard forest inventory data and use allometric equations to estimate live tree biomass carbon (other carbon pools may be obtained from lookup tables).

[2] Jenkins et al. (2003a).

[3] Note that volume equations used by landowners should align with "mean volume" specifications (e.g., rotten/cull deductions) of Smith et al. (2006). Different volume equations and deductions will produce volume estimates that differ from those used in the tables.

[4] Smith et al. (2006).

Another aspect of a carbon accounting framework is consistent or comparable representation of change, which goes beyond the identification of carbon pools. Change is affected by processes of recruitment and growth as well as disturbance, mortality, and harvest. In the most basic sense, change can be the difference between two successive stock estimates. This is common for GHG reporting based on standard forest inventories. Some components of change can be measured with intensive sampling at small scales, but in general change is estimated from measurements at two successive inventory times (e.g., total stock change, or growth/removals/mortality estimates, or remotely sensed data), or based on models of ecosystem or biogeochemical change. A basic approach to quantifying change in forest carbon is based on the quantities defined for forest carbon stocks. Net annual carbon stock changes are calculated by taking the difference between the inventories and dividing by the number of years between the inventories for a selected forest or forest area (e.g., Δ stock = ($stock_2$ – $stock_1$)/time). This stock-change approach (IPCC, 2006) is the change method applied to FIA strategic-scale inventories for the stock-change values reported in the U.S. National GHG Inventories (e.g., U.S. EPA, 2011).

Six Steps to Forest Entity Carbon Estimation

The approach to estimation of carbon stocks and fluxes in the forest sector is as follows:

Step 1: **Determine landowner size class based on forest area.** Based on the acreage under consideration, landowners are divided into two groups: “small” landowners and “large” landowners as defined in Section 6.2.1.

Step 2: **Collect forest data.** For both size classes of landowners, some level of forest inventory (i.e., field survey) data is required. However, there are differing data requirements for small landowners and large landowners.

Small landowners should collect basic data on species mix (i.e., type of forest) and stand age (or time since last major disturbance) within their forest. Greater inventory detail can lead to more precise estimates of carbon, but even broad generalizations about the region, age (and/or mean volume), and type of forest can lead to a carbon estimate. The objective is to obtain reasonable and consistent estimates over time at the lowest cost. If a small landowner wishes to conduct an inventory and follow the recommended guidance for large landowners, they are free to choose this option. The principal tradeoff is between cost and accuracy; collecting inventory data increases the cost of developing estimates but increases accuracy.

Large landowners should gather more extensive data about forest and stand characteristics. A thorough forest inventory is created using industry standards and practices of the type described in GTR NRS-18: *Measurement Guidelines for the Sequestration of Forest Carbon.* Variables considered must include dominant species, dominant age class, stand density, and site class. Inclusion of additional variables, while not required, will improve accuracy of carbon estimates.

Step 3: **Estimate initial forest carbon stock and annual fluxes.** Quantities of carbon change over time. Forest carbon estimates are divided into six discrete, mutually exclusive pools, including live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic carbon. A number of pool-specific carbon conversion methods are available; these methods use the inventory data gathered in Step 2 to quantify carbon for each pool. However, the specific methods to be used differ depending on the landowner size class.

(Continued)

(Continued)

Small landowners, after collecting observational data, can use lookup tables from Smith et al. (2006) (also known as GTR-NE-343: *Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States*) to estimate carbon stocks and carbon stock changes. The lookup tables are categorized by region, forest type, previous land use, and in some cases, management activity. Users must identify the categories for their forests and estimate the area of forestland. To facilitate use of the data from GTR-NE-343, a tool could incorporate the data such that, in most cases, landowners would be able to select their stand characteristics from a drop-down menu of defaults. Based on the landowner's selections from the default menus, the tool would produce estimates of carbon stocks in each of the six carbon pools.

Large landowners should use the data collected in their forest surveys to perform model runs using the FVS model. FVS will use the site- and stand-specific data to provide more accurate estimates of carbon stocks in each of the carbon pools (excluding soil carbon, which FVS does not estimate). Soil carbon estimates can be determined from a range of methods including sampling or existing forest soil carbon estimate datasets depending on a specific entity's circumstances.

Though the methods differ for small landowners and large landowners, both calculate initial carbon stocks and expected annual rates of accumulation under average conditions (repeating the field survey at prescribed intervals will help calibrate or validate the stock change estimates).

The methods also allow for adjustments due to HWPs (Step 4), forest management practices (Step 5), and natural disturbances (Step 6).

<u>Step 4</u>: **Adjust carbon estimates due to HWPs.** Harvesting activities can have considerable impact on carbon quantity across the six forest carbon pools. In terms of emissions, the fate of the harvested material must be considered as well, including whether the material is used in HWPs or for energy. As above, the methods for estimating these impacts differ depending on the landowner size class.

For HWPs, *small landowners* should rely on data provided in lookup tables in GTR-NE-343, which provides factors for calculation of carbon in HWPs based on region, timber type, and industrial roundwood category. The lookup tables divide the harvested forest materials pool into four distinct fates: products in use, landfill, emitted with energy capture, and emitted without energy capture. Carbon emissions differ depending on the fate, which in turn depends on the region and harvest material characteristics. By using the lookup tables, landowners can adjust carbon estimates accordingly.

Large landowners should rely on FVS to model forest management practices, resulting in estimates of the carbon impact of these practices (e.g., harvesting). For example, FVS can consider the type of harvest (e.g., clear cut versus strategic thinning) and project the results of this harvest on carbon stocks, thus allowing users to quantify the carbon impact of various harvesting activities, as well as adjusting for the ultimate fate of harvested materials. The harvested forest material pool is divided by FVS into the same four distinct fates as for GTR-NE-343: products in use, landfill, emitted with energy capture, and emitted without energy capture. Harvests also impact forest growth over time, which is modeled by FVS.

(Continued)

(Continued)

Step 5: **Adjust carbon estimates due to improved forest management.** Forest management practices, such as thinning or fertilization, may impact carbon fluxes as well. As above, the methods for estimating these impacts differ depending on the landowner size class.

FVS allows *large landowners* to quantify the impact of various forest management practices. For example, using keywords (or combinations of keywords) provided by FVS, users can generate estimates for the impact of stand density management, site preparation methods, vegetation controls, various densities of planting stock, fertilization, rotation length management, prescribed fire/control burns and fuel load management, and pest and disease control. With given stand and tree-list data, users can develop a baseline, which can then be compared to alternative management strategies. This allows for assessment of carbon impact of implementing those management practices. It should be noted that FVS is the recommended method, even if a large landowner has its own custom inventory and modeling system, which might be considered superior to regional models such as FVS. The adoption of a single, recommended method for landowners allows for transparent, consistent, comparable, and complete estimates across landowners appreciating that there will be a likely trade off in the accuracy, cost effectiveness, and ease of use of the method for those landowners with custom systems. Future development may include a means for large landowners to use custom models in this framework, but this option is not available at this time.

Unfortunately, the lookup tables do not allow for estimates associated with improved forest management. If prescribed fire/control burning is used by either landowner type, it is recommended that the emissions for the activity be calculated as guided in Step 6.

Step 6: **Adjust carbon estimates due to forest fires and other natural disturbances.** Natural disturbances, such as forest fires, storms, wind, drought, or pest/insect infestation, can also have considerable impact on carbon quantities across the six forest carbon pools. Landowners should estimate the carbon impact of natural disturbances.

For forest fires, wildfires, and prescribed/controlled burns, both small and large landowners should rely on FOFEM to generate carbon estimates. FOFEM input requirements include basic forest type, site location, and dominant species data, but also allows users to input additional information, depending on a specific entity's circumstances, on amount of duff, moisture content, and other variables associated with fire. The severity of the fire can be categorized by percent of the land affected. The resulting output includes estimates of carbon emissions.

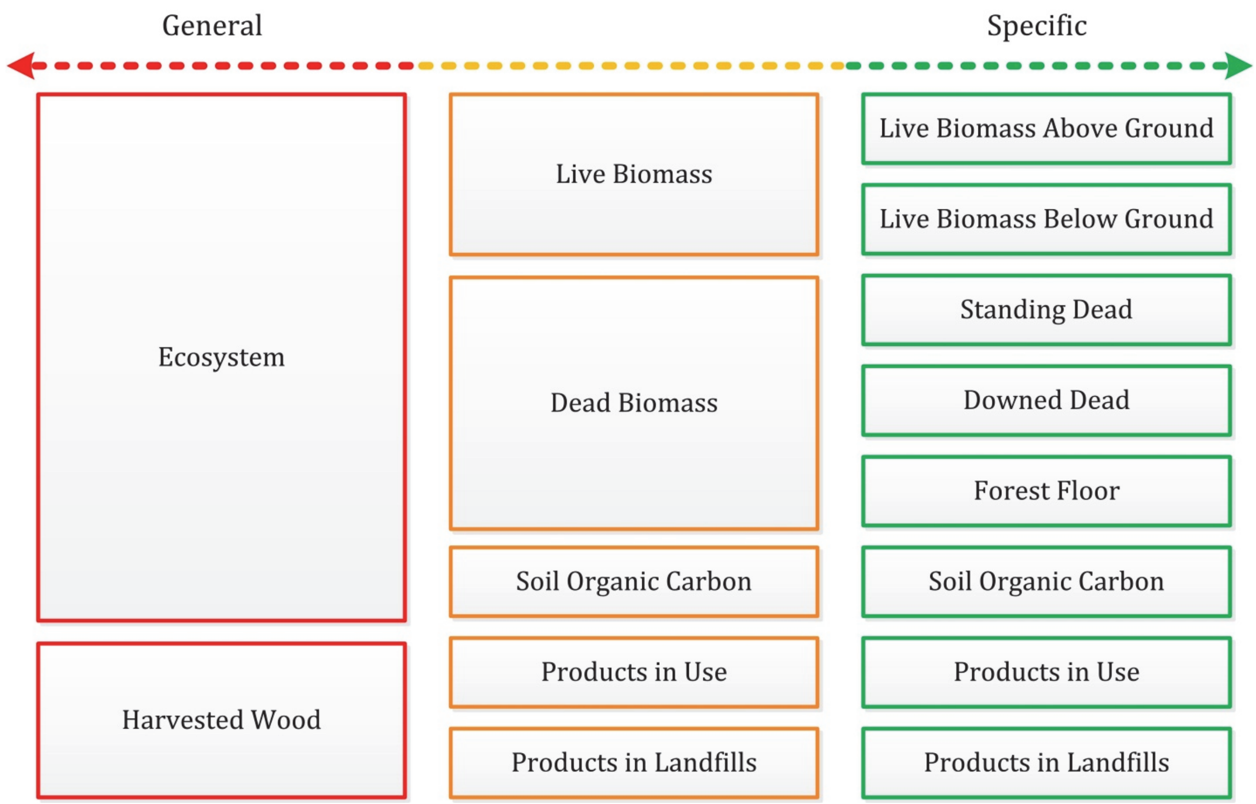
The methods assume s*mall landowners* can provide observational estimates for the impacts of natural disturbances such as pests, based on the percentage of forestland affected by the disturbance. *Large landowners* may model impacts of pests through available keywords and extensions provided by FVS.

The philosophy behind these six steps is that they allow the entity to assess what carbon stocks they have under any present conditions and what stocks they might expect given implementation of a particular harvesting regime, change in forest management practices, and/or a variety of natural disturbances.

6.2.1.1 Forest Carbon Pools

Carbon reporting—such as for the U.S. reporting commitment to the United Nations Framework Convention on Climate Change (UNFCCC), which is met by the U.S. EPA's official GHG inventory (e.g., U.S. EPA, 2011)—provides a framework for the pools described here. However, the pools are modified to more closely correspond to types of forest inventory data. For example, forest carbon can be easily categorized according to aboveground versus belowground, or living versus dead plant material. In practice, classifications of carbon pools depend on the forest data and how they are used. As such, the pools described below are jointly defined by UNFCCC reporting requirements and the use of FIA forest inventory as the primary data source. In other words, the pools defined below are a convenient set, but definitions and boundaries around pools can vary according to specific carbon estimation procedures/capabilities and reporting needs (see Figure 6-4).

Figure 6-4: Forest Carbon Pool Hierarchy Showing How Forest Carbon Pools Can Be Delineated into Even Smaller Pools Dependent on the Entity Needs and Inventory Capabilities



Live trees: A large woody perennial plant (capable of reaching at least 15 feet (4.6 m) in height) with a diameter at breast height (DBH) or at root collar (if multistemmed woodland species) greater than 1 inch (2.5 centimeters [cm]). Includes the carbon mass in roots (i.e., live belowground biomass) with diameters greater than 0.08 in (2 millimeters [mm], stems, branches, and foliage.

Understory: Roots, stems, branches, and foliage of tree seedlings, shrubs, herbs, forbs, and grasses.

Standing dead trees: Dead trees of at least 1 inch (2.5 cm) DBH that have not yet fallen, including carbon mass of coarse roots, stems, and branches, but that do not lean more than 45 degrees from vertical (Woudenberg et al., 2010), including coarse nonliving roots more than 0.08 in (2 mm) in diameter.

Down dead wood (also known as coarse woody debris): All nonliving woody biomass with a diameter of at least 3 inches (7.6 cm) at transect intersection, lying on the ground. This pool also includes some less-than-obvious components of DDW: (1) debris piles, usually from past logging; and (2) previously standing dead trees that have lost enough height or volume, or lean greater than 45 degrees from vertical, so they do not qualify as standing dead trees.

Forest floor: The litter, fulvic, and humic layers, and all fine woody debris with a diameter less than 3 inches (7.6 cm) at transect intersection, lying on the ground above the mineral soil.

Soil organic C: All organic material in soil to a depth of generally 3.3 feet (1 meter [m]), including the fine roots (e.g., less than 0.08 in (2 mm) in diameter) of the live and standing dead tree pools, but excluding the coarse roots of the pools mentioned earlier.

Harvested wood: Wood removed from the forest ecosystem for processing into products, not including logging debris (slash) left in the forest after harvesting.

These pool definitions are developed around a common set in use by a number of publications (e.g., Smith et al., 2006) and at the forest stand level, which in turn differ from stock definitions used by the United States to meet UNFCCC national reporting requirements.

Also notable (in the reporting list) is the inclusion of HWP (covered in detail in Section 6.5), which assumes that a measurable portion of wood removed at harvest remains sequestered from reemission to the atmosphere for a period of time that can be estimated. Pools and estimation of stocks are organized primarily according to data collection and estimation with FIA's permanent inventory plots (phase two (P2), the standard inventory measurements; and phase three (P3), the forest health measurements). Note that pool definitions are not independent of related estimators; details related to estimation are not addressed until subsequent sections of this guidance.

6.2.2 Data Collection for Forest Carbon Accounting

Forest carbon is typically estimated indirectly, through applying conversion constants to a standard forest inventory, using a localized biogeochemical model, or simply looking up specific forest attributes (e.g., stand age, forest type) in a lookup table (e.g., Smith et al., 2006). For the purposes of this documentation, a standard set of carbon pool definitions that are part of FIA's national inventory are delineated that correspond to available lookup tables (Smith et al., 2006).

6.2.2.1 Live Trees

The tree carbon pools include aboveground and belowground (coarse root) carbon mass of live trees. Separate estimates are made for full-tree and aboveground-only biomass to estimate the belowground component. Tree carbon estimates within the FIADB (USDA Forest Service, 2012; Woudenberg et al., 2010) are based on Woodall et al. (2011) and Jenkins et al. (2003a). The per-tree carbon estimates are a function of tree species, diameter, height, and volume of wood. Belowground biomass is calculated as a varying proportion of aboveground biomass. Again, this is dependent on species and size of individual trees. The pool of live trees within the FIADB is defined as trees, or woody biomass with greater or equal to 1 inch (2.5 cm) DBH. However, trees less than 5 inches (12.7 cm) DBH are sampled differently than those that are 5 inches (12.7 cm) or more. These differences should not affect precision in the overall amount of tree carbon or stand level density. Saplings are trees at least 1 inch (2.5 cm) but less than 5 inches (12.7 cm) DBH. The "sapling" versus larger tree distinction is based on sampling differences on the FIA plots. This illustrates that pool classification is dependent on both the obvious physical and spatial separation in a stand as well as data sources.

6.2.2.2 Understory

Understory vegetation is a minor component of biomass or the live plant component. Understory vegetation is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 1 inch (2.5 cm) DBH. In FIADB-based carbon inventory, it is assumed that 10 percent of understory carbon mass is belowground. This general root-to-shoot ratio (0.11) is near the lower range of temperate forest values provided in IPCC (2006) and was selected based on two general assumptions: ratios are likely to be lower for light-limited understory vegetation compared with larger trees, and a greater proportion of all root mass will be less than 0.08 in (2 mm) in diameter. Estimates of carbon density are based on information in Birdsey (1996), which was applied to FIA permanent plots.

6.2.2.3 Standing Dead

The standing dead tree carbon pools include aboveground and belowground (coarse root) mass. Estimates and allometry are essentially similar to those for live trees, with some additional considerations for decay and mechanical/structural damage (Domke et al., 2011; Harmon et al., 2011). Carbon conversions vary slightly, but 50 percent is a useful round value for dead wood. However, specific carbon content is less for the litter and organic layers of the forest floor. There is not a dead plant material pool corresponding to understory; it is assumed these very quickly become litter or small woody debris. Pairing pool definitions (boundaries) with data sources is also very important with the pools of dead plant material, because measurements specific to estimates are much less likely for DDW, forest floor, etc. In the FIADB the distinction between "standing" and "down" dead wood is based on angle of lean and is applied to P2 (phase two, "standard" forest inventory plot) and P3 (phase three, a smaller number of plots that include additional measurements such as soils and forest floor) data; other definitions may vary. For small diameter standing dead trees, estimates exist but are problematic: FIA data only provide samples of standing dead trees at 5 inches (12.7 cm) DBH or larger. Estimates of saplings (1–5 inch (2.5—12.7 cm) DBH trees) necessarily will be modeled (Woodall et al., 2012).

6.2.2.4 Down Dead Wood

DDW is defined as pieces of dead wood no longer a part of standing dead or snags, yet distinct from smaller or advanced decayed wood of the forest floor. The definition largely corresponds to the P3 down woody material pool, and represents a slight change from the past definition. This pool also includes some less-than-obvious components of DDW: (1) debris piles, usually from past logging; (2) previously standing dead trees that have lost enough height or volume or lean greater than 45 degrees from vertical so they do not qualify as standing dead; (3) stumps with coarse roots (as previously defined); and (4) nonliving vegetation that otherwise would fall under the definition of understory.

6.2.2.5 Forest Floor or Litter

The forest floor is the layers of litter, often classified as the fibric (O_i), hemic (O_e), and sapric (O_a) organic layers above the mineral soil and smaller than DDW. This classification represents a change from the past definition, which also included the small woody debris from the DDW pool. Organic soils present additional challenges when delimiting this pool.

6.2.2.6 Forest Soil Organic Carbon (SOC)

This pool is organic carbon within the soil but excluding coarse roots as defined for live trees, understory, standing dead trees, and stumps—all as defined above. By convention, large pieces of woody material that are separately and independently estimated through sampling and allometry are excluded. Depth is arbitrary and so far has been defined by the dataset in use. The dataset should represent samples of as much of the organic carbon as possible, although peatlands present a unique problem. A common sampling depth is 1 m, although this is not an IPCC standard. Adequate sampling depth may be ascertained through local knowledge; 3.9 to 7.9 inches (10 to 20 cm) may be adequate for some forest ecosystems, while others require greater depths. Datasets of soil maps from surveys are another source of data (in addition to P3 plots). SOC variability extends to relatively large-scale maps such as locations surrounding P2/P3 plots. That is, soils maps are based on data with the same variability as seen in the P3 subplot-to-subplot precision.

Note that the pool definitions used by FVS do not match definitions used by FIA in all cases. While the main categories of live and dead biomass will include the same elements, the FIA definition of forest floor includes fine woody debris, while the FVS-FFE definition places fine woody debris in the DDW category. FIA considers trees under 1 inch (2.5 cm) DBH to be part of the understory pool, while FVS tracks these as trees regardless of size. Future work is likely to include the capability of FVS-FFE to generate a carbon report with pools corresponding to the definitions used by FIA in national accounting.

6.2.3 Estimation Methods

The flexibility in using the best obtainable data balanced with the needs and resources of each individual forest owner can provide good/valid forest carbon estimates if some basic guidelines are followed:

- Carbon pools should be explicitly identified to make it possible to identify possible gaps or overlaps between pools. Identifying and recognizing that a gap exists (for example, there are no seedling data, or standing dead trees were not measured) is more useful than fuzzy boundaries between pools.
- Consistent pool definitions and methods for carbon estimation within those pools are required for valid estimates of change. That is, change should be based on the same pools and methods at both time 1 and time 2.

6.2.3.1 Live Trees

Various approaches are used for estimates of tree biomass or carbon content; ultimately, each relies on allometric relationships developed from a characteristic subset of trees. Here, live trees include stems with DBH of at least 1 inch (2.5 cm). Allometry can incorporate whole trees or components such as coarse roots (greater than 0.08 to 0.20 inches (0.2 to 0.5 cm); published distinctions between fine and coarse roots are not always clear), stems, branches, and foliage. Live tree belowground carbon estimates can be troublesome, but overall accuracy is best if the boundary is set to conform to available data rather than a predefined threshold.

Recommended options for obtaining estimates of carbon stock of live trees are:

- Small landowners (as defined in Section 6.2.1): Values obtained from lookup tables (e.g., either those in Smith et al., 2006, or as otherwise provided) categorized by geographic region, forest type, and age class.
- Large landowners (as defined in Section 6.2.1): Standard forest inventory, estimates calculated using individual tree measurement (diameter) and the FVS-FFE module with the Jenkins biomass equations (Jenkins et al., 2003a).

Biomass equations must be applied appropriately; using equations outside the diameter or geographic ranges for which they were developed will introduce additional error to the estimates. Given the hundreds of different tree species growing in diverse habitats across the United States, it is beyond the scope of this document to suggest the magnitude of the effect of alternative tree volume models beyond the national-scale models suggested herein. Regardless of the estimation approach selected, it is critical to use that method consistently over time. Estimates produced from different methods will vary; changing estimation methods over time will introduce additional error.

Although we are currently specifying only the use of biomass equations by Jenkins et al. (2003a), it is understood that these equations may not be the most appropriate in all circumstances. For example, using equations outside the diameter or geographic ranges for which they were developed will introduce additional error to the estimates. Some Jenkins equations have limits to the allowable diameters. Specific guidance will be developed in the future to facilitate the use of different biomass equations such as those used by FIA based on the CRM and locally-specific equations. Refer to Figure 6-3 for a decision tree for the forest carbon accounting source category showing which carbon accounting assumptions (e.g., simulation model, allometric equations, and lookup tables) are recommended for an entity depending on the size class and type of activity data available.

Sampling and Allometry. Recommended approaches are based on the application of allometric relationship to sampled inventory data. The FIADB-based estimates of live tree carbon are based on the plot data–P2 data and CRM biomass estimation (Woodall et al., 2011). In addition, a large number of other allometric relationships have been developed for tree biomass (biomass regression equations). Many biomass equations are available for a variety of forest types; for example, possible older citations are Ter-Mikaelin and Korzukhin (1997); see also citations in Jenkins et al. (2003b). The equations recommended in this report are the Jenkins et al. (2003a) equations, which are nationally consistent and straightforward to apply. Future development or integration of this method into a software tool should consider implementation of the CRM biomass estimation method in order to better align with the methods used for U.S. GHG inventory reporting. The CRM approach is computationally complex, and is not included at this time.

Inventory designs and protocols are well documented by a variety of authors and will not be discussed further here. A good example is Pearson et al. (2007), which is written specifically for carbon inventories.

Lookup Tables. Published summary values of similar or representative forests provide quick and inexpensive means of roughly assessing likely forest carbon. A good example of such lookup values are the past revised 1605(b) guidelines, with the forest tables published as Smith et al. (2006). Alternative versions of representative values include FIA online applications such as FIDO or EVALIDator, FIA-related applications such as COLE, or models from spatial data such as the FIA biomass map or the National Land Cover Dataset layers.

Simulations/Modeling. Not only do forest biometrical models provide a platform for estimating future scenarios of forest carbon stocks, but they can also be a rapid methodology for entity-level calculation of current forest carbon stocks. The FVS is one such simulation tool that can provide estimates of current forest carbon stocks given an elementary forest inventory was conducted (e.g., number of trees, size, and species). In addition, and perhaps a more powerful aspect of such a tool, is that projections of future stand attributes can be acquired (e.g., forest carbon stocks 50 years from present) as described in Dixon (2002) and Hoover and Rebain (2008; 2011).

6.2.3.2 Understory

Estimation procedures and data sources are limited for this pool. Unless an entity has the capability to develop localized understory models and allometric relationships, the development of carbon estimates for these pools will be limited to lookup tables and simulations/modeling. Values are provided in the Smith et al. (2006) lookup tables, which are based on Birdsey (1996) and modified to apply to FIA data; see U.S. EPA Annex 3.12 (2010) for additional details. The FIADB condition table includes estimates based on this model, so estimates based on similar stands can be obtained from the FIADB. Understory values are provided in the carbon reports in FVS and are regional default values set within the model.

6.2.3.3 Standing Dead

The prevailing difference in volume/biomass/carbon estimation of standing dead trees from live trees is the incorporation of decay reduction factors and rotting/missing/cull components (Domke et al., 2011; Harmon et al., 2011).

Sampling and Allometry. FIA inventory-based estimation for standing dead trees is from P2 plot, condition, and tree records. Tree mass in the FIADB is calculated according to CRM methods (Woodall et al., 2011) with refinements to the CRM approach specific to standing dead trees proposed by Domke et al. (2011). During a standard forest inventory, standing dead trees are measured and tallied, and large landowners can use this information with FVS to produce estimates of the biomass and carbon in this pool.

Lookup Tables. Published summary values of similar or representative forests provide quick and inexpensive means of roughly assessing likely forest carbon. A good example of such lookup values are the past revised 1605(b) guidelines, with the forest tables published as Smith et al. (2006). Alternative versions of representative values include FIA online applications such as FIDO or EVALIDATOR, and FIA-related applications such as COLE. Note that some differences may appear among pool estimates compared to the sample estimates, because some or all are based on empirical models (regressions) and not the direct plot-level measurements that are now available within the FIADB. Small landowners can obtain estimates of the standing dead pool using the Smith et al. (2006) lookup tables.

6.2.3.4 Down Dead Wood

The recommended method for obtaining estimates of carbon stock of DDW for large landowners is estimation from transect data collected during the inventory. Care should be taken to adhere to the bounds between the DDW and forest floor pools (noting that fine woody debris is considered part of the forest floor pool in this guidance). Small landowners may refer to the lookup tables for pool estimates.

Sampling and Allometry. A variety of sampling and estimation protocols is available for the DDW pool; a straightforward and commonly used approach can be found in Pearson et al. (2007).

Lookup Tables. Regional averages by forest type are as described in Smith et al. (2006), or estimates can be summarized and extracted from the FIADB condition table to correspond to the entity's forest. However, note that the current FIADB's DDW from the condition table is a model independent of P3 sampling. See Smith et al. (2006), U.S. EPA Annex 3.12 (2010), Woodall et al. (2013), and Domke et al. (2013) for details.

Simulations/Modeling. DDW carbon values are provided in the carbon reports in FVS. Values may be supplied by the landowner; if these data are not available, regional default values based on P3 data or available data for the region and forest type are automatically input by the model.

6.2.3.5 Forest Floor or Litter

Recommended options for obtaining estimates of carbon stock of forest floor for all landowners is the use of lookup tables based on forest type, region, and stand age. Large landowners who are changing land uses from non-forest to forest may wish to collect data for this pool.

Sampling and Allometry. Landowners wishing to estimate these pools from field data can use fine woody debris sampling and carbon conversion according to Woodall and Monleon (2008), and forest floor using the approach described by Pearson et al. (2007). Note that while Pearson et al. (2007) apply a mass to carbon conversion factor of 0.5 (Smith et al., 2006)), others use a conversion factor of 0.37. Landowners who are estimating the forest floor pool using field data should apply the 0.37 conversion factor.

Lookup Tables. Regional averages by forest type are as described in Smith et al. (2006); estimates can also be summarized and extracted from the FIADB condition table to correspond to the entity's forest. These estimates are based on simulations described in Smith and Heath (2002). Note that the current FIADB condition table estimates of forest floor are these modeled values independent of the P3 sampling.

Simulations/Modeling. Forest floor carbon values are provided in the carbon reports in FVS. Values may be supplied by the landowner; if these data are not available, regional default values based on P3 data or available data for the region and forest type are automatically input by the model (FVS employs the 0.37 mass to carbon conversion factor when estimating this pool).

6.2.3.6 Soil Organic Carbon

Possible options for obtaining estimates of SOC stocks are:

- Sampling, following standard field methods;
- Datasets such as the Soil Survey Geographic (SSURGO) Database, State Soil Geographic (STATSGO) Database, or the Digital General Soil Map of the United States (STATSGO2); and
- Stand/forest classification: extract range of modeled estimates from FIADB condition table.

Sampling and Allometry. Soil sampling and carbon estimation according to FIA P3 plot protocols can be found at the USDA Forest Service FIA Library: Field Guides for Standards (Phase 3) Measurements;[7] methods are also available in Pearson et al. (2007), Hoover (2008), and others.

Soils data are generally considered difficult to measure and spatially quite variable. The consequence is that the costs are high and the payoff is likely low. Our recommendation is that sampling is only useful if there is an important reason to do so, such as a change from non-forest to forest or vice versa. If a wildfire occurs and there is significant consumption of peatlands, sampling should be conducted and emissions calculated using FOFEM and/or CONSUME models. This situation is most likely to be found in the Southeast or North Central States.

Lookup Tables. Forest soil organic carbon estimates—representative values or lookup tables. Data sets such as STATSGO or SSURGO are possible sources. Estimates can be summarized and extracted from the FIADB condition table to correspond to the entity's forest; these are based on a STATSGO/P2 overlay (Smith et al., 2006; U.S. EPA, 2010).

6.2.4 Limitations, Uncertainty, and Research Gaps

There is often tremendous uncertainty associated with estimates of forest carbon baselines, such that even at large scales (e.g., state-level) the power to detect statistically significant changes in forest carbon stocks is limited to major disturbances (Westfall et al., 2013). Compounding the sampling error often associated with forest inventories, there is measurement and model error that may not be acknowledged. Users of any inventories, lookup tables, or models should remain aware of these potential errors during their application of information.

There is a level of uncertainty associated with not only tree volume/biomass equations, but also with the various forest carbon pools (e.g., belowground to forest floor) found across a diversity of forest ecosystems (e.g., tropical to boreal) in the United States. Research to refine approaches to forest carbon accounting and refinements of associated models is currently in progress. Perhaps

[7] http://fia.fs.fed.us/library/field-guides-methods-proc/

some of the most needed improvements are for individual tree volume/biomass equations, especially for traditionally non-commercial species. Another forest carbon pool that is being investigated is soil organic carbon. Although the soil carbon pool is not expected to change quickly in comparison to live tree pools, in many areas of the United States it is the largest carbon stock (e.g., northern Minnesota). Beyond reducing the uncertainty associated with estimates of carbon pools, research is being conducted to refine understanding of the effects of disturbance and climate change on carbon pools.

6.3 Establishing, Re-establishing, and Clearing Forests

Methods for Establishing, Re-establishing, and Clearing Forest

- IPCC algorithms developed by Aalde et al. (2006).
- These options use:
  - Allometric equations from Jenkins et al. (2003a), or FVS with the Jenkins et al. equations where applicable; and
  - Default lookup tables from Smith et al. (2006; GTR NE-343)—default regional values based on forest type and age class developed from FIA data.
- These methods were selected because they provide a range of options dependent on the size of an entity's forest land.

6.3.1 Description

Conventional parlance attributes changes of carbon on a site undergoing land-use change into three directional processes: establishing (i.e., afforestation), re-establishing (i.e., reforestation), and clearing forest (i.e., deforestation). In recent years, the term forest degradation has been used to acknowledge that an existing forest can be significantly reduced in carbon stocks and can be considered a source of emissions, as long as the reduction in carbon stocks is not an aspect of normal forest management. However, this is not a form of land-use change because the land remains in forests. This is an important consideration under forest management, but may also be important when human use and removals of forest stocks take place even when not prescribed by a management regime. The most important source of GHG emissions from forests is associated with forest clearing (IPCC, 2007). The conversion of forests to other land uses immediately reduces the stock of carbon in aboveground biomass and soil organic matter, and is likely to reduce the long-term carbon storage potential of the land. The carbon that was once stored in forest biomass and soil is reduced through rapid oxidation by fire or slowly over time by microbial decomposition. Some of the biomass can also be removed from the site and converted to forest products such as lumber, paper, pulp, and other products that have longer term but variable decomposition rates—and hence longer term and variable emissions over time. All of these components of land-use change need to be accounted for when determining the changes in site carbon stocks due to land-use change.

A parcel of land can be converted to forest, plantation, or other treed landscape either through intentional planting or the natural process of secondary succession. Land that had once been in forest is returned to forest through re-establishment. Note that this applies to land that is not currently in forest, not to forest land that is regenerated as part of forest management. Land that had not been in forest, such as grasslands, can be converted to forests through establishment. In either case, generally speaking, the stock of carbon in biomass and soil organic matter will increase over time as a result of this type of land-use change. Biomass increases predictably as trees and other vegetation are established on the site. Soil organic matter also changes, but in less predictable ways. For instance, the establishment of a forest plantation on grassland in cool temperate regions may result in a temporary loss of carbon in soil organic matter before it builds up again after the plantation is fully established. For both accounting and planning purposes, these changes in stocks of carbon must be estimated and accounted for when assessing the effects of land-use change.

Current international definitions are presented below and draw a distinction between lands that have never been under forest cover and those which were in forest cover in the past but have not been forested recently (e.g., for the last 50 years). These definitions are presented here because they are commonly used in the literature; however, in terms of carbon accounting for live biomass, there is no practical difference between the two categories. The greatest impact is on the soil carbon pool. Where the aim is to estimate entity-level GHG fluxes, these two categories will be treated together and termed “establishing forest” in this guidance.

6.3.1.1 Establishing Forest

Establishment is the conversion of a non-forest site that is not naturally a forested or treed ecosystem or had never been in forest to a forest or similar tree-dominated land cover. Examples of establishment include the conversion of bare land to a forest and conversion of grasslands to forests or plantation. In practical terms, and for the sake of this guidance, land that had been in agriculture or other non-forest land cover for a long time (e.g., more than 50 years) that is converted to tree cover can also be viewed as establishment. Hence, established forest land is that which has not been dominated by trees for more than 50 years.

6.3.1.2 Re-establishing Forest

Re-establishment is the reversion of forests or tree cover on sites that had formerly and recently been (e.g., less than 50 years) in forest or dominated by tree cover. Examples of re-establishment include natural regeneration of a disturbed or cleared parcel of forest to a secondary forest, conversion of agricultural land to a forest, and establishment of a plantation on a site that had once been forest but is now in another land use (such as cropland). It is important to distinguish between re-establishment as a land-use change and forest regrowth as part of forest management or the result of a natural disturbance. For example, a land-use change from agriculture to forest is considered here as re-establishment, where forest regeneration following a wind throw or clear-cutting is not considered a land-use change resulting in re-establishment.

In the international conventions, the IPCC Special Report on Land Use, Land-Use Change, and Forestry (IPCC, 2000), which was developed explicitly for carbon inventory, defines re-establishment as "the establishment of trees on land that has been cleared of forest within the relatively recent past; the planting of forests on lands which have, historically, previously contained forests but which have been converted to some other use." Establishment and re-establishment both refer to establishment of trees on non-treed land. Re-establishment refers to creation of forest on land that had recent tree cover, whereas establishment refers to land that has been without forest for much longer. A variety of definitions differentiate between these two processes. Some definitions of establishment are based on phrases such as "has not supported forest in historical time;" others refer to a specific period of years, and some make reference to other processes, such as "under current climate conditions." The IPCC Guidelines define establishment as the "planting of new forests on lands which, historically, have not contained forests" (IPCC, 2000).

As noted above, for the practical purposes of reporting under these methods, a change from non-forest to forest cover will be termed establishing forest, and the 50 year time horizon will not apply.

6.3.1.3 Clearing Forest

Clearing is the conversion of a forest or tree-dominated site to another land use other than forest or a tree-dominated site. Often clearing results in the complete removal of aboveground live biomass. Examples of clearing include the conversion of a forest woodlot to cropland or pasture, conversion of a forest woodlot to commercial or residential use, and conversion of a natural forest to agriculture.

6.3.1.4 Other Important Considerations

Distinction between Land-Use Change and Land-Cover Change. It is very important to understand and delineate the difference between land-*cover* change and land-*use* change. Because the terms "land use" and "land management" are often confused or used interchangeably the distinction is defined here. A basic definition of land cover is "the observed physical and biological cover of the Earth's land as vegetation or human-made features." A basic definition of land use is "the total of arrangements, activities, and inputs undertaken in a certain land-cover type (a set of human actions). The social and economic purposes for which land is managed (e.g., grazing, timber extraction, conservation)." The conventions found in the literature—Turner et al. (1994), Skole (1994), and Lambin et al. (2006)—are followed and were adopted by the IPCC in 2000. It is recognized that in adoption of the terminology of land use, land-use change, and forestry, the IPCC Good Practice Guidance document (IPCC, 2006) generalized the use of terms to include the six broad land-use categories defined in IPCC (2003) Chapter 2 and recognized that these land-use categories are a mixture of land cover (e.g., forest, grassland, wetlands) and land use (e.g., cropland, settlements) classes. For convenience, they are here referred to as *land-use* categories.

We recognize here that the term land-use change can be adopted to include land-cover changes, as well as land-use changes. Thus, for this guidance, as with IPCC, land-use change will be the conversion of the "type of vegetation" from one cover type, such as a forest dominated by trees, to a completely different cover type, such as cropland dominated by non-woody food crops. The direction of cover change determines the nature of the change in carbon stocks (e.g., forest clearing versus establishment). Generally speaking, land-use change is the most important consideration for a landowner, since this process usually results in the largest change in onsite carbon.

However, we also recognize that landowners will have important changes to their lands through the management activities that they deploy, and these activities can have important implications for carbon stocks and GHG emissions and removals. Thus, we also recognize the concept and terminology of land-management change, which is a change in the type of activity being carried out on a unit of land, and thus how it is managed or used, such as changing the management practices within a forest from selective harvest to protection. Land-management change may or may not have a significant impact on carbon and other GHGs.

Land management explicitly refers to how the land is being managed or used, while land use refers to what is on the land. An example of land management is a tree-dominated site that is used as a working forest or woodlot. As such, a landowner can change the management plan for the site—for instance, changing its use to a forest reserve —without radically changing its cover. Nonetheless, even such change in use can affect the amount of carbon stored on the site and in the soils. Typically, when a forest stand land management is changed without affecting its cover type it is considered a managed forest, and its accounting protocols follow those for forest management rather than for establishing forests. Thus it is important to determine and document both the land-use and land-management changes that occur on the site, and explicitly associate the carbon estimation approach to either establishing/clearing forests (Section 6.3) or forest management (Section 6.4), but not both.

Establishing and Clearing Forest versus Forest Management. For reasons of order and consistency, establishing and clearing forest is distinguished from management, which is addressed in Section 6.4. Forestry operations such as thinning, artificial regeneration, and harvesting are associated with managed forest systems. Unless forestry activities lead to a change from one land use to another land-use, these activities are not treated using establishing and clearing forest accounting principles. The initial conversion from forest to agriculture, for example, would use the establishing and clearing forest rules, followed by the application of rules for agriculture. Similarly, when a non-forest land cover is converted to a managed forest the initial conversion would be treated as establishing forest and use these methods, but subsequent management of the stand would follow forest management (e.g., forest carbon accounting and forest management) methods.

Types of Forest. From a strict carbon accounting point of view, the land-cover designation does not matter, nor does its change in cover type as long as one has good estimates of carbon stocks, and can measure or estimate their changes. However, data used to estimate changes in carbon are often reported and organized by forest type, so the composition and structure of the forest often comes into the computation methods. Moreover, to avoid double counting, it is important to define what type of landscapes can be considered as a forest for establishing and clearing forest. There are two elements of a definition of forests that are warranted. The first is a basic definition of a forest. There are a range of conditions of treed landscapes where establishing and clearing forest activities can take place, from preserved forests to woodlots to open and widely spaced tree landscapes and urban treed landscapes. There are hundreds of variations of definitions of forest (Lund, 1999) and for each of these there are subtypes. Examining the implications of each variant would not be fruitful; the result would be greater confusion, rather than the clarity sought. In a strict sense, a forest is defined here using the U.S.-specific definition of forest land (Smith et al., 2009). These are lands with tree crown cover (or equivalent stocking level) of more than 10 percent, width of at least 120 feet (36.6 m), and area of 1 acre (0.4 ha). Trees should be able to reach a minimum height of 6.6–16.4 feet (2–5 m) at maturity *in situ*. A forest-land unit may consist of closed forest formations where trees of various stories and undergrowth cover a high proportion of ground, or open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent.

Second, landowners may have a diverse land base that is affected by different forestry activities, managed at different intensities, or that has a variety of existing data. One of the first steps in preparing entity-wide or sub-entity estimates of carbon fluxes from forests is to organize the underlying data on land conditions into manageable units, referred to here as forest *strata*. Land should be grouped into forest strata using a logical framework that aggregates similar land units. For example, land could be partitioned by average tree age, forest type, productivity class, and management intensity. In many cases forest strata will be contiguous, although this is not a necessary condition. The landowner can select the type of stratification scheme to employ; and there are several guides available to do this. The better the stratification, the more accurate and precise are the carbon estimations with the minimal amount of data collection.

The definition of a forest is useful for consistency in reporting and covers a wide range of conditions. However, note that the technical methods can apply to any treed landscape. The adoption of the international nomenclature for forests allows the consideration of a range of site conditions and situations. Forests in the United States are varied, from scrub woodlands in semi-arid zones to mature deciduous and coniferous complexes in the humid zones. In addition, human managed systems, such as woodlots and plantations, are considered as forests.

Similar Modalities and Variants of Establishing, Re-establishing, and Clearing Forest. This section recognizes that establishing and clearing forest are similar to and indeed conceptually related to several other land-cover change modalities, which are treated in other protocols. These include but are not limited to agro-forestry, which involves the use of trees on farms; urban forests and widely spaced tree complexes; trees on landscapes outside of forests; woodlands and savanna systems; orchards; and palm and horticulture complexes. Although the measurement and estimation methods described here may be easily adapted to these land covers and land uses, they are not treated in this section.

6.3.2 Activity Data Collection

Activity data are measurements or estimations of magnitude of human activity resulting in emissions or removals taking place during a given period of time. Most often the area of land that is converted from one land use to another is the most important type of activity data. Data on area burned, management practices, and lime and fertilizer use are other examples of activity data. For establishing and clearing forest, activity data consists mostly of information, preferably in map form with delineated boundaries. For small landowners, it is possible to delineate an area of land-cover change by foot using simple distance measurements or with the aid of a GPS. A landowner may have different activities occurring on a single property, and thus each of the forest strata should be mapped and have separately delineated activities. Remote sensing or aerial photography can be useful for any landowner with access to these data, but are especially useful for larger land units. Historical information on changes in the areas of land uses on a property is also important, and these data are frequently found in air photo archives or other map records. In addition to the areas and rates of clearing and/or establishment, it is necessary to collect data on specific aspects and details of these activities. This may include data on tree types, biomass, clearing intensity, wood removals, tree planting densities, and other factors that described the modality of the establishing and clearing forest activities.

6.3.2.1 Establishing Forest

For an establishment activity, it is important to gather basic information on the area and location of each stratum of land use that is being established. For the most part an establishment activity will be a plantation or similar type of establishment/forestation activity. Thus, basic information on site preparation, species selection, and densities of plantings can be used with a projection of the long-term plan for the site to make a reasonable *ex-ante* calculation. If natural regeneration is the primary means of establishment, estimates of seedling counts can be used to develop a growth projection. Alternatively, regional yield tables may be used to estimate projected stocks. The prior use and management of the stratum or land use should also be documented, since the historical use of the land influences carbon stock and stock change estimates. For instance establishment of a forest stand on grassland will have a different result in terms of carbon than establishment on a row crop agricultural field. Once a forest is well established, for all practical purposes it becomes a managed forest and should be treated using the methods in the next section on forest management. We consider the land-use stratum to be a forest when the characteristics of the stand meet the definition of a forest. Most often this will be when the site is well stocked to the definitional crown cover and height of trees.

6.3.2.2 Clearing Forest

The most important activity data to collect are the area and rates of forest clearing for each stratum or parcel in the project area. It is also important to know the intensity of clearing and if there are remaining trees or other vegetation left on site after clearing. To estimate emissions, it is necessary to know also the characteristics of the stratum that is to be cleared, including the biomass and soil organic matter of the site. The process of clearing a site is an activity that can also be characterized. Information needed includes the fraction of the aboveground biomass that would be burned, the fraction that is left behind onsite as slash and debris, the fraction that would be removed in the form of wood products, and the fraction that is removed in the form of other products.

6.3.3 Estimation Methods

This section lays out the minimum necessary parts of a computation scheme for estimating carbon stocks and carbon emissions in biomass and soil associated with establishing and clearing forest. The descriptions laid out here are generalized. The basic concept behind them is simple: the stock, or mass, of carbon on a site changes, and the task of estimation is to compute the difference in stocks between the land use before and after the intervention or disturbance. When a site is cleared, stocks go down and this results in emissions to the atmosphere. When a site is established, stocks go up and this results in removals from the atmosphere.

6.3.3.1 Units of Measurement

All stock computations are performed in terms of mass of carbon in kilograms or metric tons per unit area in metric system units (carbon per hectare or C ha^{-1}). Rate data are reported in terms of change in carbon per ha over time, as in carbon per hectare per year (C ha^{-1} $year^{-1}$). All carbon biomass is referenced to its dry weight basis and the fraction of biomass in carbon. For the purpose of this guidance, the fraction of dry biomass that is carbon is 0.5. An example stock is 100 metric tons C ha^{-1}, and an example stock change is 100 metric tons C ha^{-1} $year^{-1}$. It is important to differentiate between units of carbon and CO_2 equivalents (CO_2-eq) and report the appropriate units to the reporting entity. For example, some reporting programs (e.g., carbon markets) require the conversion of metric tons of carbon to metric tons CO_2-eq. This convention places all carbon mass estimates into units of CO_2, which can be derived by multiplying the carbon mass by 44/12.

6.3.3.2 Stocks and Fluxes

The stock of carbon is the amount of carbon in biomass and soil on a site. The stock change is the difference in the stocks from one time period to the next. This change can be positive or negative, depending on whether the site is experiencing clearing, degradation, restoration, or establishment. Declining stocks over time from clearing or degradation result in emissions, while accumulating stocks over time from establishment or restoration are referred to as sequestration.

6.3.3.3 Delineating and Characterizing the Site Used in Computation

To estimate carbon stocks and fluxes, it is necessary to define the mapped extent and the features of the site. For small areas, such as a farm woodlot or forest stand, the boundaries are defined geographically using a GPS device. If surveyors' reports or other forms of maps and photos such as aerial imagery are available, they can be used. There are a growing number of online tools that are available (e.g., Google Maps) that provide detailed imagery of land that can be used to draw boundaries of the proposed sites. After defining the precise boundaries, a land-cover classification should be performed to define the various vegetation, cover, or soil strata within the site. For instance, a re-establishment project with two zones within the boundaries, one for a commercial plantation and the other for natural regeneration, would be stratified into two stands. If the project or property is to be a single cover, such as a natural regeneration forest or a plantation forest, the project site can be a single stratum; but other factors may be important, such as land slope or soil conditions. If there will be a future management activity associated with the project, this stratum should also be delineated. In short, any area within the project boundary that would have different cover or carbon characteristics should be separately delineated. Standard mapping coordinates, projections, and geodetic datums should be used.

6.3.3.4 Carbon Pools under Consideration

Generally, IPCC and other sources reference five pools of carbon to measure—aboveground live biomass, belowground live biomass, standing dead and downed debris, litter, and soil organic carbon. The landowner or project developer should identify from the beginning the pools that will be accounted. All pools should be included, unless one can show that a pool's stock changes are small and unimportant—the *de minimis* assumption (less than 10 percent of the total baseline stock, see more below)—or can show that a pool would not have stock losses or emissions (e.g., forest clearing). In these cases, the landowner is choosing to be conservative in estimation of the impact of the establishing and clearing forest on the atmosphere for that pool. For instance, in an establishment project where the estimation of soil carbon change may be difficult, time consuming, or costly, and the soil carbon change is assumed to be *de minimis* in magnitude, it may be eliminated. Or, if it can be demonstrated that the soil pool will be accumulating carbon, the landowner may select to not count that pool and thus be conservative in the sequestration potential of the project. Wood products that are removed from the site through harvest are not by themselves considered a separate pool, but the landowner is advised to document this amount and its fate, whereby fate can be, for example hardwood products, paper products, or firewood (see Section 6.5).

6.3.3.5 Initial Carbon Stock Measurement

The carbon stocks in the measured pools that are to be reported need to be determined at the beginning of the project in order to define a reference carbon amount to which future changes will be compared. Whether the site is a forest before its conversion or agricultural land before re-establishment of tree cover, the initial conditions in terms of carbon must be reported. The initial carbon stocks in all strata are individually determined from lookup tables, satellite imagery, or FIA database, or are measured and reported according to the detailed measurement methods given below. The reporting of the baseline can get complicated in some cases. Typically the baseline is the current carbon stocks. However, in situations where the carbon stocks are changing, the baseline is computed over time as the forward looking carbon stocks that would occur in the absence of the project or intervention.

6.3.3.6 The Ex-Ante Computation

Once initial carbon stocks are determined (the Type I estimate), the project developer needs to make a forward projection of the expected carbon stock changes, and its deviation from what would have occurred on the site without the intervention of a project or land-cover change (Type II and III estimates). This is somewhat problematic since it is not possible to predict the future with certainty. However, a number of tools and methods are available to make these projections with reasonable certainty (see Table 6-3). An important reason for making this computation is that the carbon stock would change over time in the absence of the project's intervention. For example, an abandoned farm field could be expected to naturally go through old-field succession even without a reestablishment project. Hence, the project-related carbon changes need to be compared with the no intervention/no action estimate over time, not just from the start of the project, to get a true accounting of net carbon benefits. Landowners would want to make the *ex-ante* computation so that they can evaluate a range of future establishment, clearing, or management options to select the one that best suits their carbon and other outcome needs.

6.3.3.7 Measurement and Monitoring

After the initiation of the project intervention (e.g., tree planting), ongoing measurements of actual carbon stock changes need to occur. This is often referred to as the monitoring phase of the project. Methods for ongoing measurement are described below. The project developer should keep organized records of the measurements made over a routine and standard time frame. Annual measurements are usually either not logistically possible or too time-consuming and expensive.

Thus, it is recommended that after the initial measurement, these measurements are repeated every 5 years.

6.3.3.8 Permanent Sample Plots

For small projects such as farm woodlots, or tree and forest stands, a complete inventory of carbon in the reporting pools, strata, and project land can be performed. However, for large areas, installing and delineating a number of sample plots is required. These sample plots are established in the project area on a stratified basis, laid out randomly or systematically—i.e., each land cover stratum has an established number of systematically or randomly placed plots. Methods for forest inventory are well described and available from a variety of sources and will not be further described here (e.g., Pearson et al., 2007). Both the number and location of the plots need to be considered. It is important to remember that the plots are established for the purpose of sampling a forest stand or project stratum. The sample estimate will be as accurate as the number and location of the sample plots permit. The number of plots will relate to the accuracy of the estimates; in simple strata such as plantations, the number of sample plots can be extremely low, but in complex natural stands the number will have to be greater. A good stratification will reduce the necessary number of plots. The location of the plots is important to capture the spatial heterogeneity of the stand. The plots are to be well marked and made permanent for repeat measurements over many years. For forest clearing computations, it is not necessary to make permanent plots unless the process of clearing is selective degradation over a long period of time. For forest clearing, lots only need to be measured once before the intervention and once after the intervention has been completed.

6.3.3.9 Measurement versus Estimation

In some cases, it will not be possible to measure the initial carbon stocks or post-intervention carbon directly. For instance, a forest clearing event may occur without the opportunity to establish plots in the forest, or it may not be possible to measure a large-area establishment event. In these cases, regional summary values of the forest carbon stocks may be of use (Smith et al., 2006).

6.3.3.10 Allometry, Biomass Expansion Factors, and Standard Values

The conventional approach to biomass estimation is to use allometric equations based on species-specific information (Jenkins et al., 2003b; 2003a). An allometric approach can be based on DBH or a combination of DBH, canopy height (H), and wood density on an individual tree basis for the entire stand or for trees in the permanent plots. The allometric equation predicts either volume of wood in the main stem or whole tree biomass or carbon. In the former case, it is then necessary to estimate a whole tree biomass expansion factor (Smith et al., 2003). Alternatively, the entity can use standard values for stocks and growth rates based on lookup tables (DOE, 1992; Smith et al., 2006). For large areas of forests converted through clearing, it may be acceptable to use standard values for stocks per unit area, such as those published by IPCC (2003; 2006).

6.3.3.11 Stocks versus Change in Stocks over Time

For estimation of forest establishment it is necessary to compute the change in stocks over time, which will be a measurement of net sinks of carbon through sequestration. Forest clearing computation is essentially the same but with the opposite sign to indicate emissions. The subtle difference is that establishment requires some means to estimate the accumulation of carbon on the project site over time. This is accomplished using either direct measures or yield models. For forest clearing, it is necessary to know the initial stock of carbon in the forest stand, and how it then changes with disturbance. The latter requires data on the partitioning of post-disturbance carbon components, as removals, and slash and debris left on site.

6.3.3.12 Forest Clearing Removals and Dead Material on Site

The difference of carbon stocks before and after forest clearing is the carbon that has been removed by harvest as wood products or other products (e.g., energy feedstocks), and that left behind on the site as slash and debris (Skog, 2008). If these mass amounts are known, they can be included directly into the computations. If they are not known, they can be estimated and represented as fractions of the original standing stocks prior to disturbance. All removals such as these constitute immediate and future emission sources, as they decay over different time scales. Therefore, it is necessary to assign mass amounts to four long-term decay pools with turnover times of 1, 10, 100, and 1,000 years. The emissions are computed along an exponential decay function related to the turnover time of the pool. For example, carbon lost due to immediate oxidation by fire is placed into the 1-year pool, and the charcoal component is placed into the 1,000-year pool. Other removals are placed into the 10- and 100-year pools.

6.3.4 Specific Protocol for Computation

6.3.4.1 Actual Carbon Removals by Sinks in Establishing Forest

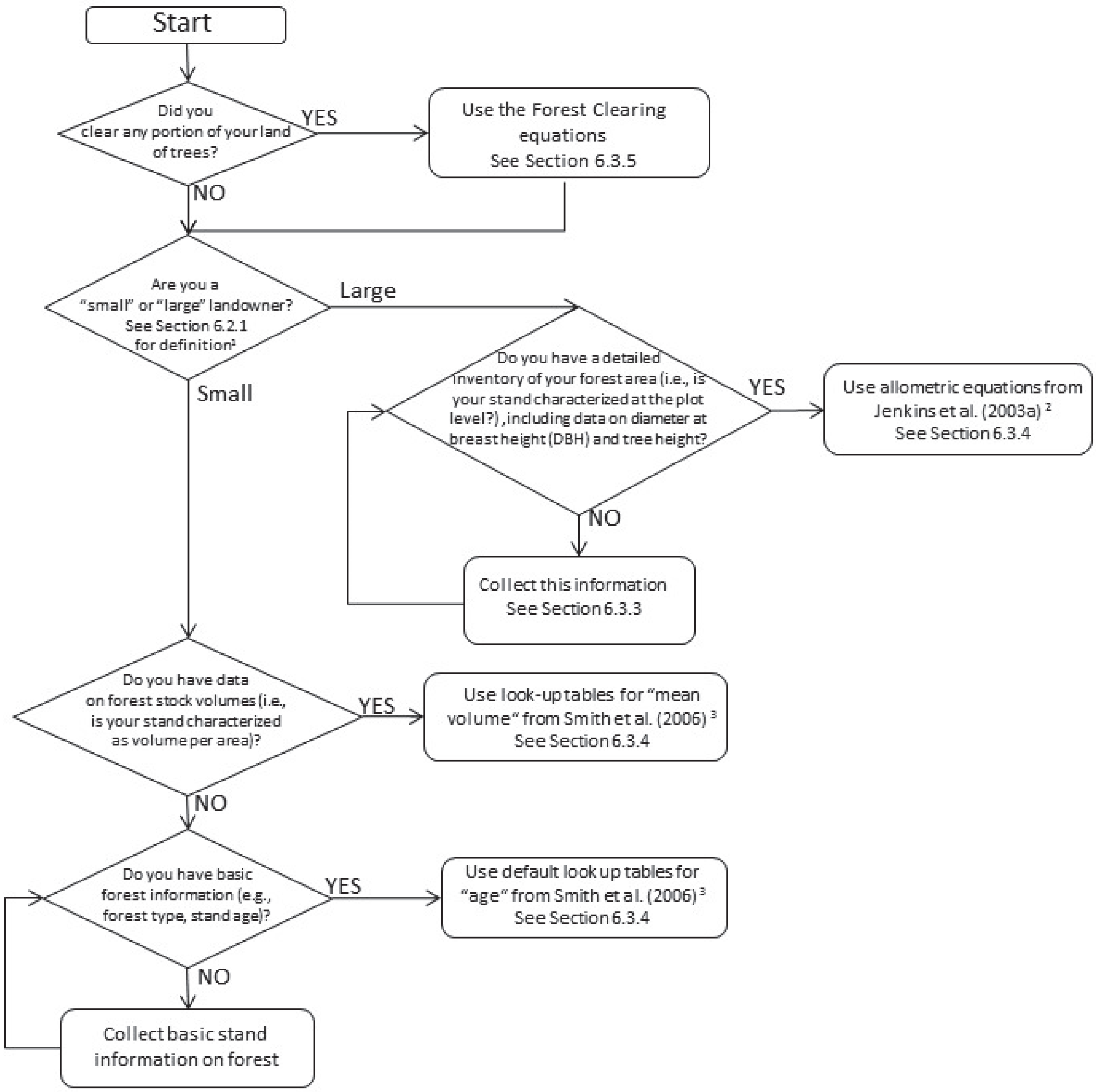
The basic approach to estimation of emissions to, or removals from, the atmosphere is to multiply the activity data by emission factors or, in this case, multiply the land-use change area by site biomass carbon and soil organic matter carbon. These procedures describe the recommended method of estimating carbon—using allometric equations to estimate biomass directly from DBH using the equations of Jenkins et al. (2003a).

Stratification of the project area may be carried out to improve the accuracy and the precision of the carbon estimates. Where required, stratification could be made according to tree species, age classes, or forest management practices. Figure 6-5 shows a decision tree indicating which method is more applicable for a particular landowner.

This protocol will follow the two-tier approach described earlier in the document. Small landowners can use default tables (i.e., Smith et al., 2006) and equations for the appropriate region and forest type group to estimate biomass of their forest systems. Large landowners should use basic forest data collected in the field on sample plots with allometric equations (Jenkins et al., 2003a) to estimate the biomass of individual trees and entire stands. If small landowners want to use sample plots and allometric equations, they are free to do so. Small landowners should contact a consulting forester or perhaps a university extension person to best understand requirements for field sampling.

While most of the fluxes from an establishment project are removals from the atmosphere, there may be some emissions associated with some aspects of the project. The actual net CO_2 removals by sinks can be estimated using the equations in this section. When applying these equations for *ex-ante* calculations of net anthropogenic CO_2 removals by sinks, landowners will provide estimates of the values of those parameters that are not available before the start of the project period and commencement of the monitoring activities. Participants should retain a conservative approach in applying these estimates.

Figure 6-5: Decision Tree for Establishing, Re-establishing, and Clearing Forests Showing Methods Appropriate for Estimating Forest Carbon Stocks



[1] Small landowners (see Section 6.2 for definition) may use generalized lookup tables based on region, forest type, and age class to estimate carbon stocks. Large landowners (see Section 6.2 for definition) should collect standard forest inventory data and use allometric equations to estimate live tree biomass carbon (other carbon pools may be obtained from lookup tables). However, large landowners who do not engage in any management activities or plan to manage their holdings may use lookup tables for all pools; but if active management occurs, the inventory approach should be used.

[2] Jenkins et al. (2003a).

[3] Smith et al. (2006).

The actual net CO_2 removals by sinks in year *t* are equal to:

Equation 6-1: The Actual Net CO_2 Removals by Sinks in Year *t*

$$\Delta C_{ACTUAL,t} = \Delta C_{PJ,t}$$

Where:

$\Delta C_{ACTUAL,t}$	= Actual net CO_2 removals by sinks in year *t* (metric tons CO_2 eq $year^{-1}$)
$\Delta C_{PJ,t}$	= Project CO_2 removals by sinks in year *t* (metric tons CO_2 eq $year^{-1}$)

Equation 6-2: Project CO_2 Removals by Sinks are Calculated as Follows (between two dates for a time period of *t*)

$$\Delta C_{PJ,t} = \sum_{i=1}^{t} \Delta C_{project,i,t} \times 44/12$$

$$\Delta C_{project,i,t} = [(C_{trees,i,t2} - C_{trees,i,t1}) / T] + \Delta C_{soil,i,t}$$

Where:

$\Delta C_{PJ,t}$	= Project CO_2 removals by sinks in year *t* (metric tons CO_2 eq $year^{-1}$)
$\Delta C_{project,i,t}$	= Average CO_2 removals by living biomass of trees and soil for stratum *i*, for year *t* (metric tons carbon $year^{-1}$)
$C_{trees,i,t}$	= Carbon stock in living biomass of trees for stratum *i*, in year *t* (metric tons carbon)
$\Delta C_{soil,t}$	= Average annual change in carbon stock in soil organic matter for stratum *i*, for year *t* (metric tons carbon $year^{-1}$)
T	= Number of years between years t_2 and t_1 (years)

Estimation of Carbon Stock in Living Biomass of Trees at the Stratum Level. The carbon stock in living biomass of trees for stratum *i* ($C_{trees,i,t}$) is estimated using the following approach: The mean carbon stock in aboveground biomass per unit area is estimated based on field measurements in permanent sample plots.

Step 1: Determine based on measurements (*ex post*), the DBH at typically 4.3 feet (1.3 m) above ground level, and also preferably height (H), of all the trees above some minimum DBH in the permanent sample plots.

Step 2: Calculate the aboveground biomass for each individual tree of a species, using allometric equations appropriate to the tree species (or groups of them if several tree species have similar growth habits) in the stratum.

Step 3: Estimate carbon stock in aboveground biomass for each individual tree *l* of species *j* in the sample plot located in stratum *i* using the selected or developed allometric equation applied to the tree dimensions resulting from **Step 1**, or multiply the result of **Step 2** by 0.5 (i.e., the fraction of dry biomass to carbon conversion factor), and sum the carbon stocks in the sample plot.

Step 4: Convert the carbon stock in aboveground biomass to the carbon stock in belowground biomass using the equations provided in Jenkins et al. (2003a) or by multiplying the result of **Step 3** by 0.26 (i.e., the root-to-shoot ratio). Sum the aboveground carbon stock and belowground carbon stocks.

Step 5: Calculate total carbon stock in the living biomass of all trees present in the sample plot *sp* in stratum *i* at time *t*.

Step 6: Calculate the mean carbon stock in living biomass of trees for each stratum, as per Equation 6-6.

Equation 6-3: Estimate Carbon Stock in Aboveground Biomass for Each Individual Tree

$$C_{AB,\,i,\,sp,\,j,\,t} = \sum_{t=1}^{N_{j,\,sp}} CF_j \times f_j\,(DBH,\,H)$$

Where:

$C_{AB,i,sp,j,t}$ = Carbon stock in aboveground biomass of trees of species *j*, on sample plot *sp*, for stratum *i* (metric tons carbon)

CF_j = Carbon fraction of dry matter (dm) for species or group of species type *j* (metric tons carbon (metric ton dm)$^{-1}$)

f_j (DBH,H) = An allometric equation linking aboveground biomass of a living tree (metric tons dm) to DBH and possibly tree height (H) for species *j*, in year *t* (metric tons dm)

Note: For *ex-ante* estimations, mean DBH and H values should be estimated for stratum *i,* in year *t* using a growth model or yield table that gives the expected tree dimensions as a function of tree age. The allometric relationship between aboveground biomass and DBH and possibly H is a function of the species considered. Alternatively there are estimators and tools that project carbon growth rates directly without input of DBH.

i = 1, 2, 3, … M_{PS} strata in the project scenario

j = 1, 2, 3, … S_{PS} tree species in the project scenario

l = 1, 2, 3, … $N_{j,sp}$ sequence number of individual trees of species *j*, in sample plot *sp*

t = 1, 2, 3, … *t** years elapsed since the start of the project activity

Equation 6-4: Convert the Carbon Stock in Aboveground Biomass to the Carbon Stock in Belowground Biomass

$$C_{BB, i, sp, j, t} = C_{AB, i, sp, j, t} \times R_j$$

Where:

$C_{BB, i, sp, j, t}$	= Carbon stock in belowground biomass (BB) of trees of species *j*, in plot *sp*, in stratum *i*, for year *t* (metric tons carbon)
$C_{AB, i, sp, j, t}$	= Carbon stock in aboveground biomass (AB) of trees of species *j*, in plot *sp*, in stratum *i*, for year *t* (metric tons carbon)
R_j	= Root:shoot ratio appropriate for biomass stock, for species *j* (dimensionless)

Equation 6-5: Calculate Total Carbon Stock in the Living Biomass of All Trees Present in the Sample Plot

$$C_{tree, i, sp, t} = \sum_{j=1}^{Sps} (C_{AB,i,sp,j,t} + C_{BB,i,sp,j,t})$$

Where:

$C_{tree, i, sp, t}$	= Carbon stock in living biomass of trees on plot *sp* of stratum *i*, for year *t* (metric tons carbon)
$C_{AB, i, sp, j, t}$	= Carbon stock in aboveground biomass (AB) of trees of species *j*, in plot *sp*, in stratum *i*, for year *t* (metric tons carbon $tree^{-1}$)
$C_{BB, i, sp, j, t}$	= Carbon stock in belowground biomass (BB) of trees of species *j*, in plot *sp*, in stratum *i*, for year *t* (metric tons carbon $tree^{-1}$)
i	= 1, 2, 3, … M_{PS} strata in the project scenario (PS)
j	= 1, 2, 3, … S_{PS} tree species in the project scenario (PS)
t	= 1, 2, 3, … *t** years elapsed since the start of the project activity

Equation 6-6: Calculate Mean Carbon Stock in Tree Biomass for Each Stratum

$$C_{tree,\,i,\,t} = (A_i / Asp_i) \sum_{sp=1}^{Pi} C_{tree,\,i,\,sp,\,t}$$

Where:

$C_{tree,i,t}$ = Carbon stock in living biomass of trees in stratum *i*, for year *t* (metric tons carbon)

$C_{tree,\,i,\,sp,\,t}$ = Carbon stock in living biomass of trees on plot *sp*, of stratum *i*, for year *t* (metric tons carbon)

Asp_i = Total area of all sample plots in stratum *i* (ha)

A_i = Area of stratum *i* (ha)

sp = 1, 2, 3, … = Pi sample plots in stratum i in the project scenario

i = 1, 2, 3, … = M_{PS} strata in the project scenario (PS)

t = 1, 2, 3, … = t^* years elapsed since the start of the project activity

Soil Organic Carbon. For strata that contain only mineral soils, *ex-ante* and *ex-post* $\Delta C_{soil,\,i,\,t}$ change is estimated from Equation 6-7.

Equation 6-7: Estimating Change in Carbon Stocks for Strata That Contain Only Mineral Soils

$$\Delta C_{soil,\,i,\,t} = A_i * \Delta C_{forest,\,i} \text{ for } t \leq t_{equilibrium,\,i}$$

$$\Delta C_{soil,\,i,\,t} = 0 \text{ for } t > t_{equilibrium,\,i}$$

Where:

$\Delta C_{soil,\,i,\,t}$ = Average annual change in carbon stock in soil organic matter for stratum *i*, for year *t* (metric tons C $year^{-1}$)

A_i = Area of stratum *i*; hectare (ha)

$\Delta C_{forest,\,i}$ = Average annual increase in carbon stock in soil organic carbon pool for forest system in stratum *i* (metric tons C ha^{-1} $year^{-1}$)

$t_{equilibrium,i}$ = Time from start of the project activity until a new equilibrium in carbon stock in soil organic matter is reached for forest system in stratum *i* (years)

The default value of $\Delta C_{forest\ i}$ = 0.5 metric tons C ha^{-1} $year^{-1}$, and a $t_{equilibrium}$ of 20 years,$_i$ shall be used.

Changes in carbon stock in soil organic matter are not monitored *ex-post* (i.e., measured before and after the equilibrium period), but are instead estimated *ex-ante* (i.e., predicted based on the specified default value and equilibrium period).

Other Pools. Sample plots need to be set up in such a ways that the small herbs and bushes, as well as forest floor litter is also measured. To do this, establish several small collection plots measuring 3.3 feet by 3.3 feet (1 m by 1 m) on the forest floor. Collect all liter, herbs, and small debris in the subplot and weigh it using a field scale, and dry small sample to get the dry weight fraction.

Multiply the average dry weight of litter by 0.37 to compute the plot litter carbon, and by 0.5 to compute the plot herbs and seedling carbon. For small trees and bushes establish a few small plots measuring 16.4 feet by 16.4 feet (5 m by 5 m) in the sample plot. Cut and weigh all small trees and bushes. Establish a dry weight basis and multiply the dry weight by 0.5 to compute a subsample carbon value. Standing dead wood also needs to be estimated. Most published studies suggest this pool is small and can be ignored.

Non-CO_2 GHGs. Non-CO_2 GHGs, including CH_4 and N_2O are calculated based on emission factors applied to the parcel biomass. Thus, the parcel biomass is multiplied by a factor from default values for that time of stand or planting activity. These emissions and removals will vary depending on the management practice, e.g., natural succession, plantations, fertilization.

6.3.5 Actual GHG Removals and Emissions by Sources and Sinks from Forest Clearing

The above suite of equations can be used to estimate the sources and sinks of carbon from forest clearing, with the results having a different sign than establishment and re-establishment. The fundamental computation is in Equation 6-8.

Equation 6-8: Computing Emissions of Carbon from a Forest Clearing

$$E_d = f(D \times C/ha)$$

Where:

E_d	= Emissions of carbon from forest clearing, D (metric tons carbon year^{-1})
D	= The rate of forest clearing (ha year^{-1})
C/ha	= The stock of carbon in the forest system prior to clearing (metric tons carbon ha^{-1})

The precise computation in Equation 6-9 requires the measurement or estimation of the differences in carbon stocks in the forest system and the land-cover system that it is converted to. It also requires an understanding a computation of the partitioning of the products that were removed from the site or left as slash and debris. For material left onsite and burned, GHG emissions should be calculated using the CONSUME model. Hence, C_f is estimated from standard per-area forest type carbon stocks or from plot data. The fractions *fy* and *dy* are estimated or directly measured (for simplicity it is possible to assume that *dy* is the fraction of the turnover time, as in 1/1, 1/10, 1/100 or 1/1,000). E_s is the soil flux that is represented in lookup tables, and based on the time-varying rate of carbon loss as a percentage of the original forest soil carbon.

Equation 6-9: Computing the Partitioning of the Products That Were Removed from the Site or Left as Slash or Debris in 1 Year

$$E_d = D\,[\,(C_f - C_c) \times \sum_{i=1}^{y} (fy \times dy)\,] + E_s$$

Where:

E_d = Emissions of carbon from forest clearing, D (metric tons carbon year^{-1})

D = The rate of forest clearing (ha year^{-1})

C_f = The carbon stock prior to forest clearing (metric tons carbon ha^{-1})

C_c = The carbon stock after forest clearing (metric tons carbon ha^{-1})

fy = The fraction of original carbon stock in long-term decay pool *y*

dy = The decay function for the mass quantities in decay pool y (long-term decay pools are 1-, 10-, 100- and 1,000-year turnover times)

Es = Emissions from soil (metric tons carbon year^{-1})

6.3.6 Limitations and Uncertainty

There are published methods for formally estimating uncertainty of the estimation, generally based on the number and distribution of the permanent plots, and how they are applied to the whole stratum. These uncertainty estimates can be used *a priori* to establish the number of plots needed to achieve a level of accuracy. They can also be used to attach an uncertainty value to the final estimate. But perhaps the most challenging component of uncertainty lies in the use of various expansion factors where precise field estimates are not known. In particular, the estimation of non-CO_2 GHG fluxes is very uncertain, and must be used with some degree of caution. This is especially true for N_2O in all activities and CH_4 in cases of forest establishment. Considerably more research is necessary to make these estimates.

Another uncertainty in most estimates is the fraction of standing dead biomass. Based on some work (Woodall and Monleon, 2008), it is believed to be small, but the variation with forest types, stand age, conditions, and activities is large. When using default values this may be a challenge to the final estimation. In the case where direct measurements are to be made onsite, the standing dead can be measured along with standing live biomass. This may be an approach that has special benefit if the site being cleared has been intensely damaged by pests or disease.

Perhaps the most problematic area is the computation of whole tree biomass from allometry. There is a very good North American literature on allometry for stem volumes and biomass but less on whole tree volume and biomass. Most allometry is based on volumes rather than whole tree biomass or carbon. Frequently a limited number of simple expansion factors are deployed to expand the volume of the main stem to the biomass of the whole tree including its branches. These models need to be refined to better make the estimation. This may be important since most landowners will not have the ability or interest to conduct their own destructive tree sampling to extract local whole tree biomass allometry (i.e., a Tier 3 approach).

Table 6-3: Examples of Forest Carbon Calculators

Developer	Website
USDA Forest Service tools for carbon inventory, management, and reporting	http://www.nrs.fs.fed.us/carbon/tools/
FAO ExACT	http://www.fao.org/tc/exact/en/
TARAM (BioCF and CATIE)	http://wbcarbonfinance.org/Router.cfm?Page=DocLib&CatalogID=31252
CO_2Fix	http://www.efi.int/projects/casfor/models.htm
GORCAM	http://www.joanneum.at/gorcam.htm
CASS	http://www.steverox.info/software_downloads.htm
FullCam	http://www.ieabioenergy-task38.org/workshops/canberra01/cansession1.pdf
COLE	http://www.ncasi2.org/COLE/
Reforestation/Afforestation Project Carbon Online Estimator	http://ecoserver.env.duke.edu/RAPCOEv1/
Winrock AFOLU Calculator	http://winrock.stage.datarg.net/CarbonReporting/Welcome

6.4 Forest Management

Methods for Forest Management

- Range of options dependent on the size/management intensity/data availability of the entity's forest land including:
  - FVS-FFE with Jenkins (2003a) allometric equations;
  - Default lookup tables of management practice scenarios; and
  - FVS may be used to develop a supporting product providing default lookup tables of carbon stocks over time by region; forest type categories, including species group (e.g., hardwood, softwood, mixed); regeneration (e.g., planted, naturally regenerated); management intensity (e.g., low, moderate, high, very high); and site productivity (e.g., low, high).
- The methods were selected because they provide a consistent and comparable set of carbon stocks over time under management scenarios common to the forest types and management intensities.

6.4.1 Description

Forest management is concerned with meeting landowner objectives for a forest while satisfying biological, economic, and social constraints. Forest managers use a wide variety of silvicultural techniques to achieve management objectives, most of which will have impacts on the carbon dynamics (see Table 6-4). The primary impacts of silvicultural practices on forest carbon include enhancement of forest growth (which increases the rate of carbon sequestration) and forest harvesting practices (which transfers carbon from standing trees into wood products and residues, which eventually decay). Some forest management activities will result in accelerated loss of forest carbon, such as when soil disturbance increases the oxidation of soil organic matter, or when prescribed burning releases CO_2. Furthermore, some forest management activities result in fossil fuel emissions (e.g., from the utilization of mechanized equipment, transportation). However, recent evidence suggests these emissions are fairly minor. Markewitz (2006) estimated that fossil emissions from silvicultural activities in intensively managed pine plantations were about 3 Mg C ha^{-1} over a 25-year rotation. These emissions were very low relative to the subsequent sequestration of carbon in the forest and in wood products. Côté et al. (2002) report emissions from silvicultural activities totaled about 9 percent of total emissions from a pulp and paper operation and about 4 percent of gross forest sequestration. In a life-cycle analysis from the Pacific Northwest, Johnson et al. (2005) reported fossil emissions of CO_2 from forestry operations amounted to 8.02 to 8.12 kg CO_2-eq m^{-3} of harvested logs, or less than 1 percent of the 935 kg CO_2-eq contained in a cubic meter of a Douglas-fir log. In the dry Ponderosa pine forests of Arizona, a thinning treatment resulted in CO_2 emissions from fossil fuels of 334 kg CO_2-eq ha^{-1}, about 1.1 percent of the 30,213 kg CO_2-eq ha^{-1} of firewood removed in the thinning operation (Finkral and Evans, 2008).

This section describes general categories of forest management activities and their impacts on carbon storage. The details vary widely across the United States with different forest types, ownership objectives, and forest stand conditions. It is important to engage professional foresters when considering harvests or other silvicultural practices. An important distinction to be made at the outset is between planted forests, or plantations, and forests that have been naturally regenerated. Productivity rates, silvicultural practices, and management objectives may be markedly different for planted versus natural forests. In planted forests, conditions are typically optimized for increased growth, which increases carbon sequestration over slower growing, naturally regenerated forests. However, methods for inventorying, monitoring, and assessing carbon storage in both planted and natural forests are the same; variability may be less in single-species plantations, but approaches are identical. Small landowners will use the regional default tables to estimate the potential changes in GHG fluxes from changes in forest management, while large landowners will use standard forest inventory data in combination with the simulation feature of the FVS-FFE to assess changes in sequestration and emissions from changes in practice.

Table 6-4: Common Forest Management Practices

Practice	Description	Benefits
Stand density management	Controlling the numbers of trees per unit area in a stand through a variety of techniques, such as underplanting, precommercial thinning, and commercial thinning	▪ Maintains stand at a tree density that provides optimal growing space per tree for best utilization of site resources ▪ Allows concentration of site resources on “crop” trees
Site preparation	Preparing an area of land for forest establishment by removing debris, removing competing vegetation, and/or scarifying soil when needed	▪ Improves survival and initial growth of planted or naturally regenerated seedlings or sprouts ▪ Enhances regeneration of desired species ▪ Provides conditions favorable for planting of seedlings
Vegetation control	Removing, through chemical or mechanical means, undesirable vegetation that would compete with the desired species being regenerated	▪ Improves survival and growth of desired trees/species
Planting	Planting of seedlings by hand or machine to establish a new forest stand	▪ Controls species composition and genetics of newly established stand ▪ Controls stocking (density) of trees per unit area for optimal growth/survival

Practice	Description	Benefits
Natural regeneration	Establishing a new forest stand by allowing/enhancing natural seeding or sprouting	▪ Results in mix of species ▪ Species that sprout from stumps and roots will rapidly recapture the site ▪ Low cost relative to planting ▪ May involve less soil disturbance thereby reducing erosion
Fertilization	Augmenting site nutrients through the application of nitrogen, phosphorous, or other elements essential to tree growth	▪ Enhances growth of trees ▪ Reduces the time for trees to reach merchantable size ▪ Eliminates or reduces nutrient deficiencies that would impair forest growth/survival
Selection of rotation length	Choosing the timing of final harvest so as to optimize the mix of forest products that can be obtained from the stand	▪ Controls the relative amounts of pulpwood and sawtimber products ▪ Allows landowner to respond to wood products markets by optimizing product mix
Harvesting and utilization	Removal of trees from the forest, and cutting and separating logs for forest products markets	▪ Selection of appropriate harvesting systems can provide logs for markets while minimizing damage to residual trees or disturbance of soil ▪ Choice of harvesting and silvicultural cutting system will impact subsequent regeneration of the stand; systems can be chosen to influence the species composition of the regenerated stand
Fire and fuel load management	Reducing the risk of loss to wildfire by controlling the quantity of fuels in a forest stand by controlled fire or mechanical treatments	▪ Reduces the damage caused by severe wildfires by eliminating excessively high fuel loads ▪ May influence the species composition of the understory
Reducing risk of emissions from pests and disease	Recovering value of timber after damaging events and/or preventing further damage by interrupting spread of pests/diseases	▪ Salvage harvests recovers value in damaged timber by removing it before it is unusable ▪ Sanitation harvests prevent spread of pests/diseases
Short-rotation woody crops	Producing merchantable trees in very short time periods through intensive management (genetics, herbicide, fertilization)	▪ Reduces the time for trees to reach merchantable size

The remainder of this section describes these forest management practices and their impact on carbon stocks.

6.4.1.1 Stand Density Management

Management of forest stand density (number of trees per unit area) is important to achieve optimal growth. Overstocked stands (too many trees) or understocked stands (too few trees) will grow less fiber, and therefore store less carbon, than might be desirable. In overstocked stands, trees compete with each other for scarce resources (nutrients, water, and light), and such stands may have high numbers of trees of poor size and quality and are highly susceptible to wildfire or other reversal disturbances. Reducing the stocking in overstocked stands will concentrate growth in trees of more desirable species and quality. Understocked stands do not fully utilize the resources of the site and therefore do not achieve the growth potential of a fully stocked stand. Stand density management seeks to maintain a fully stocked stand.

Density of an existing forest stand may be increased by underplanting, which involves planting additional trees (possibly of different species) beneath an existing tree canopy. This treatment may be desirable for stands in which adequate advanced regeneration of desired species is lacking. Underplanting is designed to increase the likelihood of successful regeneration following the eventual harvest of the overstory. Thus, while the immediate carbon impact of this treatment is low, there may be substantial eventual improvement in carbon stocks compared with a stand without underplanting.

Decreasing the density of a forest stand is accomplished through thinning, or cutting some proportion of the trees in a stand. This may be done as precommercial thinning, in which case most of the trees to be cut are too small to economically justify their removal from the forest, and they are left in the stand to decay naturally. While precommercial thinning provides no immediate economic benefits, it may be used to improve the stocking level, species composition, and overall health of a stand; it represents an investment in creating a more valuable, productive forest. Precommercial thinning and stand density management also can reduce the risk of reversal from drought, insects, disease, and possibly fire. From a carbon standpoint, precommercial thinning will remove carbon from the live tree pool and increase the carbon in the dead wood pool. If the slash is burned, the GHG emissions should be accounted for using the CONSUME model when the burn occurred.

If trees to be thinned are of proper species, size, and quality, commercial thinning may be performed. In commercial thinning, trees are targeted for removal based on their species, size, and the management objectives. Thinned trees are removed from the stand and sold to appropriate forest products markets. Thus, commercial thinning will shift carbon from the live tree pool and into dead wood and litter (branches, foliage, and stumps remaining in the stand after harvest), and HWP pools.

6.4.1.2 Site Preparation Techniques

Regenerating a forest stand after harvest may require treatments to create the most desirable conditions for development of the new stand. This may involve removing debris from the prior stand, removing undesirable competing vegetation, scarifying or disturbing the soil for enhanced regeneration of species that require such conditions, and creating space or proper conditions for planting trees.

A wide variety of techniques are available to meet the specific regeneration objectives; they vary considerably across geographic regions, topography, site conditions, and forest species under management. General categories of site preparation techniques include mechanical methods, chemical applications, and prescribed fire.

Mechanical methods displace unwanted vegetation, move or break down logging residues, and/or cultivate the soil (Nyland, 2002). Mechanical site preparation uses a variety of machines and equipment, and may be limited by site factors such as terrain and soil conditions. Because mechanical site preparation involves soil disturbance, there is increased oxidation and emission of CO_2 from the soil organic matter for a period of time after site preparation.

Chemical applications involve the use of herbicides targeted at controlling undesirable vegetation so that the preferred species of trees have improved survival. Chemicals may be applied through ground or air spraying or injection into individual trees. Chemical site preparation involves little to no soil disturbance and has minimal effect on soil carbon emissions.

Prescribed burning may be used to reduce the amount of debris (limbs, tops, and foliage) from prior harvests, kill advanced regeneration of trees of undesirable species, and control pests that inhabit decaying wood left from the prior stand. Some fire-adapted species require burning to open cones and disperse seed for the new stand. Clearly, prescribed fire for site preparation will result in combustion and emission of CO_2 from woody materials left on the site, but will avoid the soil disturbance of mechanical techniques. The FOFEM model for natural fuels and the COMSUME model for activity generated fuels can be used to address this type of burning and allows estimation of GHG emissions and consumption.

6.4.1.3 Vegetation Control

Control of competing vegetation is one means of enhancing the growth of desirable trees in a forest. For example, in a pine plantation, where pine trees are the species of primary interest, growth of pines is increased when hardwood competition is removed. Vegetation control may be accomplished mechanically (such as girdling undesirable trees) or chemically. Vegetation control is especially important at two stages in the life of a stand: at establishment (planting or regeneration) and later in the rotation but before trees are past the sapling stage.

At establishment (e.g., of a plantation), the primary competition may come from herbaceous vegetation that can quickly outgrow the planted trees and suppress their growth or increase mortality. Herbicides may be effective at controlling herbaceous competition and providing the newly planted trees a chance to grow sufficiently to capture the site. Mid-rotation release of trees may require an additional application of chemical control to reduce competition and focus growth on desirable trees.

Vegetation control has been estimated to have contributed 35 percent of the substantial gain in plantation productivity relative to unimproved plantations (Stanturf et al., 2003). The primary carbon stock impact of vegetation control is a transfer of carbon stock from the live tree to standing dead biomass pool. Trees released from competition will usually exhibit a growth response to balance the loss of growth on the vegetation removed (i.e., overall forest productivity and sequestration will remain unchanged).

6.4.1.4 Planting

One popular form of regenerating a forest stand following clearcutting is to establish a plantation by planting trees of a desirable, fast-growing species, potentially utilizing an improved genetic source, at a consistent spacing selected to optimize growth. Plantation management practices include combinations of treatments to control competing vegetation and manage tree nutrition through fertilization, thinning, and use of genetically improved stock (Vance et al., 2010). Because of these efforts, plantations may be up to six times more productive than naturally regenerated stands of the same species (Carter and Foster, 2006). Successful plantation establishment entails careful selection of species, genetics, and spacing (planting density).

Species used in planted stands typically are selected for high growth rates, low susceptibility to damage from insects and disease, and quality and value. For example, in the U.S. South, loblolly pine is the most widely planted tree species because it is native to the area, fast-growing relative to other pines, and resistant to disease (Schultz, 1997). Longstanding genetic improvement programs have led to the production of improved genetic sources for forest plantation species. Genetically improved seedlings are available from commercial and state tree nurseries; essentially all of the 1.2 billion loblolly pine seedlings planted annually in the U.S. South are the result of tree improvement programs (McKeand et al., 2003). In the Pacific Northwest, genetic improvement in Douglas fir trees has led to increases in productivity (volume production) in excess of 25 percent (St. Clair et al., 2004). Finally, selection of planting density (trees per unit area) can affect overall stand productivity, necessity for thinning, ability to access the stand with equipment to conduct silvicultural operations, and time required until trees reach merchantable diameters. All of these factors combine to determine the likely survival and growth rates of a forest plantation. Plantation productivity is directly related to rate of forest sequestration. Any activity increasing productivity will improve sequestration rates.

6.4.1.5 Natural Regeneration

Certain forest types are regenerated most efficiently using natural regeneration, in which seedlings and sprouts from a recently harvested or disturbed forest will grow quickly after removal of a portion or all of the forest overstory. In this case, the species will be predictable based on the species composition of advanced regeneration from the previous stand, or if species present in the previous stand are prolific in sprouting. The species can also be predicted based on post-harvest regeneration of seedlings from residual overstory trees or from surrounding stands. Density will not be controlled during the regeneration process; frequently natural regeneration results in very dense vegetation that then goes through a natural process of competition.

Because neither the genetic source nor density are controlled during natural regeneration, these stands are frequently less productive than plantations but may be more desirable based on the objectives of the landowner (e.g., for recreation, wildlife, or different products than plantations would provide). The process of natural regeneration may entail minimal (if any) site preparation and less soil disturbance and cost than would plantations. Depending on the level of soil disturbance from the harvest of the previous stand, early soil CO_2 emissions may be lower than in planted stands.

6.4.1.6 Fertilization

Fertilization has been shown to dramatically improve the productivity of forest stands in which nutrients are limiting plant growth. For example, in the U.S. South, nitrogen and phosphorus are commonly deficient in pine plantations (Fox et al., 2007). In these areas, phosphorus fertilization may increase volume production by more than 100 percent (Jokela et al., 1991). Nitrogen and phosphorus fertilization has been shown to increase growth by 1.6 tons acre^{-1} year^{-1} (Fox et al., 2007).

The two primary types of forest fertilization currently practiced in the South are phosphorus-fertilization on deficient sites (usually at or near time of planting), and nitrogen and phosphorus fertilization in mid-rotation stands (e.g., ages 8 to 12). Volume gains vary, with highest gains where stands are most nutrient-limited.

The direct carbon impact of fertilization of forests is the observable increase in growth and therefore sequestration. Other impacts have been noted in agricultural settings, including increased emissions of other GHGs such as NO_x and N_2O. Results from agricultural fertilizer applications may not be directly applicable to forestry operations. Recent research in western Canadian forests showed soil GHG fluxes were neutral following fertilization (Basiliko et al., 2009). In an analysis of fertilization of pine plantations in the southeastern United States, Albaugh et al. (2012) found that carbon sequestration in forest growth far exceeded the emissions associated with fertilizer production, transport, and application (8.70 Tg year^{-1} CO_2 sequestration versus 0.36 Tg year^{-1} emissions). Thus, forest fertilization when applied appropriately can dramatically increase carbon sequestration when compared to unfertilized stands.

6.4.1.7 Selection of Rotation Length

One significant decision that forest managers make is the selection of the rotation length, or target age at which a regeneration harvest (final harvest; often but not necessarily a clearcut) will occur.

The decision affects the timing of other stand treatments. For example, thinnings and some fertilization treatments are targeted for a certain time before final harvest. It also affects the mix of forest products that might be expected from the harvested stand. Stands harvested at relatively young ages will yield primarily trees suitable for pulpwood markets, while longer rotations may involve more thinnings and will increase the proportion of sawtimber-sized trees in the stand. Because these different products have different longevities (see Section 6.5), the rotation length will have a significant impact on the overall carbon dynamics of a forest (and its subsequent pool of carbon in HWPs). Furthermore, longer rotations result in greater average carbon storage in the forest, with resulting higher levels of sequestration (Stainback and Alavalapati, 2002). It is widely recognized that increasing rotations from harvesting at financial maturity to harvesting closer to ages at which stands reach a steady state between growth and mortality can be beneficial for carbon storage (van Kooten et al., 1995).

A variety of decision criteria are available for identifying the optimal rotation length for different sets of objectives. If carbon storage is one of the important objectives, longer rotations will be beneficial (Liski et al., 2001).

6.4.1.8 Harvesting and Utilization Techniques

Regeneration harvests (also called rotation harvests or final harvests) are conducted to harvest trees for forest products markets and to promote the regeneration of desirable species for the next stand. To meet the twin objectives of regeneration and production of merchantable timber, forest managers may choose from a wide array of techniques and operational approaches. The silvicultural system will be chosen to determine which trees are to be removed from the stand, and a harvesting system will be chosen to determine the best logging approach to do so.

The silvicultural system determines what proportion of the forest stand is to be removed in the harvest, and will dictate whether the resulting stand will be even-aged (a stand of trees of a single age class) or uneven-aged (a stand of trees with three or more age classes) (Helms, 1998). Harvests range from clearcuts, in which most or all of the overstory is removed, to a variety of partial harvests. Partial harvests include systems such as seed-tree, shelterwood, group selection, individual tree selection, diameter-limit, and others. Harvest techniques that open most or all of the canopy (such as clearcutting or seed-tree harvests) will promote the regeneration of species that thrive in sunlight and do not tolerate shade. Clearcutting is also the preferred technique when the next stand is to be established by planting rather than natural regeneration.

After selection of a silvicultural system for regeneration, forest managers will select a harvesting system for the felling and extraction of trees from the site. Again a wide variety of systems are available, from individual tree-felling by chain saw with extraction by horse teams, to highly mechanized systems involving skidders, feller-bunchers, forwarders, and other types of equipment. When terrain conditions prevent ground-based vehicular extraction of felled trees, it may be done using cable yarding systems or helicopters. Logging systems that minimize soil disturbance and impacts on unharvested trees and understory may reduce these harvest-associated emissions.

When trees are harvested from a forest, they may produce a variety of products for specific markets. For example, large-diameter trees of certain species are preferred for sawtimber markets, while pulpwood markets accept roundwood with smaller diameters or even chips. Thus, a harvesting operation will often involve merchandising—the sorting, cutting, and separating of logs for delivery to different markets. Depending on the silvicultural system chosen, trees without market value (e.g., too small, poor form, or undesirable species) may be cut and left onsite to decay. In addition, a great deal of logging “slash” may be produced; this material may consist of branches, portions of trees beyond merchantability limits (tops), roots, and foliage. Where biomass energy markets exist, some of this material may be removed and used to replace fossil energy GHG sources;

otherwise it may be left onsite to decay or be burned during site preparation with associated GHG emissions. The proportion of woody material removed from a harvesting operation is termed utilization; high levels of utilization mean more woody biomass is removed and less remains on site.

There are many carbon consequences to the selection of a silvicultural and harvest system. Partial harvests will leave substantial carbon in live trees on the site, whereas clearcut harvest will leave very little. On certain soils, mechanized systems for felling and extracting trees will result in more soil disturbance and subsequent CO_2 emissions than low-impact systems (Nave et al., 2010). The harvesting impact on soil carbon is greater for the forest floor than for carbon in the mineral soil, but these effects are shorter lived and may be modest over longer time intervals (Nave et al., 2010). The availability of markets for smaller-diameter material or trees of nonmerchantable species will affect how much residue (slash) is left on the site. Availability of strong markets will generally lead to higher utilization and less residue. It is important to keep accounting boundaries in mind to ensure that there is no omission or double counting of emissions or removals. The IPCC methodologies have adopted the convention that emissions from burning biomass for energy should not be accounted in the energy sector, but should be accounted in the land-use sector. We conform to this convention. If, for example, forest residues are burned for energy, the CO_2 emissions are not counted in the energy sector, and there should be a reduction in the amount of fossil fuel burned. But the CO_2 emissions from the burned residue will be accounted as a decrease in carbon stocks in the land-use sector, and emissions will be no different than if the residues had been piled and burned in the forest. That is, a complete accounting of emissions when residues are burned for energy will show emissions saved in the energy sector but no change in the land-use sector.

6.4.1.9 Fire and Fuel Load Management

Many forest types have a natural dependence on disturbance from fire. As mentioned previously, it may play a role in natural regeneration, but it has many other functions including nutrient release, natural thinning and pruning, as well as modifying fuel structure and loading. Without prescribed fire, many forest types may be at a much higher risk of reversal of growing carbon stock. In regions of the country where wildfire is a concern, forest managers may take a more active role in managing the levels of potential fuels in a forest. Fuel management cannot prevent ignitions of wildfires, but can decrease levels of intensity, severity, and spread. Two common approaches to fuel load management are prescribed burning and mechanical fuel treatments.

Prescribed fire is any fire intentionally ignited by management under an approved plan to meet specific objectives. When forest fuels are burned under carefully selected conditions (weather, fuel, moisture, etc.), fuels can be reduced to levels that decrease the risk of damaging wildfires. Other objectives for use of fire and controlled burn may be to reduce threat from non-native invasive species and maintenance of many endangered species throughout the United States.

Mechanical fuel treatments are similar to harvesting operations, in that specific classes of trees are cut and removed. For example, all trees below a threshold diameter may be removed in a thinning (Johnson et al., 2007). The result should be decreased availability of fuels that would increase wildfire severity.

The carbon impact of fuel treatments is two-fold. First, it inevitably results in emissions of CO_2 from the material removed or burned. However, second, its goal is to reduce the potential for much larger future emissions (and increased environmental damage) from wildfires in areas where they are a threat. A wildfire could result in a reversal of the previous gains in carbon on the site. Wildfire intensity and resultant loss of carbon is highly variable and depends upon site specific conditions and effects. Wildfire can occur at low to moderate intensity, which like a prescribed fire may result in a more resilient and productive site over the long term. The challenge is that the immediate CO_2

emissions from a wildfire or prescribed fire/control burn are readily quantifiable, whereas the avoided emissions from potential wildfires are not and, because treatments may not take place in the areas where wildfire occurs, they could create extra emissions that would not otherwise have happened. Recent research indicates that prescribed burning has a minimal impact on forest carbon budgets, especially in the eastern United States. Impacts observed from mechanical and fire treatments were also fairly short-lived (Boerner et al., 2008). Disposition of removed materials is a key factor to consider when assessing the GHG implications of fuel management treatments. Prescribed fire can have significant effects on reducing the risk of reversal that could result from a wildfire.

6.4.1.10 Reducing Risk of Emissions from Pests and Disease

Silvicultural intervention may also be called for when forests are damaged by weather, insects, or disease. For example, when insect outbreaks such as pine beetle infestations kill patches of trees, removal of trees at or near the infestation site may prevent populations of harmful insects from spreading further. When harvests are designed to respond to pest and disease problems, they may be called sanitation harvests.

When weather events such as ice storms, hurricanes, or severe winds (or a wildfire) cause extensive damage to forest stands, quick removal of the downed timber may provide an opportunity to recover some of the financial value of the timber and may prevent the buildup of very large fuel loads. When economic value is captured from a harvest of damaged timber, it is termed a salvage harvest.

Both salvage and sanitation harvests remove trees, sometimes with market value and sometimes without. The carbon impacts are reflected in the amount of woody material removed from the forest and whether the material removed enters markets for wood products or for energy. Similar to wildfire treatments, in both sanitation and salvage harvests, however, the removal of biomass may be compared with the alternative of leaving the material in the forest to decay or burn, resulting in CO_2 emissions. For some carbon accounting systems, this difference is crucial; the assumption that emissions would have occurred without the activity affects baseline assumptions against which carbon sequestration is measured.

6.4.1.11 Short-Rotation Woody Crops

Short-rotation woody crops, also called biomass plantations or biomass energy plantations, are tree plantations managed with a very high intensity to produce fiber crops in a relatively short time frame (e.g., 5–10 years). These plantations are more like agricultural crops in the level of intensity of treatments (e.g., fertilization, weed control, and sometimes irrigation). Wood grown in this manner is usually suitable for use by biomass energy facilities or possibly pulp mills, but the cost to produce this wood is very high compared with traditional plantations. For some species, it is possible to regenerate these stands by coppicing, or cutting to promote sprouting from intact root systems, which avoids the cost of planting new trees. Regeneration by sprouts can result in dense stands exhibiting very fast growth.

The carbon dynamics in a short-rotation woody crop system are similar to conventional plantations, except for the accelerated growth and reduced rotation length. In some short-rotation woody crop systems, cover crops may be grown to prevent erosion and maintain soil fertility. Cover crops would also serve to increase carbon storage on site.

6.4.2 Activity Data

Carbon storage from forest management activities is estimated applying three different types of estimates. Estimate Type I focuses on the effects of management activities on carbon stocks for a given year. Estimate Type II focuses on the effects of management activities on carbon stocks over a period of years in the future and must be based on projections. Estimate Type III examines the difference in projected carbon stocks between sets of alternative scenarios of potential management. This section will discuss the activity data needs for each of the types of estimates for the various forest management activities. In general, however, the estimation approaches and data needs will be of two types: (1) forest inventory data; and (2) stand projection models.

For Type I, in cases where a management activity has altered the carbon stock in specific pools, the best estimates may be obtained by having forest inventory data before and after the treatment, such that the difference can be attributed to the management activity. Forest inventory data should include measurements obtained in the forest at a series of plots, with lists of the trees in each plot. Usually for each tree it is necessary to know the species, diameter, and sometimes height. From these measurements, stand-level estimates of tree density (trees per unit area), basal area (cross-sectional bole area at 4.5 feet (1.4 m) from the ground), species composition, and tree volume and biomass can be computed.

Another approach, used for Type II and Type III estimates, requires the use of stand projection models to estimate the responses of the forest to management activities. Such models have been created for a wide variety of forest types and treatments; an example is the FVS family of models discussed earlier. Projection models for forecasting forest conditions (and carbon stocks) typically require measures or indices of forest productivity. A commonly used measure of forest productivity is site index, which represents the height that trees on a site will reach by a certain base age. For example, on land with a site index of 65 (base age 25), the average height of dominant and co-dominant trees in a stand will be 65 feet (19.8 m) when the trees reach age 25.

The most accurate Type II and Type III estimates are from models developed specifically for a given plantation species or narrowly defined forest type. For example, there are many models available to estimate effects of management on commonly planted and highly researched species such as Douglas fir or loblolly pine (e.g., Amateis and Burkhart, 2005; Burkhart, 2008; Carlson et al., 2008; Li et al., 2007; Sucre et al., 2008). At this time, the FVS family of models is the recommended method for estimating forest carbon stocks. In incorporating this method into any software tool, a data portal that allows the user to load their existing stand data and management activity data for translation into the FVS format is recommended and would prove useful. Future development may also permit custom models to interface with an estimation tool. At this time, however, such capability is not available. In cases where such models are not available, it may be necessary to generalize by aggregating forest types and management activities and perform projections based on categories of management intensity for general forest types. Management intensity categories are defined in Section 6.4.3.

The remainder of this section is organized as follows:

- Stand Density Management
- Site Preparation Techniques
- Vegetation Control
- Planting
- Natural Regeneration
- Fertilization
- Selection of Rotation Length
- Harvesting and Utilization Techniques
- Fire and Fuel Load Management

- Reducing Risk of Emissions from Pests and Disease
- Short-Rotation Woody Crops

6.4.2.1 Stand Density Management

Stand density management activities include underplanting, precommercial thinning, and commercial thinning. In each case, the primary data requirements for Type I estimates are tree inventories before and after the treatment, which can indicate the change in stocking levels and the quantity of biomass removed during thinnings. In the case of thinnings, it is important to know the volume or biomass directed to different wood products markets (e.g., pulpwood, sawtimber, or energy) to properly account for the carbon in HWPs.

For Type II and III estimates of the future carbon dynamics of the stand after these treatments, stand projection models will require a measure of site index in addition to the inventory information collected for Type I estimates.

6.4.2.2 Site Preparation

The primary information requirement for estimates of stock changes due to site preparation is whether soil disturbance has occurred during site preparation. Mechanical site preparation techniques that involve soil disturbance will be assumed to lead to a short-term loss of soil carbon storage followed by a recovery. Chemical or other treatments that don't involve soil disturbance will not result in soil CO_2 emissions beyond what may have occurred during harvesting. For Type II and III estimates, the site preparation technique should be recorded in the event that models may differentiate between growth rates corresponding to various site preparation techniques.

6.4.2.3 Vegetation Control

For Type I estimates, it is necessary to have inventory information before and after vegetation control treatments if the vegetation control involves woody material. (Carbon stocks are not expected to be substantially different for herbaceous control treatments near time of planting.) When vegetation is killed but not removed, the carbon stock impacts involve primarily the redirection of stock from one pool (live trees) to another (standing dead trees).

For Type II and III estimates, some models may project stand growth differently if competing vegetation is removed. In such cases, similar inventory information before and after treatment will be necessary.

6.4.2.4 Planting

The act of planting itself involves a negligible carbon stock change for the year of planting. Thus, a Type I estimate would show no carbon stock change following a planting.

For all subsequent years, however, critical parameters are the species planted, the original planting density (trees per acre), and the survival rate (in percent) after one growing season. Because most early mortality occurs within one year of planting, the percentage of trees surviving at year one provides a robust estimate of stand density for growth projections. It will also be important for Type II and III estimates to record the genetic stock used (e.g., first generation, open-pollinated, mass-controlled pollinated, clonal) in the event that projection models are developed for specific genetic sources. Some measure of site productivity (e.g., site index) will be needed as well.

6.4.2.5 Natural Regeneration

As in the case of plantation establishment, carbon stock changes at the time of natural regeneration are negligible.

Type II and III estimates will require information on species mix, stand density, and some information on stand productivity. In cases in which stand productivity cannot be measured directly (by measuring existing trees for site index), some estimates can be derived from soils databases such as SSURGO, or from field characterization of soil series and reference to soil maps and manuals.

6.4.2.6 Fertilization

Type I estimates will show no immediate carbon stock changes relative to fertilization for the year in which the activity occurred. N_2O emissions will occur at time of fertilization; activity data should include number of acres fertilized, application rate, and type of nitrogen applied.

Type II and III estimates involving stand projection may make use of models which incorporate information about the fertilization treatment. Application rates (pounds per acre) and elemental composition (nitrogen, phosphorus, potassium) should be recorded.

6.4.2.7 Selection of Rotation Length

Type I estimates are not applicable to selection of rotation length. Type II and III estimates may entail experimentation with rotation lengths in modeling exercises to test the carbon stock implications of different rotation length strategies. Such experimentation will simply involve the comparison of models run with all parameters held constant except for rotation length.

6.4.2.8 Harvesting and Utilization Techniques

Harvesting has the largest immediate impact on forest carbon stocks. Consequently, for Type I estimates, the landowner needs to collect accurate and sufficiently detailed forest inventory information before harvest and after harvest in the case of partial cutting. Because ongoing sequestration of carbon stocks follows different pathways for different forest products, the disposition of the harvested material into different product pools (e.g., pulpwood, sawtimber) needs to be recorded. This information should be readily available as part of sales records. Default factors are available to estimate carbon in harvesting residues (slash).

In the case of partial harvests (where there is a residual stand to project), or projections of impacts of different harvesting or silvicultural systems, complete inventory data and productivity estimates (e.g., site index) for the stand are needed.

6.4.2.9 Fire and Fuel Load Management

For Type I estimates, pre-treatment data on fuel loading with focus on the material to be removed in the treatment needs to be collected. An example of data collection protocols for fuel data can be found in Brown (1974). Post-treatment assessment of residual material will indicate the amount removed in the treatment. The type of treatment (burn or mechanical) and the disposition of fuel (consumed, left onsite, removed) should be recorded. If consumed, FOFEM or CONSUME can be used to calculate the GHG emissions from a prescribed burn.

Type II and III estimates of the carbon stock impacts of fuel treatments will require specialized fire models that could indicate likely outcomes of the fuel treatment relative to no treatment and a subsequent wildfire; available tools include models such as CONSUME (Joint Fire Science Program, 2009) and the FVS-FFE module (Reinhardt and Crookston, 2003). See Table 6-13 where a low-severity fire could be compared to the crown fire effect based on FOFEM outputs.

6.4.2.10 Reducing Risk of Emissions from Pests and Disease

For estimates of carbon stock impacts of sanitation and salvage harvests, pretreatment and post-treatment inventories are required. In the pretreatment inventory, the extent and nature of damage are needed to estimate the carbon stock that has shifted from live to dead biomass prior to treatment.

Modeling for Type II and III estimates may entail simply projecting the residual (post-treatment) stand. To fully evaluate the carbon stock impacts of the treatment, models or assumptions are needed for estimating the spread of the insect or disease absent the treatment. Tools for such modeling or assumptions may be hard to obtain.

6.4.2.11 Short-Rotation Woody Crops

Estimation of carbon stock impacts from plantations of short-rotation woody crops would follow the same general procedure as other plantation estimates. No stock changes would be expected at time of planting (carbon in seedlings or planting stock is negligible). Projections for Type II and III estimates require the availability of models to project growth and yield of the species planted under the management scenarios envisioned.

6.4.3 Management Intensity Categories

In the previous section, the use of models to predict forest responses to management activities was discussed. Many such models are available for specific management practices in plantations of certain species or in specific forest types. These models are varied in their input requirements and their applications. To develop a nationally consistent approach, the infinite combinations of sequences of specific management activities and forest types need to be generalized. Using a single modeling framework, such as FVS (Dixon, 2002) and categories of management intensities, allows for the simulation of suites of management activities in a wide variety of forest types and conditions with a single set of inputs. This approach to defining management intensity categories is similar to that used by Siry (2002).

Therefore, in this section categories of forest types and management intensities that represent broad combinations of commonly applied activities in the forest types of the United States are defined. Default tables of carbon stocks for these categories could then be developed to provide consistent and useful information about likely carbon stock implications of forest management activities across the country.

6.4.3.1 Defining Forest Type Categories

The first distinction in defining management intensity categories is the identification of the broad species grouping: hardwood, softwood, or mixed. Hardwood forest types are dominated by hardwood tree species such as oak, maple, cottonwood, birch. Softwood types are dominated by softwood tree species such as pine, spruce, or Douglas fir. Mixed types exhibit no clear dominance of one species group. The second major distinction is whether the stand was planted or naturally regenerated. Certain management activities are far more likely to be applied to plantations than natural stands. Most plantations are softwoods, with the exception of some short-rotation woody crops of hardwood types such as cottonwood, willow, hybrid poplar, or aspen.

6.4.3.2 Defining Categories of Management Intensity

Four categories of management intensity are defined based on commonly encountered practices. For example, almost all forest fertilization is applied to plantations rather than naturally regenerated stands, so fertilization will be considered part of management intensities related only to plantations. Similarly, stands that are fertilized are usually also treated with herbicide to control competing vegetation so that the fertilization benefit accrues to the desired crop species.

The four categories of management intensity are low, moderate, high, and very high. Low intensity generally refers to minimal management intervention (e.g., natural regeneration or older softwood plantations without genetically improved stock). Moderate intensity incorporates some level of active management such as intermediate harvests (e.g., thinnings). High intensity applies only to plantations and incorporates the use of superior genetic stock and vegetation control. Very high intensity management applies to aggressively managed softwood or hardwood plantations in which substantial effort is made to maximize growth using genetics, vegetation control, and fertilization. The resulting combinations of forest types, intensities, and management practices are summarized in Table 6-5.

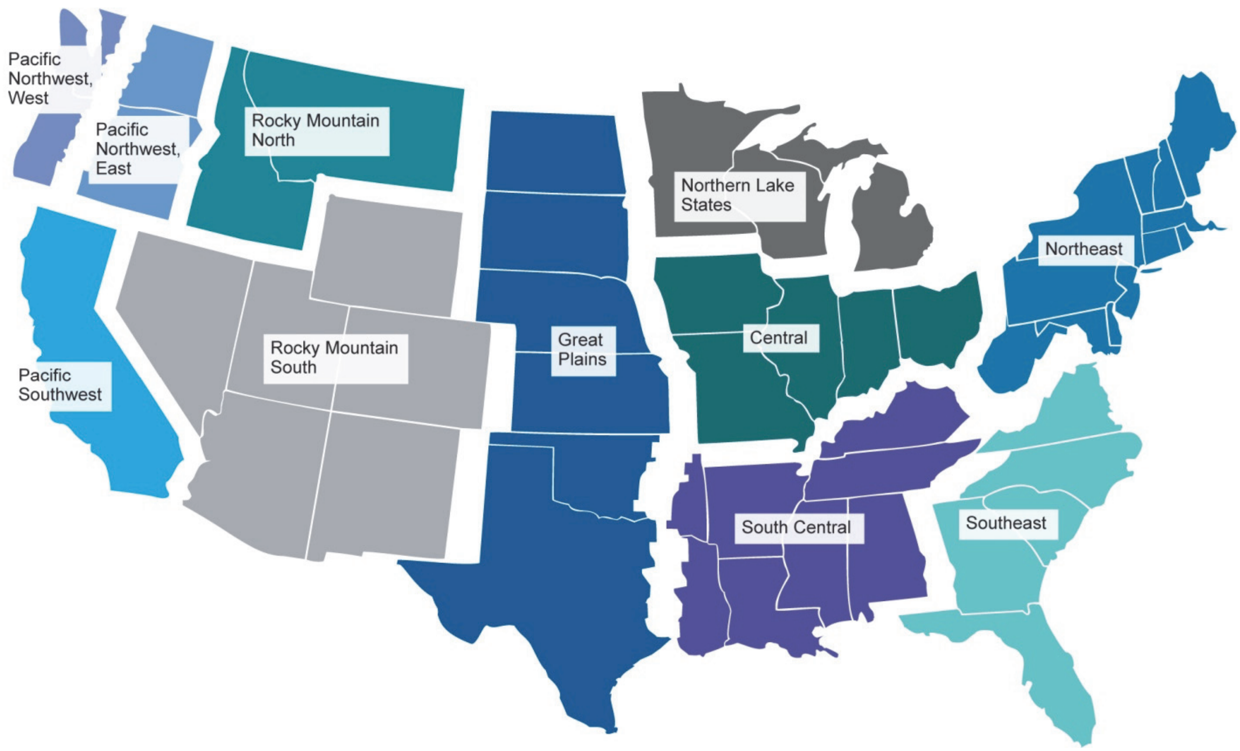
Table 6-5: Management Intensity Categories

Forest Type[a]/Management Intensity[b]	Stand Density Mgmt	Planting	Superior Genetics	Vegetation Control	Fertilization
Hardwood/low					
Hardwood/moderate	X				
Mixed/low					
Mixed/moderate	X				
Softwood (Nat)/low					
Softwood (Nat)/moderate	X				
Softwood (Plt)/low		X			
Softwood (Plt)/moderate	X	X	X		
Softwood (Plt)/high	X	X	X	X	
Softwood (Plt)/very high	X	X	X	X	X
Hardwood (Plt)/very high[c]	X	X	X	X	X

[a] Forest type refers to the combination of species group and regeneration (Nat = naturally regenerated; Plt = Planted).
[b] An X indicates that the practice indicated is applied for the management intensity category.
[c] Very high intensity hardwood plantations are usually encountered in the context of short-rotation wood crops or biomass plantations.

Figure 6-6 shows the specific regions (e.g., Pacific Northwest, West; Pacific Northwest, East; Pacific Southwest; Rocky Mountain North; Rocky Mountain South; Great Plains; Northern Lake States; Central; South Central; Northeast; and Southeast) for which silvicultural options by the most commonly managed forest type were developed.

Figure 6-6: Map of Specific Regions of Forest Management



For the management intensity categories illustrated in Table 6-5, common silvicultural options by the most commonly managed forest types for specific regions of forest management (see Table 6-6) are described. This list is not exhaustive, since silvicultural prescriptions may often be tailored to site specific conditions; however, the list provides the practices frequently applied in commonly managed forest types. The management objective may not necessarily be timber production; in some regions and types habitat restoration, rangelands, or forest health may be the primary management objectives. Table 6-6 provides a list of commonly used silvicultural prescriptions for common forest types in each region.

Table 6-6: Common Silvicultural Options by Most Commonly Managed Forest Type

Region	Forest Type	Generalized Practice
Northeast[a]	Northern hardwoods: beech, sugar maple, yellow birch, and associates	Single tree selection: harvest 40–50 ft^2 per acre every 20 years across a range of size classes in stands with 120–130 ft^2 basal area (BA)
		Clearcut: when 120–130 ft^2, then commercial thinning
		Commercial thin: At age 90–100 (120ft^2) thin to 70–80 ft^2
		Standard shelterwood: Harvest 40–50 ft^2 from below, leaving 80 ft^2 in overstory; remove overstory in 10–15 years
	Spruce–fir: red/white spruce, balsam fir	Shelterwood: Harvest 60 ft^2 from below (leave 100 ft^2); harvest remainder in 10–15 years
		Single tree selection: At 160 ft^2, remove 50 ft^2 in all sizes, every 20 years

Region	Forest Type	Generalized Practice
		Commercial thinning: At age 50–60, thin from 150 down to 100 ft^2
Central[b]	Oak–hickory	Clearcut
		Shelterwood: following local guidelines
		Group selection with commercial thinning to B-level stocking on Gingrich Guide (Gingrich, 1967)
		Precommercial/commercial thinning to B-level stocking on Gingrich Guide
		Diameter limit cut: To 12 inches DBH
		Prescribed fire: to promote oak regeneration or woodland restoration
	Elm–ash–cottonwood	Clearcut
		Individual tree selection: following local guidance
		Diameter limit cut: To 12 inches DBH
	Maple–beech–birch	Clearcut
		Shelterwood: following local guidance
		Group selection with commercial thinning to B-level stocking on Gingrich Guide
		Individual tree selection:
		Commercial thinning to B-level stocking on Gingrich Guide
		Diameter limit cut: To 12 inches DBH
	Oak–pine	Clearcut:
		Shelterwood:
		Group selection with commercial thinning to B-level stocking on Gingrich Guide
		Diameter limit cut: To 12 inches DBH
		Prescribed fire: To promote woodland restoration
Rocky Mountain South[c]	Dry montane: ponderosa pine, Douglas fir	Selection cutting: Harvest 20–30 ft^2 per acre every 20–30 years across size classes in stands to 40–80 ft^2 BA
		Commercial thinning: At age 60–80 thin to 50–60 ft^2 BA
		Shelterwood: Harvest 60–80 ft^2 BA from below; leave 30 ft^2 in overstory; remove overstory in 5–10 years
	Aspen	Coppice: At age 100
	Lodgepole pine	Clearcut: At age 120–150
	Spruce–fir	Single tree selection: Harvest 20–30ft^2 per acre every 20–30 years across size classes in stands to 80–120 ft^2 BA
	Woodland types: pinyon–juniper, Gambrel oak	Selection cutting: Harvest to 40–60 ft^2 BA
Southeast[d]	Upland hardwood	Clearcut: At age 35–50
		Single tree selection: Harvest 40–60 ft^2 per acre in stands with 100–140 ft^2 per acre
	Bottomland hardwood	Single tree selection: Harvest 40–60 ft^2 per acre in stands with 100–140 ft^2 per acre
	Pine plantation – low intensity	Plant with non-improved seedlings 600–700 per acre, thin to 60–70 ft^2 per acre at age 18–24, clearcut at age 25–35
	Pine plantation – medium intensity	Plant with improved seedlings 600–700 per acre, thin to 60–70 ft^2 per acre at age 18–22, fertilize after thinning with nitrogen and phosphorus (if needed), clearcut 5–7 years after thinning

Region	Forest Type	Generalized Practice
	Pine plantation – high intensity	Plant with improved seedlings 600–700 per acre, herbaceous weed control age 2–4, thin to 60–70 ft^2 per acre at age 16–20, fertilize after thinning with nitrogen and phosphorus (if needed), clearcut 5–7 years after thinning
South Central[d]	Upland hardwood	Clearcut: At age 35–50
		Single tree selection: Harvest 40–60 ft^2 per acre in stands with 100–140 ft^2 per acre
	Bottomland hardwood	Single tree selection: Harvest 40–60 ft^2 per acre in stands with 100–140 ft^2 per acre
	Pine plantation – low intensity	Plant with non-improved seedlings 450–700 per acre, on lower quality sites, thin to 60–70 ft^2 per acre at age 18–20; on higher quality sites, thin to 60–70 ft^2 per acre at age 12–16, on higher quality sites, thin again at age 20–24, clearcut 5–7 years after thinning
	Pine plantation – medium intensity	Plant with improved seedlings 600–700 per acre, on lower quality sites, thin to 60–70 ft^2 per acre at age 18–20; on higher quality sites, thin to 60–70 ft^2 per acre at age 12–16, fertilize after thinning with nitrogen and phosphorus (if needed), on higher quality sites, thin again age 20–24, clearcut 5–7 years after thinning
	Pine plantation – high intensity	Plant with improved seedlings 600–700 per acre, herbaceous weed control age 2–4, on lower quality sites, thin to 60–70 ft^2 per acre at age 18–20; on higher quality sites, thin to 60–70 ft^2 per acre at age 12–16, fertilize after thinning with nitrogen and phosphorus (if needed), on higher quality sites, thin again at age 20–24, clearcut 5–7 years after thinning
Northern Lake States[e]	Aspen–birch	Clearcut: 50–60 year rotation
		Shelterwood: When birch is main component: two cut system, commercial thinning at age 40–50 on high quality sites
	Northern hardwoods	Shelterwood: two stage; first cut 20 years prior to rotation age; commercial thinning as required
		Single tree/group selection with 10–20 year cutting cycle
	Oak	Clearcut: On lower quality sites, and on high quality sites where adequate advanced regeneration is present; commercial thinning as required
		Shelterwood: On high quality sites when adequate advanced regeneration is not present; commercial thinning as required
	Jack pine	Clearcut: 50–60 year rotation (note that jack pine managed for Kirtland's warbler habitat will have additional management requirements)
	Red pine	Clearcut: Commonly followed by site preparation and planting 900 per acre, commercial thinning beginning at age 25–40
		Shelterwood: Where disease risk is low; often used with prescribed fire; commercial thinning beginning at age 25–40
	White pine	Shelterwood: Two stage system; commercial thinning beginning at age 40

Region	Forest Type	Generalized Practice
	White spruce/balsam fir	Clearcut: When adequate regeneration is present
	White spruce/balsam fir	Shelterwood: Two stage system, when adequate regeneration is not present
	Lowland conifer	Clearcut: When adequate regeneration is present; patch and strip clearcuts may be used in some cases
	Lowland conifer	Shelterwood: Two stage system, when adequate regeneration is not present
Great Plains[f]	Ponderosa pine	Two-cut Shelterwood: reduce basal area to below 60 ft^2 per acre, then remove remaining overstory after adequate regeneration is present
Great Plains[f]	Ponderosa pine	Precommercial thinning as necessary to maintain desired densities
Great Plains[f]	Ponderosa pine	Artificial regeneration may be required after catastrophic disturbances or to establish forests on previously unforested land; this may be done through broadcast seeding or planting
Rocky Mountain North[g]	Ponderosa pine	Plant 400–500 trees per acre, precommercial thin to 200–300 trees per acre, commercial thin to 150–200 trees per acre at age 30–40; clearcut harvest at age 60–80
Rocky Mountain North[g]	Lodgepole pine	Site prepare to expose mineral soil seedbed, natural regeneration by seeding, precommercial thin to 200–400 trees per acre, patch clearcut harvest at age 80–100
Pacific Southwest[h]	Mixed conifer: ponderosa pine, sugar pine, Douglas fir, incense cedar, white fir, Jeffrey pine, and California black oak	Commercial thin: Starting at ages near 40 and continuing at various periodic cycles until regeneration; post-thinning stocking generally ranges between 150–250 ft^2; variable rotation length, depending on objectives
Pacific Southwest[h]	Mixed conifer: ponderosa pine, sugar pine, Douglas fir, incense cedar, white fir, Jeffrey pine, and California black oak	Commercial thinning with both patch regeneration and reserved areas: Similar to above, but with higher levels of variation in post-thinning stocking levels, small patches of regeneration, primarily to increase pine species, and small areas reserved from harvest, maintaining larger/older trees providing relatively unique wildlife habitats; variable rotation length, depending on objectives
Pacific Northwest, East[i]	Douglas fir/Ponderosa pine – low intensity	Site preparation by site scarification in small spots, natural regeneration, precommercial thin at age 20–25 years to 100–250 trees per acre, patch clearcut or seed-tree harvest at age 50–70
Pacific Northwest, East[i]	Douglas fir/Ponderosa pine – medium intensity (on more productive sites)	Mechanical site preparation to scarify soil and remove competing vegetation, plant with improved seedlings at approx. 400–500 per acre, precommercial thin at age 15–20, commercial thin at age 30–40, patch clearcut or seed-tree harvest at age 50–70
Pacific Northwest, West[j]	Douglas fir	Site prepare stand with pre-emergent herbicides, plant with improved seedlings at approx. 450 per acre, commercial thinning as needed at age 20–30, fertilize as needed at age 30–40, clearcut harvest at age 40–50

DBH = Diameter at breast height
[a] Personal communication: Bill Leak.
[b] Personal communication: Steve Shifley.
[c] Personal communication: James Youtz, Jim Thinnes.
[d] Personal communication: Steve Prisley.
[e] Planning documents and silviculture guides, and personal communication with staff on the Huron-Manistee, Ottawa, and

Hiawatha National Forests.
[f] See Shepperd and Battaglia (2002).
[g] See Youngblood (2005).
[h] Personal communication: Joe Sherlock.
[i] See Briggs (2007).
[j] See Hanley and Baumgartner (2005).

6.4.3.3 Applying Default Tables of Management Practice Scenarios

Once the general categories of forest types and management intensities are defined, a modeling framework such as FVS could be used to develop sets of default tables of carbon stocks in various pools over time under management scenarios common to the forest types and management intensities. Note that at this time, these lookup tables are not available; developing default carbon stock values for forest management practices is a task requiring a significant level of time and effort. In the absence of such tables, small landowners wishing to estimate the effects of changing management practices (a Type III estimate) will need to use the methods described for large landowners.

Table 6-7 shows an unpopulated example for the default lookup tables of management practice scenarios. The default tables would provide regional estimates of timber volume and carbon stocks for a specific forest type group (e.g., loblolly-shortleaf pine stands) under a specific (e.g., Softwood (planted)/very high) management intensity on forest land after clearcut harvest in a specific region (e.g., the Southeast) for low productivity and high productivity sites.

Table 6-7: Regional Estimates of Timber Volume and Carbon Stocks for a Specific Forest Type Group (e.g., Loblolly-Shortleaf Pine Stands) Under a Specific (e.g., Softwood (Planted)/Very High) Management Intensity on Forest Land after Clearcut Harvest in a Specific Region (e.g., the Southeast) for Low Productivity and High Productivity Sites

Note: At this time, populated tables are not available; development of such tables is not certain.

Age	Mean Volume	Mean Carbon Density					
		Live Tree	Standing Dead Tree	Down Dead Wood	Forest Floor or Litter	Total Nonsoil	
Years	$m^3\ ha^{-1}$	---------------------Metric Tons C ha^{-1} (Low Productivity)------------					
0	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-
55	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-
65	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-
75	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-

Age	Mean Volume	Mean Carbon Density					
		Live Tree	Standing Dead Tree	Down Dead Wood	Forest Floor or Litter	Total Nonsoil	
Years	$m^3\ ha^{-1}$	---------------------Metric tons C ha^{-1} (high productivity)-----------					
0	-	-	-	-	-	-	
5	-	-	-	-	-	-	
10	-	-	-	-	-	-	
15	-	-	-	-	-	-	
20	-	-	-	-	-	-	
25	-	-	-	-	-	-	
30	-	-	-	-	-	-	
35	-	-	-	-	-	-	
40	-	-	-	-	-	-	
45	-	-	-	-	-	-	
50	-	-	-	-	-	-	
55	-	-	-	-	-	-	
60	-	-	-	-	-	-	
65	-	-	-	-	-	-	
70	-	-	-	-	-	-	
75	-	-	-	-	-	-	
80	-	-	-	-	-	-	
85	-	-	-	-	-	-	
90	-	-	-	-	-	-	

6.4.4 Estimation Methods

6.4.4.1 Stand Density Management

Type I estimates may be developed for stand density management. For underplanting, carbon stocks are essentially unchanged immediately after the treatment. For precommercial thinnings, carbon is moved from the live tree pool to the standing dead pool and/or forest floor pool; quantities will be low and essentially just accelerate the natural mortality of these smaller trees, thus accounting for this activity may be unnecessary. For commercial thinning, the live tree carbon stock is reduced and carbon is moved into HWPs, so these pools need to be estimated using procedures outlined in Section 6.2 and Section 6.5.

Type II and III estimates may be developed using forest growth models (i.e., FVS) specific to the forest type and practices used.

6.4.4.2 Site Preparation Techniques

Carbon stock changes that are due to mechanical site preparation techniques will consist of some oxidation of soil organic carbon that will be replaced over time by forest growth. For long-term monitoring, it may be assumed that soil carbon stocks will be stable under sustainable forest management (Smith et al., 2006). Thus, Type I estimates could reflect short-term losses of soil carbon stocks based on assumptions appropriate to the forest type and region.

6.4.4.3 Vegetation Control

Control of woody vegetation will exhibit patterns similar to precommercial thinning: transfer of carbon stocks from live tree to dead tree pools. Quantities will likely be small and the effect of short duration; hence accounting for these impacts using Type I estimates may be unnecessary.

For Type II and III estimates, vegetation control may be expected to have a beneficial impact on the growth of the residual stand that should be modeled accordingly.

6.4.4.4 Planting

Negligible carbon stock changes are expected at the time of establishment of a new plantation, so Type I estimates will show no stock changes. For Type II and III estimates, the plantation activity establishes a new stand that can then be modeled based on species, site index, and initial stocking (planting density times year 1 survival percent).

6.4.4.5 Natural Regeneration

As in the case of plantation establishment, carbon stock changes at the time of natural regeneration are negligible. For Type II and III estimates involving projections of stand growth over time, initial stocking, species mix, and site productivity will define the stand parameters for growth projections.

6.4.4.6 Harvesting and Utilization

Depending on the harvesting and silvicultural system used, multiple stock changes occur with a rotation harvest. Live tree biomass stocks are reduced by the amount of harvested wood (up to 100 percent of the live tree biomass pool). These removals should be balanced by additions to HWP pools and slash/residue in the forest floor and dead wood pools. Because losses to soil organic carbon pools from disturbance by mechanized harvesting systems are of relatively short duration, it is common to consider the loss and recapture as a steady state (e.g., Smith et al., 2006), though this may differ depending on soil characteristics.

In the case of partial harvests, there is a residual stand for which carbon stocks remain to be projected over time. Post-harvest inventory information provides the critical stand parameters to be input into growth models. In the absence of a post-harvest inventory, pre-harvest inventory data can be adjusted to reflect the loss of trees removed by the harvest (e.g., by decreasing the numbers of trees by species and diameter class based on harvest records).

6.4.4.7 Fire and Fuel Load Management

Type I estimates of carbon stock changes due to fuel treatments or prescribed fire should reflect losses to live tree biomass according to the material burned, killed, or removed (from pre and post-treatment inventory data). For a prescribed fire, emissions can be calculated using FOFEM. If slash is left from the fuel treatment, CONSUME may also be used.

Type II and III estimates simply involve projecting the stand based on information from the post-treatment inventory.

6.4.4.8 Reducing Risk of Emissions from Pests and Disease

Type I carbon stock estimates will involve computation of losses to live tree biomass from the sanitation or salvage harvest, with additions to HWP pools as appropriate.

Type II and III estimates simply involve projecting the stand based on information from the post-treatment inventory.

6.4.4.9 Short-Rotation Woody Crops

Negligible carbon stock changes are expected at the time of establishment of a new plantation, so Type I estimates will show no stock changes. For Type II and III estimates, the plantation activity establishes a new stand that can then be modeled based on species, site index, and initial stocking (planting density times year 1 survival percent).

6.4.5 Limitations and Uncertainty

6.4.5.1 Measurement Uncertainties

Forest inventory data, from which most estimates in this section are derived, contain uncertainty as a result of sampling and measurement error. Furthermore, equations are used to estimate biomass from tree measurements (species, diameters, heights), and these equations introduce additional errors. These uncertainties, however, are well documented and can be quantified.

6.4.5.2 Model Uncertainties

For the development of Type II and Type III estimates, models are used to project current conditions into the future. These types of estimates are based initially on inventory data and are subject to the measurement uncertainties discussed above, but are also subject to modeling error. Modeling error can be documented in part based on the diagnostics reported (if any) from the model development process. Greater uncertainties are introduced when models are applied beyond the conditions for which they were developed (e.g., biomass equations applied to species for which no biomass data were collected, forest growth models applied to stands receiving different management than the stands used for model development, etc.). Model uncertainties also increase with the projection period (the distance into the future for which estimates are obtained). Some of the model uncertainties are cancelled out when results from two similar model runs are compared (i.e., a Type III estimate). For example, if a model slightly overestimates carbon stock in a forest with and without some treatment, the difference between the two model estimates may be accurate even if the individual estimates are not.

6.4.5.3 Generalization Uncertainties

For the purpose of applying nationally consistent estimation methods to Type II and III estimates, it is necessary to generalize situations into broad forest types and management intensities. Thus, some precision is lost in applying a generalized, aggregated estimate to a particular set of management activities.

6.5 Harvested Wood Products

Method for Harvested Wood Products

- Method uses U.S.-specific HWPs tables.
- The HWPs tables are based on WOODCARB II model used to estimate annual change in carbon stored in products and landfills (Skog, 2008).
- The entity uses these tables to estimate the average amount of HWP carbon from the current year's harvest that remains stored in end uses and landfills over the next 100 years.
- This method was selected because it is suitable to represent the amount of carbon stored in products in use and in landfills.

6.5.1 General Accounting Issues

When forest landowners harvest wood for products, a portion of the wood carbon ends up in solidwood or paper products in end uses, and eventually in landfills, and can remain stored for years or decades. This report suggests a specific measure, along with estimation methods, that forest landowners can use to report carbon additions to the stock of HWPs from wood they harvest. The accounting framework used to track HWP carbon is similar to the framework that the United States uses to report national-level annual changes in HWP carbon stocks under UNFCCC.

The national accounting framework and these methods adopt the production approach, which entails the following: (1) estimating the annual carbon additions to and removals from the stock of carbon held in wood products in use and in landfills, (2) tracking only carbon in wood that was harvested in the United States (U.S. EPA, 2011), and (3) providing estimates that track wood carbon held in products, even if is the products are exported to other countries.

Estimates of the annual contribution of HWPs to carbon stocks may be made for Type I, Type II, and Type III estimates of forest carbon change as outlined in Section 6.2:

- For Type I estimates, the focus is on estimating the annual contribution of HWPs to carbon stocks for a given current year or recent past years.
- For Type II estimates, the focus is on estimating the annual contribution of HWPs to carbon stocks for a projected period of years in the future.
- For Type III estimates, the focus is on estimating the *change* in the annual contribution of HWPs to carbon stocks between: (1) a base case with one scenario for forest management (and harvest); and (2) a second scenario for forest management (and harvest) that is intended to change carbon flux.

For each of the Type I, II, or III estimates, these methods recommend that forest landowners report the annual contribution of HWPs to carbon stocks using a specific measure intended to approximate the climate mitigation benefit associated with storing carbon in HWPs over time. The recommended measure is the estimated *average* amount of HWP carbon from the current year's harvest that remains stored in end uses and landfills *over* the subsequent 100 years.

The intent of this measure is to approximate the average annual climate benefit of withholding carbon from the atmosphere by a certain amount each year for 100 years as described by a "decay" curve. This average benefit is one that can be credited in the year of harvest. This estimate of average effect is conceptually similar to the measure of the radiative forcing impact of a current year emission of CO_2, CH_4, or other GHG. One ton of CO_2 emissions—in GHG accounting—is equated to the radiative forcing it causes over the 100 years following the emission. The radiative forcing caused in each year is weighted the same over each of the 100 years. We are suggesting the same convention in weighting the carbon storage in wood products equally for each of 100 years.

An estimate of average fraction of HWP carbon stored over 100 years (average amount stored over 100 years divided by the original product carbon produced) is not exactly the same as the fraction of radiative forcing avoided by storing wood products carbon (and emitting carbon slowly) over 100 years. For decay curves where a constant fraction of remaining HWP carbon is emitted each year the fraction of radiative forcing avoided over 100 years can be 0 to14 percent less than the average fraction of HWP carbon stored over 100 years depending on the decay rate.[8] Estimates of the fraction of radiative forcing avoided over 100 years could be used in place of the average carbon storage. Given the uncertainty in decay rates as an influence on estimates and the greater complexity of the radiative forcing measure, we recommend the measure of average carbon stored as an adequate proxy for the effect of wood products produced in the current year and stored over

[8] The fraction of radiative forcing avoided over 100 years was estimated (and compared to average carbon stored over 100 years) assuming a range of decay rates for first order decay curves for wood products and using the CO_2 radiative forcing response curve from the IPCC Working I 4th Assessment Report (footnote a, p. 213) (IPCC, 2007).

100 years.

The measure—average carbon stored in HWP over 100 years (with variations on how landfill carbon is included)—is used in the Climate Action Reserve (2010) Forest Project Protocols adopted by the California Air Resources Board. The protocols indicate how to calculate the level of annual carbon credits that may be sold by forest landowners who enter carbon contracts.

Note that use of the production approach to accounting is not a life-cycle assessment accounting approach that could take into account how carbon emissions from increased wood burning or increased use of wood products might offset fossil fuel emissions or emissions from making non-wood products over time. The estimates of annual change in carbon in HWPs are not intended to indicate the total impact on GHG levels in the atmosphere of using HWPs (including use of wood for energy), nor are they intended to indicate that the emission to the atmosphere took place in the United States versus other countries where products were exported. Estimation of Type III secondary GHG reduction effects of substitution of wood for fossil fuels or non-wood construction products are complex and would require specification of a baseline from which change is measured and other assumptions that are beyond the scope of these methods.

The production approach is used to acknowledge that harvesting of forests does not immediately release all of the contained carbon to the atmosphere; the accounting counts only the carbon change in HWPs in order to allow annual carbon changes in HWPs to be deducted or added to annual emissions in the energy and manufacturing sectors and carbon changes in forests, so there will be no omission or double counting of sequestration or emissions to the atmosphere. In the national accounting framework, the annual emissions from wood energy are accounted for as part of the aggregated annual change in forest plus HWP carbon.

6.5.2 Estimation Methods

6.5.2.1 Wood Products Fate/Longevity

To allow forest landowners to estimate carbon additions to HWP stocks—using average carbon stored in HWP over 100 years—lookup tables are provided that give estimates of carbon remaining stored after harvest out to 100 years.

There are two types of lookup tables: a "roundwood" type and a "primary product" type.

For the roundwood type, the landowner needs estimates of the carbon in harvested amounts of industrial roundwood: hardwood (HW) or softwood (SW), sawlogs (SL), or pulpwood (PW). Industrial roundwood is wood used for solidwood or paper products and excludes bark and fuelwood. The landowner can begin with estimates in cubic units and convert them to carbon weight or wood weight units then convert them to carbon weight (assuming 0.5 metric tons carbon per metric ton dry wood). Separate lookup "decay" tables are provided by major U.S. region and roundwood type (HW or SW, SL, or PW) that show the fraction of carbon in wood typically stored in wood products in use and in landfills, out to 100 years after the year of harvest, and the average fraction stored over 100 years.

For the primary product type of lookup tables, the landowner needs estimates of the primary wood products made from the wood harvested; i.e., SW or HW lumber, SW or HW plywood, oriented strandboard, or paper (in conventional product units). The landowner then converts these amounts to carbon weight. For each primary product, the lookup "decay" tables show the fraction of wood carbon that is typically stored in wood products in use and in landfills, from the year of harvest out to 100 years, and the average fraction of carbon stored over 100 years.

6.5.3 Activity Data Collection

6.5.3.1 Primary Product Decay Tables

In order to construct the primary product type decay tables, data are used for each U.S. region on:

- The disposition of each primary product (e.g., lumber, structural panels) to major end uses (e.g., percentage of product going to residential housing, non-residential housing, manufacturing (furniture)), and percentage going to exports;
- The decay functions indicating how quickly products go out of use for each end use;
- The fraction of material going out of use that goes to landfills; and
- The fraction of material in landfills that does not decay, and the decay rate for material in landfills that does decay.

It is assumed that there is a national market for primary products and the percentage of primary products going to each end use will be the same for each U.S. region. It is also assumed that primary products exported from the United States are used in the same way as domestic products. That is, there is a national market for each of the primary wood and paper products. Data for items (1) through (4) come from the WOODCARB II model used to estimate annual change in carbon stored in products and landfills for the U.S. Inventory of GHG Emissions and Sinks report (Skog, 2008; U.S. EPA, 2010).

If a landowner knows the traditional number of units of primary products (e.g., thousand board feet of lumber) that were made from the timber harvested from their land in a given year, they can use Tables 6-A-1, 6-A-2, and 6-A-3 to estimate the carbon contents in these products (Table 6-A-1) and estimate the amount of carbon stored in these products (in use and in landfills) out to 100 years and the average amount of carbon stored over 100 years (Table 6-A-2 [in use] and Table 6-A-3 [in landfills]).

The average amount of carbon stored over 100 years for a particular primary product is the total of the averages for products in use and products in landfills shown in Tables 6-A-2 (in use) and Table 6-A-3 (in landfills).

6.5.3.2 Roundwood Decay Tables

In order to construct the roundwood type of decay tables, data are needed for each region on the percentage of HW or SW, SL, or PW that goes to various primary wood products; for example, the fraction of SW SLs in the South that goes to lumber, panels, and paper. After the amounts of primary wood products are estimated, the primary products type decay tables can be used to construct roundwood decay tables. Data needed to divide roundwood into primary products for each region include Forest Service FIA timber product output data and national data on primary wood products production (Howard, 2012; Smith et al., 2007).

If a landowner knows the cubic feet of roundwood, in the form of HW or SW SLs or PW that is harvested from their land in a given year, they can use Table 6-A-4 and 6-A-5 to (1) estimate the weight of wood harvested; (2) convert weight of wood to carbon by multiplying by 0.5 (i.e., the fraction of dry biomass to carbon conversion factor); and (3) estimate the total amount of carbon stored in the products (the sum of amounts in use and in landfills) each year out to 100 years, and the average stored over 100 years.

If the landowner knows the weight of roundwood harvested rather than cubic feet, it would use steps 2 and 3 above.

Annual HWP carbon (average stored over 100 years) is given for each region and roundwood type in Table 6-A-5.

If the landowner is making forest growth and harvest projections (Type II and Type III estimates) and only knows the cubic feet (or weight) of growing stock of HW and SW SLs and PW that will be harvested in given future years, then Table 6-A-6 can be used to estimate the total amount of roundwood that can expected to be harvested (growing stock and non-growing stock). These total amounts of roundwood (HW and SW SLs and PW may then converted to carbon and to carbon stored (and average carbon stored over 100 years) using Table 6-A-4 and Table 6-A-5, as discussed above. To convert 1 cubic foot of dry wood to pounds multiply density by 62.4 lbs ft^{-3}. To convert 1 cubic foot to kilograms multiply density by 28.3 kg ft^{-3}.

A spreadsheet is available showing all the parameters and calculations that produce the carbon storage tables that start with primary products or roundwood harvest (Skog, 2013).

6.5.4 Limitations, Uncertainty, and Research Gaps

6.5.4.1 Uncertainty in C change estimate

General estimates of uncertainty, given as the 95 percent confidence intervals, can be made for HWP measure used in Type I carbon change estimates (current year or recent past years). These estimates of uncertainty could be provided with each of the two types of lookup tables, and can be made using Monte Carlo simulations and assumptions about HWP uncertainty that are used for the Inventory of U.S. Greenhouse Gas Emissions and Sinks report (U.S. EPA, 2011). Uncertainty could be specified for key variables including: (1) fractions of SLs PW going to various primary products; (2) fractions of primary products going to various end uses; (3) rate at which products are discarded from each end use; (4) fraction of discarded wood or paper that goes to landfills; (5) fraction of wood or paper set to landfills that is subject to decay; and (6) rate of decay in landfills of degradable wood/paper carbon.

A spreadsheet is available the could be used as a basis for Monte Carlo simulations to estimate overall uncertainty for estimates of average carbon stored over 100 years (Skog, 2013).

It would be possible but more complex to make uncertainty estimates for Type II and Type III carbon change estimates by adding estimates of uncertainty in parameters used to make projections of harvest.

Additional research is needed to improve differentiation of the various rates at which solidwood products are discarded from uses such as pallets, railroad, railcars, and furniture that are currently grouped into one category. This further differentiation would refine estimates of average carbon stored when the landowner knows which primary wood products are made from the wood that is harvested on their land. Alternate curves for discard rates from end uses, particularly discards from housing, if empirically verified, could improve estimates of average carbon stored. Estimates of uncertainty in parameters over 100 year projections are needed to give a sound estimate of the uncertainty in average carbon stored over 100 years.

6.6 Urban Forests

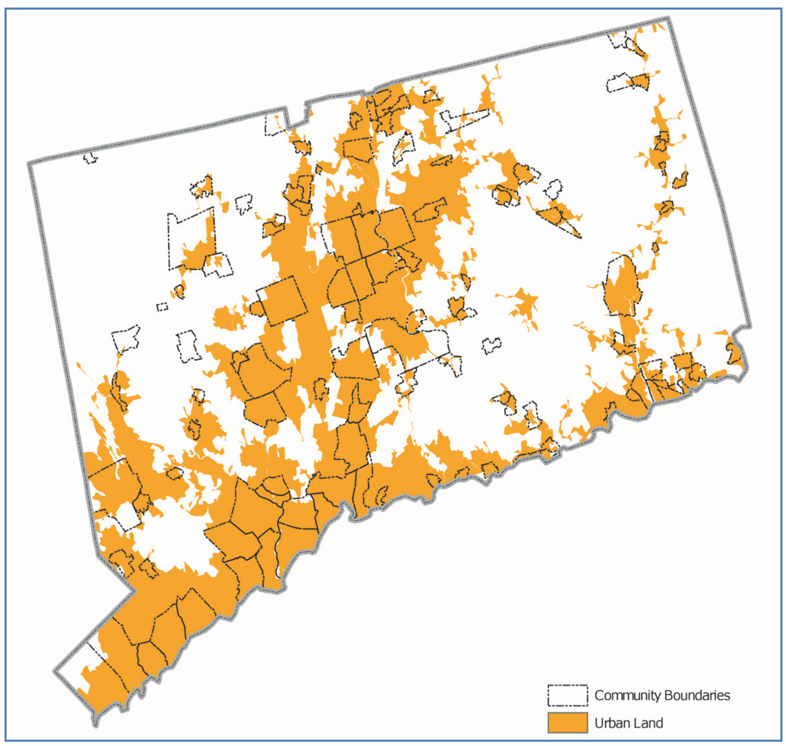
Methods for Urban Forests

- Range of options depends on data availability of the entity's urban forest land.
- These options use:
  - i-Tree Eco model (http://www.itreetools.org) to assess carbon from field data on tree populations; and
  - i-Tree Canopy model (http://www.itreetools.org/canopy/index.php) to assess tree cover from aerial images and lookup tables to assess carbon.
- Quantitative methods are also described for maintenance emissions and altered building energy use and included for information purposes only.
- The methods were selected because they provide a range of options dependent on the data availability for the entity's urban forest land.

6.6.1 Description

6.6.1.1 Defining Urban Areas and Forests

Figure 6-7: Urban and Community Land in Connecticut



Source: U.S. Census Bureau (2007).

Urban forests are composed of a population of all trees within an urban area. To delimit the extent of an urban forest, the boundaries of the urban area must be drawn. This boundary issue can be problematic, as people may conceive or define "urban" differently. To delimit urban areas in the United States, U.S. Census bureau definitions are used. These definitions differ from those used in the National Resources Inventory, which aims to identify areas that are removed from the rural land base and includes land uses such as transportation corridors.

The U.S. Census Bureau (2007) defines urban as all territory, population, and housing units located within urbanized areas or urban clusters. Urbanized area and urban cluster boundaries encompass densely settled territories, which are described by one of the following: (1) one or more block groups or census blocks with a population density of at least 386.1 people km^{-2}

(1,000 people mile^{-2}); (2) surrounding block groups and census blocks with a population density of 193.1 people km^{-2} (500 people mile^{-2}); and (3) less densely settled blocks that form enclaves or indentations or are used to connect discontinuous areas. More specifically, urbanized areas consist of territories of 50,000 or more people. Urban clusters, a concept new to the 2000 Census, consist of territories with at least 2,500 people but fewer than 50,000 people.

In addition to urban land, the Census Bureau designates places that delimit population concentrations based on incorporated or unincorporated places, such as a city, town, village, and census-designated place. These places, or "communities," also define areas where people reside, but often with a lower population density. The geographic areas of urban and communities overlap (see Figure 6-7), and either or both could be used to define urban forests. The urban land designation delimits higher population densities, but does not follow the boundaries of cities or towns that most people can relate to. The place or community boundaries follow these political boundaries, but often include both rural and urban land.

Urban land is defined based on population density, and community land is often based on political boundaries. Thus, urban forest land overlaps with forest lands. That is, forested stands that are measured as part of other programs can exist within urban or community boundaries. Assessments of urban forest effects thus have the potential to double-count effects found in forests within regional or national scale assessments. The amount of this overlap is estimated as 13.8 percent of urban area or 1.5 percent of forest area in the conterminous United States (Nowak et al., 2013) and is an important consideration for larger scale assessments. This section focuses on assessing the carbon effects of urban or community trees and forests in the United States.

Urban or community forests (hereafter referred to as urban forests) affect the carbon cycle by directly storing atmospheric carbon within the woody vegetation, but also by affecting the local climate and thereby altering carbon emissions affected by local climatic conditions. Urban tree maintenance activities also affect carbon emissions in urban areas. For a true accounting of carbon effects, all of these factors need to be considered. This report focuses on trees (defined as woody vegetation with a diameter of at least 1 inch (2.5 cm) DBH), but similar accounting could be conducted for all urban vegetation.

6.6.1.2 Accounting for Primary Urban Forest Carbon Effects

Trees sequester and store carbon in their tissue at differing rates and amounts, based on such factors as tree size, life span, and growth rate. After a tree is removed, the tree can decompose with the carbon stored in that tree emitted back to the atmosphere, or the carbon may be stored in wood products or the soil. Thus, in order to account for the total carbon in the system at one time, one needs to understand how many trees there are in the system along with information such as species and size (e.g., Nowak and Crane, 2002). To account for how the carbon stock will change through time, one must also account for growth rates, tree mortality and removals, and the disposition of the wood after removal (e.g., chipping, burning, products), which affect decomposition rates and carbon emissions. In addition, the number of new trees entering the system through tree planting and natural regeneration must be considered.

6.6.1.3 Accounting for Secondary Effects

In addition to the carbon stored in trees, the urban forest has secondary impacts on atmospheric carbon by affecting carbon emissions from urban areas. Tree care and maintenance practices often release carbon back to the atmosphere via fossil-fuel emissions from maintenance equipment (e.g., chain saws, trucks, chippers). Thus, some of the carbon gains from tree growth are offset by carbon losses to the atmosphere via fossil fuels used in maintenance activities (Nowak et al., 2002). Trees strategically located around buildings can reduce building energy use (e.g., Heisler, 1986), and consequently reduce carbon emissions from fossil-fuel-burning power plants. These energy effects are caused primarily by tree transpiration (lowering of air temperatures), blocking of winds, and shading of buildings and other surfaces. Trees typically lower building energy use in summer, but can either lower or increase building energy use in the winter depending upon the tree's location relative to a building.

"Altered building energy use" and "maintenance emissions" for urban trees are described in Section 6.6.3.1. However, while quantitative methods are described for estimating altered building energy use and maintenance emissions for urban forestry, they are included for information purposes only, since they have already been developed as part of the i-Tree software suite. However, as previously mentioned in Chapter 1, the scope of this guidance does not include other energy-related source categories that are associated with management activities related to certain agriculture and forestry activities (e.g., transportation, fuel use, heating fuel use).

6.6.2 Activity Data Collection

To estimate carbon storage, annual sequestration, and long-term carbon changes, two general approaches could be used. The first method is based on collecting data on trees in the urban area of interest; the second method involves collecting aerial data on tree cover in the area, and using tables to estimate effects based on field data from other areas. The first method, using local field data, will produce the most accurate estimates for the local area, but at increased costs and time spent by the landowner. The second method is more cost-effective and more straightforward, but its accuracy is more limited (see Table 6-8).

Table 6-8: Comparison of the "Field Data" and "Aerial" Methods for Estimating the Changes in Carbon Stocks for Urban Forests

Field Data Method	Aerial Method
Requires significant time commitment to take field measurements	Requires less time to extract necessary aerial data from an existing database
Requires access to several sample plots across an area	Does not require field measurements, only a computer with internet access
Increases specificity and accuracy	Returns a more approximate estimate
Provides a variety of output data including current carbon stock, annual carbon sequestration, and long term effects	Provides only information on total carbon stored and annual carbon sequestration

The output data from the field data method includes current carbon stock (existing carbon storage), annual carbon sequestration by trees, and long term effects of the forest (accounting for changes in tree population and disposition of carbon from trees). For the field data method (or for producing the default tables that are used in the aerial approach) the following items need to be measured and input by the landowner:

- Current Stock:
  - Number of trees by species and size class (species, DBH, height, condition, competition factor)
- Annual Sequestration:
  - Number of trees by species and size class (species, DBH, height, condition, competition factor)
  - Annual growth rates for each tree based on tree and site conditions (inches per year)
- Long Term Effects:

  - Number of trees by species and size class (species, DBH, height, condition, competition factor)
  - Annual growth rates for each tree based on tree and site conditions (inches per year)
  - Changes in tree population due to tree death and removals, and new trees planted or naturally regenerated (numbers of trees dying by species and size class, number of new trees by species and size class) (number per year)
- Proportion of removed tree biomass that is:
  - Chipped/mulched
  - Burned
  - Burned to produce energy (e.g., heat buildings)
  - Below the ground in roots
  - Used for long-term wood products
  - Left on the ground to decompose naturally
  - Put in landfills
- Decomposed; decomposition rates for wood from removed trees:
  - Percentage of biomass per year decomposed per removal class above
- Maintenance Emissions:
  - Amount (number and hours per year) of maintenance equipment used (e.g., vehicles, chippers, chain saws) for vegetation maintenance (e.g., planting, maintenance, tree removal)
  - Emission factors ($g\ C\ hr^{-1}$) for each maintenance equipment used
- Altered Building Energy Use:
  - Number of trees by species and size class within 60 feet (18.3 m) of residential building by cardinal and ordinal direction

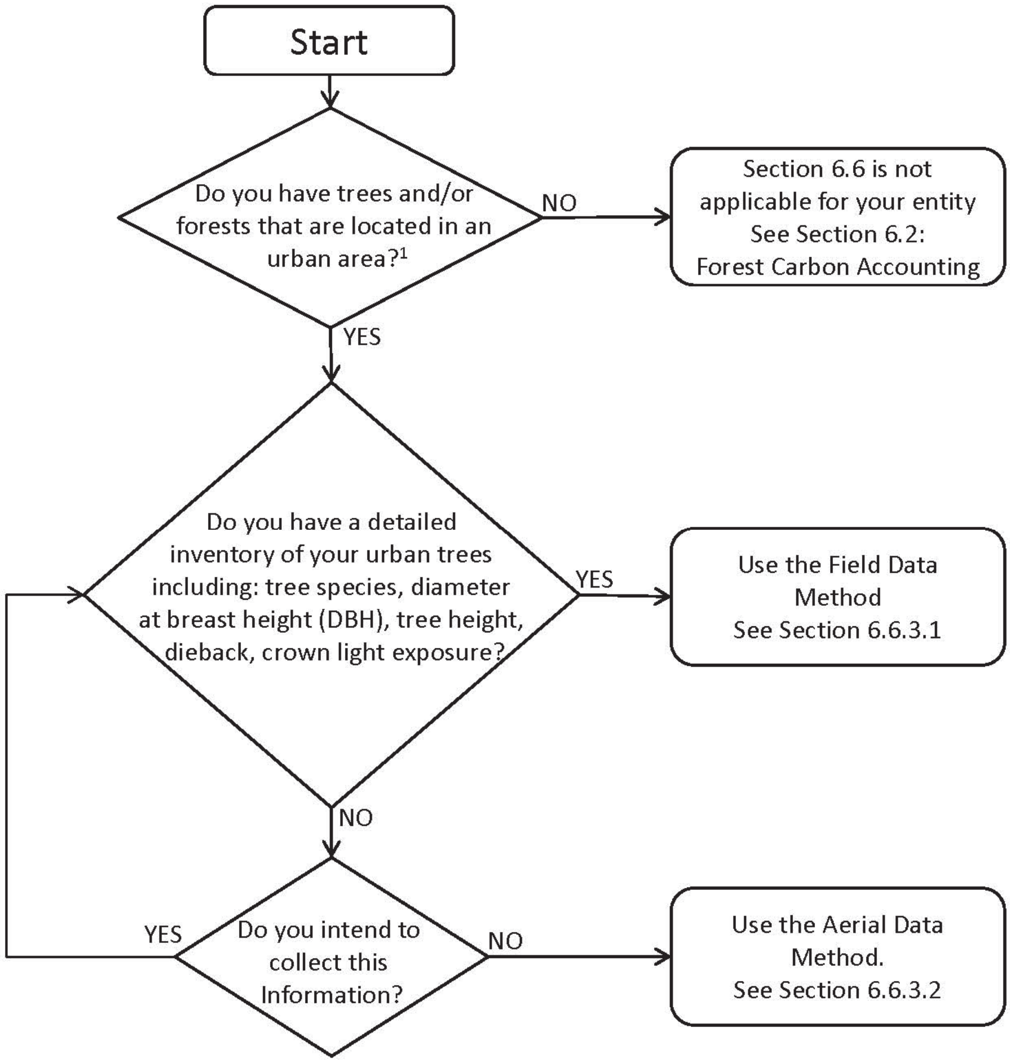
For estimating tree cover using the aerial approach, one would need to know the extent (ha) of the urban area and the percentage of tree cover within the area, and use a default table of values to convert ha of tree cover to primary and secondary tree effects in a city. To estimate change in the population, the tree cover would need to be re-measured through time.

As previously mentioned, altered building energy use and maintenance emissions for urban trees are described in Section 6.6.3.1. However, while quantitative methods are described for estimating altered building energy use and maintenance emissions for urban forestry, they are included for information purposes only, as they are part of the i-Tree software suite or can be calculated from i-Tree data.

6.6.3 Estimation Methods

The methods for estimating carbon effects in an urban forest will be detailed for the field data and aerial approaches separately. The field data method and aerial method for urban forests are described in Section 6.6.3.1 and Section 6.6.3.2. Figure 6-8 shows a decision tree indicating which method is more applicable for each type of activity data.

Figure 6-8: Decision Tree for Urban Forests Showing Methods Appropriate for Estimating Urban Forest Carbon Stocks



[1] The U.S. Census Bureau (2007) defines urban as all territory, population, and housing units located within urbanized areas or urban clusters. Urbanized area and urban cluster boundaries encompass densely settled territories, which are described by one of the following: (1) one or more block groups or census blocks with a population density of at least 386.1 people km^{-1} (1,000 people $mile^{-2}$); (2) surrounding block groups and census blocks with a population density of 193.1 people km^{-2} (500 people $mile^{-2}$); and (3) less densely settled blocks that form enclaves or indentations, or are used to connect discontinuous areas. More specifically, urbanized areas consist of territories of 50,000 or more people. Urban clusters, a concept new to the 2000 Census, consist of territory with at least 2,500 people but fewer than 50,000 people.

6.6.3.1 Field Data Method for Estimating Carbon Storage and Annual Sequestration

The field data method involves using field measurements of urban trees (i.e., a "tree list") to build a tailored, accurate estimate of carbon storage and sequestration in an urban forest. The various steps for estimating carbon (and altered building energy use) effects from an urban forest are:

(1) *Delimit boundary of urban area to be analyzed*. This information is essential to set the boundary of the analysis. U.S. Census boundary files of urban areas or places can be used to delimit the boundaries (U.S. Census Bureau, 2011). Information on these boundaries can be used to determine areas of potential overlap with other carbon estimates (e.g., non-urban forests), and to help set up a

sampling design to collect necessary field data as desired by the landowner.

(2) *Measure all trees within the urban area or sample the tree population*. Within the defined geography, all trees can be measured, or a random distribution of field plots can be measured to quantify the urban tree population as desired by the landowner. To conduct this field sampling and analysis, the i-Tree Eco model (formerly UFORE model) is available free of charge at www.itreetools.org. Field manuals exist on how to randomly select plots locations and collect the needed field data (http://www.itreetools.org/resources/manuals.php). Details on model methods also exist (e.g., Nowak and Crane, 2002; Nowak et al., 2008).

The basic field data procedure is to record information on all trees within the field plots. This information includes:

- Tree species
- DBH
- Tree height
- Dieback
- Crown light exposure
- Distance and direction to buildings

These variables are needed to assess carbon effects, but other tree variables (e.g., crown width, percentage of crown missing) can also be collected to assess other ecosystem services (e.g., air pollution removal, volatile organic compound emissions, effects on building energy use, rainfall interception, and runoff).

(3) *Enter data into i-Tree and run analyses*. After field data are collected (via paper forms or on a mobile device), data are entered into i-Tree, and the program produces standard tables, graphs, and reports that detail carbon and other ecosystem service information. In relation to carbon, results along with sampling standard errors are specifically produced by species and land use regarding:

- Carbon storage: amount of carbon currently in the existing tree stock;
- Gross annual carbon sequestration: one-year estimate as sequestration based on estimated annual tree growth, which varies by location, tree condition, and crown competition; and
- Net annual carbon sequestration: gross sequestration minus estimated carbon lost from dead or removed trees due to decomposition.

Altered Building Energy Use. In addition to the carbon effects estimated by the field data method, the i-Tree program can estimate tree effects on residential building energy use and consequent carbon emissions using methods detailed in McPherson and Simpson (1999).

Maintenance Emissions. For estimating maintenance emission effects, the following steps are suggested:

(1) *Determine vehicle use related to tree maintenance*. Determine the number of miles driven by various vehicle types.

(2) *Calculate carbon emissions from vehicles*. To estimate carbon emissions from vehicles, the latest fuel efficiency information (mpg) will be needed for each vehicle class. Divide the miles driven by the vehicle class mpg to determine the total gallons of gasoline (or other fuel) used. Multiply total gallons (or other units) used by the emissions factor in Table 6-9 to estimate carbon emissions from vehicle use (Nowak et al., 2002).

Table 6-9: Emission Factors for Common Transportation Fuels

Fuel	Emissions (lbs CO_2 per unit volume)
B20 biodiesel	17.71 per gallon
B10 biodiesel	19.93 per gallon
Diesel fuel (No.1 and No. 2)	22.15 per gallon
E85 ethanol	2.9 per gallon
E10 ethanol	17.41 per gallon
Gasoline	19.36 per gallon
Natural gas	119.90 per Mcf
Propane	5.74 per gallon

Source: Table 1.D.1, U.S. DOE (2007).

(3) *Determine maintenance equipment use*. Estimate the number of run hours used for all fossil-fuel-based maintenance equipment used on trees (e.g., chainsaws, chippers, aerial lifts, backhoes, and stump grinders). Estimates of run time for various pruning and removal equipment are given in Table 6-10.

Table 6-10: Total Hours of Equipment Run-Time by DBH Class for Tree Pruning and Removal

DBH	Pruning				Removal					
	2.3 hp Saw	3.7 hp Saw	Bucket Truck[a]	Chipper[b]	2.3 hp Saw	3.7 hp Saw	7.5 hp Saw	Bucket Truck[a]	Chipper[b]	Stump Grinder[b]
1–6	0.05	NA	NA	0.05	0.3	NA	NA	0.2	0.1	0.25
7–12	0.1	NA	0.2	0.1	0.3	0.2	NA	0.4	0.25	0.33
13–18	0.2	NA	0.5	0.2	0.5	0.5	0.1	0.75	0.4	0.5
19–24	0.5	NA	1.0	0.3	1.5	1.0	0.5	2.2	0.75	0.7
25–30	1.0	NA	2.0	0.35	1.8	1.5	0.8	3.0	1.0	1.0
31–36	1.5	0.2	3.0	0.4	2.2	1.8	1.0	5.5	2.0	1.5
+36+	1.5	0.2	4.0	0.4	2.2	2.3	1.5	7.5	2.5	2.0

Note: Table is based on ACRT data (Wade and Dubish, 1995) and assumes that crews work efficiently and equipment is not run idle (Nowak et al., 2002).
hp = Horsepower
DBH = Diameter at breast height
[a] Mean hp = 43 (U.S. EPA, 1991)
[b] Mean hp = 99 (U.S. EPA, 1991)

(4) *Calculate carbon emissions from maintenance equipment*. Calculations for emissions from equipment are based on the formula:

Equation 6-10: Calculate Carbon Emissions from Maintenance Equipment

$$C = N \times HRS \times HP \times LF \times E$$

Where:

C = Carbon emissions (g)

N = Number of units (dimensionless)

HRS = Hours used (hr)

HP = Average rated horsepower (hp)

LF = Typical load factor (dimensionless)

E = Average carbon emissions per unit of use (g hp^{-1} hr^{-1}) (U.S. EPA 1991)

Typical load factors and average carbon emissions for equipment are given in Table 6-11.

Table 6-11: Typical Load Factors (U.S. EPA, 1991), Average Carbon Emissions, and Total Carbon Emissions for Various Maintenance Equipment (from Nowak et al., 2002)

Equipment	Typical Load Factor[a]	Average Carbon Emission (g hp^{-1} hr^{-1})[b]	Total Carbon Emission (kg hr^{-1})[c]
Aerial lift	0.505	147.2	3.2[d]
Backhoe	0.465	147.3	5.3[e]
Chain saw <4 hp	0.500	1,264.4	1.5[f]
Chain saw >4 hp	0.500	847.5	3.2[g]
Chipper/stump grinder	0.370	146.4	5.4[h]

[a] Average value from two inventories (conservative load factor of 0.5 from inventory B was used for chain saws >4 hp due to disparate inventory estimates; inventory average for this chain saw type was 0.71).
[b] Calculated from estimates of carbon monoxide (U.S. EPA, 1991), hydrocarbon crankcase and exhaust (U.S. EPA, 1991), and carbon dioxide emissions (Charmley, 1995), adjusted for in-use effects. Total carbon emissions were calculated based on the proportion of carbon of the total atomic weight of the chemical emission. Multiply by 0.0022 to convert to lbs hp^{-1} hr^{-1}.
[c] Multiply by 2.2 to convert to lbs hr^{-1}.
[d] Mean hp = 43 (U.S. EPA, 1991).
[e] Mean hp = 77 (U.S. EPA, 1991).
[f] hp = 2.3.
[g] hp = 7.5.
[h] Mean hp = 99 (U.S. EPA, 1991).

(5) *Calculate total maintenance carbon emissions*. Add results of carbon emissions from vehicles and maintenance equipment.

Combined Carbon Sequestration, Altered Building Energy Use, and Maintenance Emissions. To determine current net annual urban forest effect on carbon, the carbon emissions from tree maintenance should be contrasted to net carbon sequestration from trees and altered carbon emissions from altered building energy use effects.

Changes in Carbon Sequestration, Altered Building Energy Use, and Maintenance Emissions. To determine how tree and maintenance effects on carbon change through time, the field plots or trees inventoried can be re-measured, and results between the years contrasted to estimate changes in carbon stock, net annual carbon effects, and altered building energy use effects. In addition, maintenance activity estimates should be updated when the re-measurement occurs.

6.6.3.2 Aerial Data Method

The aerial data method uses aerial tree cover estimates and lookup tables to provide a more approximate (i.e., higher degree of uncertainty), but less resource intensive estimate of annual carbon sequestration in an urban forest compared to the field data method. The various steps for estimating carbon effects from an urban forest are:

(1) *Delimit boundary of urban area to be analyzed*. This information is essential to set the boundary of the analysis. U.S. Census boundary files of urban or places can be used to delimit the boundaries (U.S. Census Bureau, 2011). Information on these boundaries can be used to determine areas of potential overlap with other carbon estimates (e.g., non-urban forests).

(2) *Conduct photo interpretation of tree cover in urban area*. To determine percentage of tree cover, the urban area can be photo interpreted using i-Tree Canopy (http://www.itreetools.org/canopy/index.php). This web tool allows users to import a shape file of, or manually delimit their area, and then randomly locate points within the area on Google® aerial imagery. The user then classifies each point according to its cover class (e.g., tree or non-tree). The program produces estimates of percentage cover and associated standard error for the cover classes. This same type of analysis could also be performed with digital aerial images using a Geographic Information System.

(3) *Estimate total tree cover in urban area*. Multiply the percentage of tree cover and standard error by urban area (ha) to produce an estimate of total tree cover and standard error (ha). Note that i-Tree Canopy will make these calculations.

(4) *Estimate carbon effects*. Multiply total tree cover (ha) by average carbon storage or annual sequestration per ha of tree cover in places or urban areas (Table 6-12). i-Tree Canopy will make these calculations based on average state or national data.

Note that to estimate effects for maintenance emissions and altered building energy use based on total tree cover, a table similar to Table 6-12 would need to be developed containing emission rates for these source categories.

Table 6-12: Metric Tons Carbon Storage and Annual Sequestration per Hectare of Tree Cover in Selected Cities and Urban Areas of Selected States (from Nowak et al., 2013)

City, State	Storage		Sequestration	
	Metric tons C ha^{-2}	Standard Error	Metric tons C ha^{-2} $year^{-1}$	Standard Error
Arlington, TX[a]	63.7	7.3	2.9	0.28
Atlanta, GA[a]	66.3	5.4	2.3	0.17
Baltimore, MD[a]	87.6	10.9	2.8	0.36
Boston, MA[a]	70.2	9.6	2.3	0.25
Casper, WY[b]	69.7	15.0	2.2	0.39
Chicago, IL[c]	60.3	6.4	2.1	0.21
Freehold, NJ[a]	115.0	17.8	3.1	0.45
Gainesville, FL[d]	63.3	9.9	2.2	0.32
Golden, CO[a]	58.8	13.3	2.3	0.45
Hartford, CT[a]	108.9	16.2	3.3	0.46
Jersey City, NJ[a]	43.7	8.8	1.8	0.34
Lincoln, NE[a]	106.4	17.4	4.1	0.63
Los Angeles, CA[e]	45.9	5.1	1.8	0.17
Milwaukee, WI[a]	72.6	11.8	2.6	0.33

City, State	Storage		Sequestration	
	Metric tons C ha^{-2}	Standard Error	Metric tons C ha^{-2} year^{-1}	Standard Error
Minneapolis, MN[f]	44.1	7.4	1.6	0.23
Moorestown, NJ[a]	99.5	9.3	3.2	0.30
Morgantown, WV[g]	95.2	11.6	3.0	0.37
New York, NY[h]	73.3	10.1	2.3	0.29
Oakland, CA[i]	52.4	1.9	na	na
Omaha, NE[a]	141.4	22.9	5.1	0.81
Philadelphia, PA[j]	67.7	9.0	2.1	0.27
Roanoke, VI[a]	92.0	13.3	4.0	0.58
Sacramento, CA[k]	78.2	15.7	3.8	0.64
San Francisco, CA[l]	91.8	22.5	2.4	0.50
Scranton, PA[m]	92.4	12.8	4.0	0.52
Syracuse, NY[a]	85.9	10.4	2.9	0.30
Washington, DC[n]	85.2	10.4	2.6	0.30
Woodbridge, NJ[a]	81.9	8.2	2.9	0.28
Indiana[o]	88.0	26.8	2.9	0.77
Kansas[p]	74.2	13.0	2.8	0.48
Nebraska[p]	66.7	18.6	2.7	0.74
North Dakota[p]	77.8	24.7	2.8	0.79
South Dakota[p]	30.6	6.6	1.3	0.26
Tennessee[q]	64.7	5.0	3.4	0.21
Average	**76.9**	**13.6**	**2.8**	**0.45**

[a] Unpublished data analyzed using the UFORE model.
[b] Nowak et al. (2006a).
[c] Nowak et al. (2011).
[d] Escobedo et al. (2009).
[e] Nowak et al. (2011).
[f] Nowak et al. (2006c).
[g] Nowak et al. (2012c).
[h] Nowak et al. (2007d).
[i] Nowak (1991).
[j] Nowak et al. (2007c).
[k] Nowak et al. (In review).
[l] Nowak et al. (2007b).
[m] Nowak et al. (2010).
[n] Nowak et al. (2006b).
[o] Nowak et al. (2007a).
[p] Nowak et al. (2012b).
[q] Nowak et al (2012a).

Combined Carbon Sequestration, Altered Building Energy Use, and Maintenance Emissions. To determine current net annual urban forest effect on carbon, the carbon emissions from tree maintenance, if available, should be contrasted to the net carbon sequestration from trees and altered carbon emissions from altered building energy use effects.

Changes in Carbon Sequestration, Altered Building Energy Use, and Maintenance Emissions. To determine tree effects on carbon change through time, the photo-interpretation points can be re-measured when newer photos become available to assess change in tree cover (e.g., Nowak and Greenfield, 2012). The i-Tree Canopy program saves the geographic coordinates of each point so the points can be re-measured in the future. Changes in tree cover and associated carbon effects between the years can be contrasted to estimate changes in carbon stock and net annual carbon effects. Changes in altered building energy use effects and maintenance effects could also be estimated if the appropriate tables are developed.

6.6.4 Limitations and Uncertainty

Field data collection estimates have fewer limitations than the aerial approach, but some limitations exist (Nowak et al., 2008). The main advantage of carbon estimation using the field data approach and i-Tree is having accurate estimates of the tree population (e.g., species, size, distribution) with a calculated level of precision. The modeled carbon values are estimates based on forest-derived allometric equations (Nowak, 1994; Nowak and Crane, 2002). The carbon estimates yield a standard error of the estimate based on sampling error, rather than error of estimation. Estimation error is unknown, and likely larger than the reported sampling error. Estimation error includes the uncertainty of using biomass equations and conversion factors, which may be large, as well as measurement error, which is typically small. The standardized carbon values (e.g., kg C ha^{-1} or lbs C (acre of tree cover)$^{-1}$) fall in line with values for forests (Birdsey and Heath, 1995), but values for cities (places) can be higher (Table 6-12), likely due to a larger proportion of large trees in city environments and relatively fast growth rates due to a more open urban forest structure (Nowak and Crane, 2002).

There are various means to help improve the carbon storage and sequestration estimates for urban trees. Carbon estimates for open-grown urban trees are adjusted downward based on field measurements of trees in the Chicago area (Nowak, 1994). This adjustment may lead to conservative estimates of carbon. More research is needed on the applicability of forest-derived equations to urban trees. In addition, more urban tree growth data are needed to better understand regional variability of urban tree growth under differing site conditions (e.g., tree competition) for better annual sequestration estimates. Average regional growth estimates are used based on limited measured urban tree growth data standardized to length of growing season and crown competition.

There are currently a very limited number of biomass equations for tropical trees in i-Tree. The model needs to be updated with tropical tree biomass equations for more accurate estimates in tropical cities. Future research is needed to obtain biomass equations for urban or ornamental tree species. Estimates of tree decay and net annual sequestration in i-Tree are quite rudimentary (Nowak et al., 2010), and can be improved with future research. The degree of uncertainty of the net carbon sequestration estimates is unknown.

Estimates of maintenance emissions and altered building energy use effects are also rather crude. Accurate maintenance emissions estimates require good estimates of vehicle and maintenance equipment use; then they rely on an average multiplier for emissions from the literature. Energy effects estimates are based on sampling proximity of trees near buildings within various tree size, distance, and direction classes from a building. Energy factors, converted to carbon emission factors based on state average energy distribution (e.g., electricity, oil) are applied to trees in each building location class based on U.S. climate zone and average building types in a state to estimate energy effects (see McPherson and Simpson, 1999). Though these estimates are crude, with an unknown certainty, they are based on reasonable approaches that provide first-order estimates of effects. It should be noted that emission reductions from altered building energy use effects might also be implicitly included in any emission estimation an entity might perform based on actual energy use data (e.g., meter readings) for the building in question.

Estimates based on aerial tree canopy effects have the same limitations as field data approaches, plus some additional limitations and advantages. The advantages include a simple, quick, and accurate means to assess the amount of canopy cover in an area, with measures that are repeatable through time. The disadvantages are that the user must use a lookup value from a table (e.g., mean value per unit of canopy cover) to estimate carbon effects. Though the tree cover estimate will be accurate with known uncertainty (i.e., standard error), the carbon multipliers may be off depending upon the urban forest characteristics. If average multipliers are used, the accuracy of those estimates will decline as the difference increases between the local urban characteristics and the values of the average multipliers. If local field data are not collected, then the discrepancy between the urban forest's characteristics and those of average values is unknown. If the average values in

Table 6-12 truly represent averages, the estimates over a large population of urban areas should be reliable. However, local estimates may be inaccurate depending upon the extent to which characteristics of the local urban forest diverge from the average values.

Both approaches can provide carbon estimates for urban areas, with differing degrees of uncertainty and work required. Both approaches can also be improved with more field data collection in urban areas, and with model and method improvements related to carbon estimation.

6.7 Natural Disturbance – Wildfire and Prescribed Fire

Methods for Emissions from Natural Disturbances

- Range of options depends on the data availability of the entity's forest land including:
  - FOFEM model entering measured biomass; and
  - FOFEM model using default values generated by vegetation type.
- These options use Reinhardt et al. (1997).
- The methods were selected because they provide a range of options dependent on the data availability of the entity's disturbed forest land.

6.7.1 Description

Fire produces GHG emissions directly through fuel consumption. Emissions produced are directly proportional to fuel consumed. Fuel consumption is in turn influenced by fuel quantity and fuel characteristics such as size, moisture content, fire weather, and fire severity. Algorithms exist for estimating fuel consumption for a variety of fuel types and conditions. Fire and other disturbances also convert live vegetation to dead, altering subsequent carbon dynamics on the site by reducing carbon captured by photosynthesis in the short run due to reduced vegetative cover, and increasing emissions from decomposition of dead vegetation. Fire severity, which is driven by the onsite factors that drive consumption as well as other physical factors, will drive the subsequent carbon dynamics and area where reversal of carbon retention may occur.

6.7.2 Activity Data Collection

For all disturbances, key activity data is the area affected. A simple descriptor is used to characterize the severity of the event. For both wildfire and prescribed fire/control burns, descriptors of severity include crown fire, stand-replacement underburn, mixed-severity underburn (some tree mortality), and low-severity underburn. Typically wildfire will be more weighted towards crown fire and higher severity versus lower severity from prescribed fire. For other disturbances, the percentage of live trees killed (or percentage basal area mortality) and the percentage of killed trees that are still standing as was covered previously in Section 6.4.2.10 and Section 6.4.4.8 are used.

6.7.3 Estimation Methods

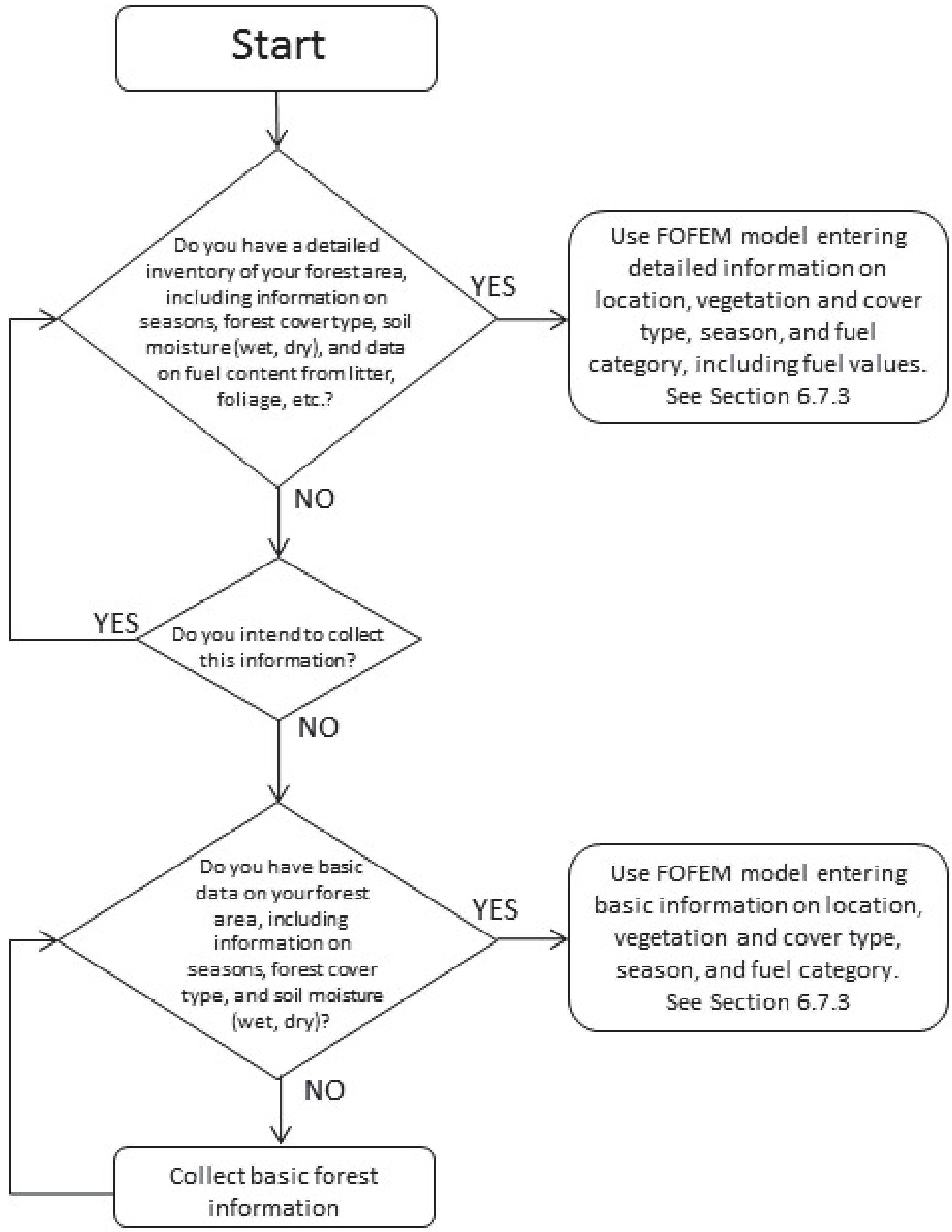
FOFEM[9] (Reinhardt et al., 1997) is recommended for estimating GHG emissions, because it is applicable nationally, computer code is available that can be linked to or incorporated into other

[9] http://www.firelab.org/science-applications/fire-fuel/111-fofem

code, and inputs are defined so that measured biomass can be entered or default values generated by vegetation type. FOFEM produces direct estimates of total CO_2, CO, CH_4, and NO_x emitted, as well as estimates of fuel consumption by component, which can be used to determine residual fuel quantities for estimating subsequent decomposition. FOFEM and/or CONSUME (Joint Fire Science Program, 2009) can also be used directly to compute emissions and consumption from fire. FOFEM algorithms can also be used to compute tree mortality in order to update estimates of live and dead biomass. Although another option is to use FVS-FFE[10] (Rebain, 2010; Reinhardt and Crookston, 2003), it is not the recommended approach for wildfire GHG calculation. FVS-FFE uses many of the same internal algorithms for estimating tree mortality, fuel consumption, and emissions as FOFEM, but also simulates stand, fuel, and carbon dynamics over time. It is a more powerful predictive tool, but substantially more work is involved in understanding the modeling framework, setting up model runs and data preparation. Alternatively, lookup tables can be built using these tools for a range of vegetation types, fuel loadings from natural and/or management processes, and fire severities, or a simplified algorithm can be developed as in the 2006 IPCC Guidelines for National GHG Inventories (IPCC, 2006).

[10] http://www.fs.fed.us/fmsc/fvs/whatis/index.shtml

Figure 6-9: Decision Tree for Natural Disturbances Showing Methods Appropriate for Estimating Emissions from Forest Fires Depending on the Data Available



6.7.3.1 Estimation of Greenhouse Gas Emissions from Fire

The calculation of GHG emissions from fires can be seen in Equation 6-11 below.

Equation 6-11: Calculate GHG Emissions from Fire

$$L_{fire} = A \times MB \times C_f \times G_{ef} \times 10^{-3}$$

Where:

L_{fire} = Amount of greenhouse gas emissions from fire (metric tons of each GHG, i.e., CH_4, N_2O, etc.)

A = Area burned (ha)

MB = Mass of fuel available for combustion (metric tons ha^{-1})

C_f = Combustion factor (dimensionless)

G_{ef} = Emission factor (g (kg dry matter burnt)$^{-1}$)

In order to use this algorithm, an estimate of A by fire severity is used. For MB, the understory, DDW, and forest floor are assumed to be available for combustion. In addition, an estimate of what portion of the live tree biomass is available for combustion (typically only foliage and fine branchwood) is used. For C_f, IPCC (2006) protocols use 0.45 for temperate forests. Separate values for C_f for biomass pools for crown fire, stand-replacement underburn, mixed-severity underburn, and low-severity underburn, by forest type, using FOFEM are provided (see Table 6-13). For G_{ef} emission factors from Urbanski et al. (2009) are recommended: 1619 g (kg dry matter burnt for CO_2)$^{-1}$, 89.6 g (kg dry matter burnt for CO)$^{-1}$, 3.4 g (kg dry matter burnt for CH_4)$^{-1}$, and from Akagi et al. (2011), 2.5 g (kg dry matter burnt for NO_x)$^{-1}$. Note that not all biomass is available for combustion; in particular, standing live tree boles are not available.

For subsequent effects, the GHG estimation methods adopted should match as closely as possible those used in other sections (e.g., HWPs). Decomposition of dead material over time will be projected using a fixed annual loss rate. The conversion of standing dead to dead-and-down should also be projected using a fixed rate and approximating the methods in FVS-FFE.

GHG emissions from natural disturbance wildfires and prescribed fires used for site maintenance and restoration should be reported separately from emissions resulting from management (sites with thinning slash, machine or hand piles, or logging slash) to facilitate the use of the estimates in decision making regarding management practices.

Table 6-13 shows an example for the default lookup tables for consumption fraction (C_f). Regions are those shown in Table 6-13, with the exception of the West region, which represents an average of all western regions.

Table 6-13: C_f Consumption Fraction

Region	Forest Type	C_f Crown Fire	C_f Stand Replacement Underburn	C_f Mixed Severity	C_f Low Severity Underburn
		%			
Northeast	Aspen–birch	84	69	59	45
	Elm–ash–cottonwood	74	47	35	20
	Maple–beech–birch	77	60	44	35
	Oak–hickory	63	49	41	32
	Oak–pine	80	61	50	38
	Spruce–fir	73	73	69	62
	White–red–jack pine	55	45	37	26

Region	Forest Type	C_f Crown Fire	C_f Stand Replacement Underburn	C_f Mixed Severity	C_f Low Severity Underburn
		%			
Northern Lake States	Aspen–birch	84	69	59	45
	Elm–ash–cottonwood	74	47	35	20
	Maple–beech–birch	77	60	44	35
	Oak–hickory	80	61	50	38
	Spruce–fir	73	73	69	62
	White–red–jack pine	55	45	37	26
Northern Prairie States	Elm–ash–cottonwood	74	47	35	20
	Maple–beech–birch	77	60	44	35
	Oak–hickory	80	61	50	38
	Ponderosa pine	60	53	47	37
Pacific Northwest, East	Douglas fir	85	79	72	60
	Fir–spruce–m.hemlock	67	64	58	44
	Lodgepole pine	77	72	64	52
	Ponderosa pine	78	53	41	27
Pacific Northwest, West	Alder–maple	82	67	48	42
	Douglas fir	71	62	55	43
	Fir–spruce–m.hemlock	67	64	58	44
	Hemlock–Sitka spruce	85	77	69	55
Pacific Southwest	Mixed conifer	79	69	50	46
	Douglas fir	66	42	30	17
	Fir–spruce–m.hemlock	67	64	58	44
	Ponderosa Pine	78	53	41	27
	Redwood	82	76	69	56
Rocky Mountain, North and South	Aspen–birch	80	61	50	35
	Douglas fir	85	79	72	60
	Fir–spruce–m.hemlock	67	64	58	44
	Lodgepole pine	77	72	64	52
	Ponderosa pine	78	53	41	27
	Mixed conifer	79	69	50	46
Southeast	Elm–ash–cottonwood	76	45	29	19
	Loblolly–shortleaf pine	66	52	44	35
	Oak–hickory	61	50	44	36
	Oak–pine	62	55	51	45
South Central	Elm–ash–cottonwood	76	45	29	19
	Loblolly–shortleaf pine	66	52	44	35
	Longleaf–slash pine	69	63	57	47
	Oak–hickory	61	50	44	36
	Oak–pine	62	55	51	45
West[a]	Pinyon–juniper	64	55	49	41
	Tanoak–laurel	70	52	43	32
	Western larch	76	68	60	47
	Western oak	65	62	56	48
	Western white pine	68	56	47	33

[a] Represents an average over all western regions for the specified forest types (PNW-W, PNW-E, PSW, RMN, RMS).

6.7.3.2 Estimation of Greenhouse Gas Emissions from Other Disturbances

For other disturbances, the primary effects are indirect: by converting live biomass to dead—and in some cases standing trees to dead, down trees—decomposition is accelerated. Currently grouping non-fire disturbance into two categories is suggested: disturbances that leave dead trees standing (insect and disease-caused mortality) and disturbance that leaves the trees on the ground (wind or ice storms).The landowner will have to estimate mortality (Section 6.7.2); then as in decomposition of fire-killed trees, a fixed decomposition rate (default value 0.015) will be used to simulate subsequent decomposition.

For insect or pathogen-caused mortality, the trees are assumed to be initially standing after death. Conversion of standing dead to dead-and-down will be projected using a fixed rate and approximating the methods in FVS-FEE. Once down, the default decomposition rate from FVS-FFE of 0.015 for dead and down wood will be used to simulate decomposition. For blowdowns or ice storms, the impacted trees are assumed to be dead and down. In this case decomposition begins immediately.

6.7.4 Limitations and Uncertainty

A major source of uncertainty in predicting fire emissions is the preburn fuel quantities. If landowners are doing some kind of inventory of live and dead biomass (see Section 6.7.2) they will have relatively robust estimates of available fuel. If they are using lookup table values by forest type, there will be more uncertainty associated with the estimates since fuel quantities vary greatly within forest type.

A related challenge is determining the appropriate degree of specificity for tracking biomass by pools (e.g., live, dead). Any kind of management or disturbance changes biomass at the time of occurrence, and also the subsequent trajectory. Subsequent management or disturbance should be applied to the changed and changing values, not the original values. This can result in a complicated simulation model like FVS, rather than a calculator. Since prefire fuel quantity is the strongest predictor of fuel consumption, determining the appropriate degree of specificity for tracking biomass by pools is not a completely academic question.

Appendix 6-A: Harvested Wood Products Lookup Tables

Table 6-A-1: 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 (2,000 lbs) C	Factor to Convert Units to Metric Tons C
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 6-A-2: 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)

Year after Production	Softwood Lumber	Hardwood Lumber	Softwood Plywood	Oriented Strandboard	Non-Structural Panels	Misc. Products	Paper
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0.908	0.909	0.908	0.908	0.908	0.903	0.880
2	0.892	0.893	0.893	0.896	0.892	0.887	0.775
3	0.877	0.877	0.878	0.884	0.876	0.871	0.682
4	0.863	0.861	0.863	0.872	0.861	0.855	0.600
5	0.848	0.845	0.848	0.860	0.845	0.840	0.528
6	0.834	0.830	0.834	0.848	0.830	0.825	0.465
7	0.820	0.815	0.820	0.837	0.816	0.810	0.354
8	0.806	0.801	0.807	0.826	0.801	0.795	0.269
9	0.793	0.786	0.794	0.815	0.787	0.781	0.205
10	0.780	0.772	0.781	0.804	0.774	0.767	0.156
15	0.718	0.705	0.719	0.753	0.708	0.700	0.040
20	0.662	0.644	0.663	0.706	0.649	0.639	0.010
25	0.611	0.589	0.613	0.662	0.595	0.583	0.003
30	0.565	0.538	0.567	0.622	0.546	0.532	0.001
35	0.523	0.492	0.525	0.585	0.501	0.486	0.000
40	0.485	0.450	0.487	0.551	0.460	0.444	0.000
45	0.450	0.411	0.452	0.519	0.423	0.405	0.000
50	0.418	0.376	0.420	0.490	0.389	0.370	0.000
55	0.389	0.344	0.391	0.462	0.358	0.338	0.000
60	0.362	0.315	0.364	0.437	0.329	0.308	0.000
65	0.338	0.288	0.340	0.413	0.303	0.281	0.000
70	0.315	0.264	0.317	0.391	0.280	0.257	0.000
75	0.294	0.242	0.296	0.370	0.258	0.234	0.000
80	0.276	0.221	0.277	0.351	0.238	0.214	0.000
85	0.258	0.203	0.260	0.333	0.220	0.195	0.000
90	0.242	0.186	0.244	0.316	0.203	0.178	0.000
95	0.227	0.170	0.229	0.300	0.188	0.163	0.000
100	0.213	0.156	0.215	0.285	0.174	0.149	0.000
Average	**0.466**	**0.430**	**0.468**	**0.526**	**0.441**	**0.424**	**0.059**

Table 6-A-3: Fraction of Carbon in Primary Wood Products Remaining in Landfills up to 100 Years after Production (year 0 indicates fraction at time of production)

Year after Production	Softwood Lumber	Hardwood Lumber	Softwood Plywood	Oriented Strandboard	Non-Structural Panels	Misc. Products	Paper
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.061	0.060	0.061	0.061	0.061	0.064	0.040
2	0.071	0.070	0.071	0.068	0.071	0.074	0.073
3	0.080	0.080	0.080	0.076	0.081	0.084	0.102
4	0.089	0.090	0.089	0.083	0.090	0.094	0.127
5	0.098	0.099	0.097	0.090	0.099	0.103	0.147
6	0.106	0.109	0.106	0.097	0.108	0.112	0.164
7	0.114	0.117	0.114	0.103	0.117	0.121	0.197
8	0.122	0.126	0.122	0.110	0.125	0.129	0.220
9	0.130	0.134	0.130	0.116	0.134	0.138	0.236
10	0.138	0.143	0.137	0.122	0.142	0.146	0.247
15	0.173	0.181	0.172	0.151	0.179	0.184	0.256
20	0.203	0.214	0.202	0.176	0.211	0.217	0.241
25	0.230	0.243	0.229	0.199	0.239	0.246	0.223
30	0.253	0.269	0.252	0.220	0.265	0.272	0.207
35	0.274	0.292	0.273	0.238	0.287	0.296	0.195
40	0.293	0.313	0.292	0.255	0.307	0.316	0.185
45	0.310	0.332	0.308	0.271	0.325	0.335	0.177
50	0.325	0.348	0.324	0.285	0.341	0.352	0.171
55	0.338	0.363	0.337	0.298	0.356	0.367	0.166
60	0.351	0.377	0.349	0.310	0.369	0.380	0.163
65	0.362	0.389	0.361	0.321	0.381	0.393	0.160
70	0.372	0.400	0.371	0.331	0.391	0.404	0.158
75	0.381	0.410	0.380	0.341	0.401	0.414	0.156
80	0.390	0.419	0.389	0.350	0.410	0.423	0.154
85	0.398	0.427	0.397	0.359	0.418	0.431	0.153
90	0.405	0.435	0.404	0.366	0.426	0.439	0.153
95	0.412	0.442	0.411	0.374	0.432	0.446	0.152
100	0.418	0.448	0.417	0.381	0.438	0.452	0.151
Average	**0.297**	**0.317**	**0.296**	**0.264**	**0.311**	**0.321**	**0.178**

Table 6-A-4: Density of Softwood and Hardwood Sawlogs/Veneer Logs and Pulpwood by Region and Forest Type Group[a]

Region	Forest type	Specific Gravity[d] of Softwoods	Specific Gravity[d] of Hardwoods
Northeast	Aspen–birch	0.353	0.428
	Elm–ash–cottonwood	0.358	0.470
	Maple–beech–birch	0.369	0.518
	Oak–hickory	0.388	0.534
	Oak–pine	0.371	0.516
	Spruce–fir	0.353	0.481
	White–red–jack pine	0.361	0.510
Northern Lake States	Aspen–birch	0.351	0.397
	Elm–ash–cottonwood	0.335	0.460
	Maple–beech–birch	0.356	0.496
	Oak–hickory	0.369	0.534
	Spruce–fir	0.344	0.444
	White–red–jack pine	0.389	0.473
Northern Prairie States	Elm–ash–cottonwood	0.424	0.453
	Loblolly–shortleaf pine	0.468	0.544
	Maple–beech–birch	0.437	0.508
	Oak–hickory	0.448	0.565
	Oak–pine	0.451	0.566
	Ponderosa pine	0.381	0.473
Pacific Northwest, East	Douglas fir	0.429	0.391
	Fir–spruce–m.hemlock	0.370	0.361
	Lodgepole pine	0.380	0.345
	Ponderosa pine	0.385	0.513
Pacific Northwest, West	Alder–maple	0.402	0.385
	Douglas fir	0.440	0.426
	Fir–spruce–m.hemlock	0.399	0.417
	Hemlock–Sitka spruce	0.405	0.380
Pacific Southwest	Mixed conifer	0.394	0.521
	Douglas fir	0.429	0.483
	Fir–spruce–m.hemlock	0.372	0.510
	Ponderosa Pine	0.380	0.510
	Redwood	0.376	0.449
Rocky Mountain, North	Douglas fir	0.428	0.370
	Fir–spruce–m.hemlock	0.355	0.457
	Hemlock–sitka spruce	0.375	0.441
	Lodgepole pine	0.383	0.391
	Ponderosa pine	0.391	0.374
Rocky Mountain, South	Aspen–birch	0.355	0.350
	Douglas fir	0.431	0.350
	Fir–spruce–m.hemlock	0.342	0.350
	Lodgepole pine	0.377	0.350
	Ponderosa pine	0.383	0.386

Region	Forest type	Specific Gravity[d] of Softwoods	Specific Gravity[d] of Hardwoods
Southeast	Elm–ash–cottonwood	0.433	0.499
	Loblolly–shortleaf pine	0.469	0.494
	Longleaf–slash pine	0.536	0.503
	Oak–gum–cypress	0.441	0.484
	Oak–hickory	0.438	0.524
	Oak–pine	0.462	0.516
South Central	Elm–ash–cottonwood	0.427	0.494
	Loblolly–shortleaf pine	0.470	0.516
	Longleaf–slash pine	0.531	0.504
	Oak–gum–cypress	0.440	0.513
	Oak–hickory	0.451	0.544
	Oak–pine	0.467	0.537
West[e]	Pinyon–juniper	0.422	0.620
	Tanoak–laurel	0.430	0.459
	Western larch	0.433	0.430
	Western oak	0.416	0.590
	Western white pine	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, FIA Program's database of forest surveys (FIADB) (USDA Forest Service, 2005) and include growing stock on timberland stands classified as medium- or large-diameter stands. Proportions are based on volume of growing stock trees.

[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 6-A-5: Average Disposition Patterns of Carbon as Fractions in Roundwood by Region and Roundwood Category; Factors Assume No Bark on Roundwood and Exclude Fuelwood

Year after Production	Northeast, Softwood								
	Sawlog					Pulpwood			
	In Use	In Landfills	Total Stored	Total Emissions		In Use	In Landfills	Total Stored	Total Emissions
0	0.569	0.000	0.569	0.431		0.513	0.000	0.513	0.487
1	0.521	0.029	0.550	0.450		0.452	0.021	0.473	0.527
2	0.505	0.037	0.542	0.458		0.400	0.038	0.438	0.562
3	0.491	0.044	0.535	0.465		0.355	0.052	0.407	0.593
4	0.478	0.050	0.528	0.472		0.315	0.064	0.379	0.621
5	0.465	0.056	0.522	0.478		0.279	0.074	0.354	0.646
6	0.453	0.062	0.516	0.484		0.248	0.083	0.331	0.669
7	0.438	0.069	0.507	0.493		0.193	0.099	0.293	0.707
8	0.425	0.075	0.500	0.500		0.152	0.111	0.263	0.737
9	0.414	0.080	0.494	0.506		0.120	0.119	0.239	0.761
10	0.403	0.085	0.489	0.511		0.096	0.124	0.220	0.780
15	0.363	0.105	0.468	0.532		0.038	0.130	0.168	0.832
20	0.332	0.121	0.453	0.547		0.022	0.124	0.146	0.854
25	0.306	0.134	0.440	0.560		0.017	0.116	0.133	0.867
30	0.282	0.146	0.428	0.572		0.015	0.109	0.124	0.876
35	0.260	0.156	0.417	0.583		0.014	0.103	0.117	0.883
40	0.240	0.166	0.406	0.594		0.013	0.099	0.111	0.889
45	0.222	0.174	0.397	0.603		0.012	0.095	0.107	0.893
50	0.206	0.182	0.388	0.612		0.011	0.093	0.104	0.896
55	0.191	0.189	0.380	0.620		0.010	0.091	0.101	0.899
60	0.177	0.195	0.372	0.628		0.009	0.089	0.099	0.901
65	0.165	0.201	0.365	0.635		0.009	0.088	0.097	0.903
70	0.153	0.206	0.359	0.641		0.008	0.087	0.095	0.905
75	0.143	0.210	0.353	0.647		0.008	0.086	0.094	0.906
80	0.133	0.214	0.347	0.653		0.007	0.086	0.093	0.907
85	0.124	0.218	0.342	0.658		0.007	0.085	0.092	0.908
90	0.116	0.221	0.337	0.663		0.006	0.085	0.091	0.909
95	0.108	0.224	0.332	0.668		0.006	0.085	0.091	0.909
100	0.101	0.227	0.328	0.672		0.006	0.085	0.090	0.910
Average	**0.235**	**0.166**	**0.402**			**0.041**	**0.095**	**0.136**	

Table 6-A-5—continued

Year after Production	Northeast, Hardwood								
	In Use	Sawlog		Total Emissions		In Use	Pulpwood		Total Emissions
		In Landfills	Total Stored				In Landfills	Total Stored	
0	0.614	0.000	0.614	0.386		0.650	0.000	0.650	0.350
1	0.559	0.034	0.594	0.406		0.580	0.032	0.613	0.387
2	0.544	0.042	0.586	0.414		0.540	0.046	0.586	0.414
3	0.530	0.049	0.579	0.421		0.503	0.059	0.562	0.438
4	0.516	0.056	0.573	0.427		0.471	0.070	0.541	0.459
5	0.504	0.063	0.567	0.433		0.443	0.079	0.522	0.478
6	0.491	0.069	0.561	0.439		0.417	0.087	0.504	0.496
7	0.477	0.076	0.553	0.447		0.374	0.101	0.475	0.525
8	0.463	0.083	0.546	0.454		0.341	0.111	0.453	0.547
9	0.452	0.089	0.540	0.460		0.316	0.119	0.434	0.566
10	0.441	0.094	0.535	0.465		0.295	0.125	0.420	0.580
15	0.397	0.117	0.514	0.486		0.239	0.137	0.376	0.624
20	0.361	0.136	0.497	0.503		0.215	0.140	0.355	0.645
25	0.330	0.152	0.482	0.518		0.199	0.141	0.340	0.660
30	0.301	0.167	0.468	0.532		0.186	0.142	0.328	0.672
35	0.275	0.180	0.455	0.545		0.175	0.144	0.319	0.681
40	0.252	0.192	0.444	0.556		0.164	0.146	0.310	0.690
45	0.230	0.202	0.432	0.568		0.155	0.148	0.302	0.698
50	0.211	0.211	0.422	0.578		0.146	0.150	0.296	0.704
55	0.193	0.220	0.412	0.588		0.138	0.152	0.290	0.710
60	0.176	0.227	0.403	0.597		0.130	0.154	0.285	0.715
65	0.162	0.234	0.395	0.605		0.123	0.157	0.280	0.720
70	0.148	0.240	0.388	0.612		0.116	0.159	0.275	0.725
75	0.136	0.245	0.380	0.620		0.110	0.161	0.271	0.729
80	0.124	0.250	0.374	0.626		0.104	0.163	0.268	0.732
85	0.114	0.254	0.368	0.632		0.099	0.165	0.264	0.736
90	0.104	0.258	0.362	0.638		0.094	0.167	0.261	0.739
95	0.096	0.261	0.357	0.643		0.089	0.169	0.258	0.742
100	0.088	0.264	0.352	0.648		0.085	0.171	0.255	0.745
Average	**0.244**	**0.192**	**0.437**			**0.178**	**0.145**	**0.323**	

Table 6-A-5—continued

Year after Production	North Central, Softwood								
	In Use	Sawlog		Total Emissions		In Use	Pulpwood		Total Emissions
		In Landfills	Total Stored				In Landfills	Total Stored	
0	0.630	0.000	0.630	0.370		0.514	0.000	0.514	0.486
1	0.579	0.031	0.610	0.390		0.454	0.021	0.475	0.525
2	0.561	0.039	0.601	0.399		0.402	0.038	0.440	0.560
3	0.545	0.047	0.592	0.408		0.357	0.052	0.409	0.591
4	0.530	0.055	0.585	0.415		0.317	0.064	0.381	0.619
5	0.516	0.062	0.577	0.423		0.281	0.074	0.356	0.644
6	0.502	0.068	0.570	0.430		0.250	0.083	0.333	0.667
7	0.485	0.076	0.561	0.439		0.196	0.099	0.295	0.705
8	0.470	0.083	0.553	0.447		0.154	0.111	0.265	0.735
9	0.457	0.089	0.546	0.454		0.123	0.119	0.241	0.759
10	0.446	0.094	0.540	0.460		0.098	0.124	0.223	0.777
15	0.401	0.116	0.517	0.483		0.041	0.130	0.171	0.829
20	0.366	0.133	0.500	0.500		0.025	0.124	0.148	0.852
25	0.336	0.148	0.485	0.515		0.020	0.116	0.135	0.865
30	0.310	0.162	0.471	0.529		0.018	0.109	0.126	0.874
35	0.286	0.173	0.459	0.541		0.016	0.103	0.120	0.880
40	0.264	0.184	0.447	0.553		0.015	0.099	0.114	0.886
45	0.243	0.193	0.437	0.563		0.014	0.096	0.110	0.890
50	0.225	0.202	0.427	0.573		0.013	0.093	0.106	0.894
55	0.208	0.209	0.418	0.582		0.012	0.091	0.103	0.897
60	0.193	0.216	0.409	0.591		0.012	0.089	0.101	0.899
65	0.179	0.222	0.401	0.599		0.011	0.088	0.099	0.901
70	0.166	0.228	0.394	0.606		0.010	0.087	0.098	0.902
75	0.154	0.233	0.387	0.613		0.010	0.087	0.097	0.903
80	0.144	0.237	0.381	0.619		0.009	0.086	0.095	0.905
85	0.134	0.242	0.375	0.625		0.009	0.086	0.095	0.905
90	0.125	0.245	0.370	0.630		0.008	0.086	0.094	0.906
95	0.116	0.249	0.365	0.635		0.008	0.086	0.093	0.907
100	0.108	0.252	0.360	0.640		0.007	0.086	0.093	0.907
Average	**0.258**	**0.184**	**0.442**			**0.043**	**0.095**	**0.138**	

Table 6-A-5—continued

Year after Production	North Central, Hardwood							
	In Use	Sawlog		Total Emissions	In Use	Pulpwood		Total Emissions
		In Landfills	Total Stored			In Landfills	Total Stored	
0	0.585	0.000	0.585	0.415	0.685	0.000	0.685	0.315
1	0.533	0.032	0.565	0.435	0.613	0.035	0.648	0.352
2	0.518	0.040	0.558	0.442	0.575	0.049	0.624	0.376
3	0.504	0.047	0.550	0.450	0.541	0.061	0.602	0.398
4	0.490	0.054	0.544	0.456	0.511	0.071	0.582	0.418
5	0.477	0.060	0.537	0.463	0.484	0.080	0.565	0.435
6	0.465	0.066	0.531	0.469	0.460	0.089	0.548	0.452
7	0.450	0.073	0.523	0.477	0.421	0.101	0.522	0.478
8	0.437	0.080	0.517	0.483	0.390	0.111	0.501	0.499
9	0.425	0.085	0.511	0.489	0.365	0.119	0.484	0.516
10	0.415	0.090	0.505	0.495	0.346	0.125	0.471	0.529
15	0.372	0.112	0.484	0.516	0.290	0.139	0.429	0.571
20	0.339	0.130	0.468	0.532	0.263	0.144	0.408	0.592
25	0.309	0.145	0.454	0.546	0.245	0.148	0.393	0.607
30	0.282	0.158	0.441	0.559	0.229	0.151	0.380	0.620
35	0.258	0.170	0.428	0.572	0.216	0.154	0.370	0.630
40	0.236	0.181	0.417	0.583	0.203	0.158	0.360	0.640
45	0.216	0.191	0.407	0.593	0.191	0.161	0.352	0.648
50	0.197	0.199	0.397	0.603	0.180	0.165	0.345	0.655
55	0.181	0.207	0.388	0.612	0.170	0.168	0.338	0.662
60	0.165	0.214	0.379	0.621	0.160	0.171	0.332	0.668
65	0.151	0.220	0.372	0.628	0.152	0.174	0.326	0.674
70	0.138	0.226	0.364	0.636	0.143	0.178	0.321	0.679
75	0.127	0.231	0.358	0.642	0.136	0.180	0.316	0.684
80	0.116	0.235	0.351	0.649	0.129	0.183	0.312	0.688
85	0.106	0.239	0.346	0.654	0.122	0.186	0.308	0.692
90	0.098	0.243	0.340	0.660	0.116	0.188	0.304	0.696
95	0.089	0.246	0.336	0.664	0.110	0.191	0.300	0.700
100	0.082	0.249	0.331	0.669	0.104	0.193	0.297	0.703
Average	**0.229**	**0.182**	**0.411**		**0.212**	**0.158**	**0.370**	

Table 6-A-5—continued

Year after Production	Pacific Northwest, East, Softwood			
	In Use	All		Total Emissions
		In Landfills	Total Stored	
0	0.637	0.000	0.637	0.363
1	0.574	0.036	0.610	0.390
2	0.551	0.046	0.597	0.403
3	0.530	0.055	0.585	0.415
4	0.511	0.063	0.574	0.426
5	0.494	0.070	0.564	0.436
6	0.478	0.077	0.555	0.445
7	0.455	0.086	0.541	0.459
8	0.436	0.093	0.529	0.471
9	0.420	0.100	0.520	0.480
10	0.406	0.105	0.512	0.488
15	0.359	0.125	0.484	0.516
20	0.327	0.139	0.466	0.534
25	0.301	0.150	0.451	0.549
30	0.278	0.160	0.438	0.562
35	0.258	0.169	0.427	0.573
40	0.239	0.177	0.416	0.584
45	0.222	0.185	0.406	0.594
50	0.206	0.191	0.397	0.603
55	0.191	0.198	0.389	0.611
60	0.178	0.203	0.381	0.619
65	0.166	0.208	0.374	0.626
70	0.155	0.213	0.368	0.632
75	0.145	0.217	0.362	0.638
80	0.136	0.221	0.356	0.644
85	0.127	0.224	0.351	0.649
90	0.119	0.227	0.347	0.653
95	0.112	0.230	0.342	0.658
100	0.105	0.233	0.338	0.662
Average	**0.238**	**0.177**	**0.415**	

Table 6-A-5—continued

Year after Production	Pacific Northwest, West, Softwoods							
	In Use	Sawlog		Total Emissions	In Use	Pulpwood		Total Emissions
		In Landfills	Total Stored			In Landfills	Total Stored	
0	0.740	0.000	0.740	0.260	0.500	0.000	0.500	0.500
1	0.674	0.039	0.713	0.287	0.440	0.020	0.460	0.540
2	0.652	0.049	0.702	0.298	0.387	0.037	0.424	0.576
3	0.632	0.059	0.691	0.309	0.341	0.051	0.392	0.608
4	0.613	0.068	0.681	0.319	0.300	0.063	0.364	0.636
5	0.596	0.076	0.672	0.328	0.264	0.074	0.338	0.662
6	0.579	0.083	0.663	0.337	0.233	0.082	0.315	0.685
7	0.558	0.093	0.651	0.349	0.177	0.099	0.276	0.724
8	0.539	0.101	0.640	0.360	0.134	0.111	0.245	0.755
9	0.524	0.108	0.631	0.369	0.102	0.119	0.221	0.779
10	0.510	0.114	0.624	0.376	0.078	0.124	0.202	0.798
15	0.457	0.139	0.596	0.404	0.020	0.129	0.149	0.851
20	0.418	0.158	0.576	0.424	0.005	0.122	0.127	0.873
25	0.384	0.174	0.558	0.442	0.001	0.113	0.114	0.886
30	0.355	0.188	0.543	0.457	0	0.105	0.105	0.895
35	0.328	0.201	0.529	0.471	0	0.098	0.099	0.901
40	0.303	0.213	0.516	0.484	0	0.093	0.093	0.907
45	0.281	0.223	0.504	0.496	0	0.090	0.090	0.910
50	0.260	0.232	0.493	0.507	0	0.086	0.086	0.914
55	0.242	0.241	0.482	0.518	0	0.084	0.084	0.916
60	0.224	0.248	0.473	0.527	0	0.082	0.082	0.918
65	0.209	0.255	0.464	0.536	0	0.080	0.080	0.920
70	0.194	0.261	0.456	0.544	0	0.079	0.079	0.921
75	0.181	0.267	0.448	0.552	0	0.078	0.078	0.922
80	0.169	0.272	0.441	0.559	0	0.078	0.078	0.922
85	0.158	0.276	0.434	0.566	0	0.077	0.077	0.923
90	0.148	0.281	0.428	0.572	0	0.077	0.077	0.923
95	0.138	0.285	0.423	0.577	0	0.076	0.076	0.924
100	0.129	0.288	0.417	0.583	0	0.076	0.076	0.924
Average	**0.298**	**0.213**	**0.511**		**0.030**	**0.090**	**0.119**	

Table 6-A-5—continued

Year after Production	Pacific Northwest, West, Hardwood					Pacific Southwest, Softwood			
	In Use	All		Total Emissions		In Use	All		Total Emissions
		In Landfills	Total Stored				In Landfills	Total Stored	
0	0.531	0.000	0.531	0.469		0.675	0.000	0.675	0.325
1	0.476	0.027	0.503	0.497		0.611	0.036	0.647	0.353
2	0.447	0.038	0.485	0.515		0.587	0.047	0.634	0.366
3	0.421	0.048	0.469	0.531		0.566	0.056	0.622	0.378
4	0.397	0.057	0.454	0.546		0.546	0.065	0.611	0.389
5	0.376	0.064	0.440	0.560		0.528	0.072	0.600	0.400
6	0.357	0.071	0.428	0.572		0.511	0.080	0.591	0.409
7	0.327	0.081	0.408	0.592		0.488	0.089	0.577	0.423
8	0.303	0.089	0.393	0.607		0.468	0.097	0.565	0.435
9	0.284	0.096	0.380	0.620		0.451	0.104	0.555	0.445
10	0.269	0.101	0.369	0.631		0.437	0.110	0.547	0.453
15	0.222	0.115	0.337	0.663		0.387	0.131	0.518	0.482
20	0.197	0.122	0.319	0.681		0.353	0.146	0.499	0.501
25	0.179	0.127	0.306	0.694		0.324	0.159	0.483	0.517
30	0.164	0.132	0.295	0.705		0.299	0.170	0.469	0.531
35	0.150	0.136	0.286	0.714		0.276	0.180	0.457	0.543
40	0.137	0.140	0.278	0.722		0.256	0.190	0.445	0.555
45	0.126	0.144	0.270	0.730		0.237	0.198	0.435	0.565
50	0.115	0.148	0.263	0.737		0.220	0.205	0.425	0.575
55	0.106	0.151	0.257	0.743		0.204	0.212	0.416	0.584
60	0.097	0.155	0.252	0.748		0.189	0.218	0.408	0.592
65	0.089	0.157	0.247	0.753		0.176	0.224	0.400	0.600
70	0.082	0.160	0.242	0.758		0.164	0.229	0.393	0.607
75	0.075	0.163	0.238	0.762		0.153	0.233	0.387	0.613
80	0.069	0.165	0.234	0.766		0.143	0.238	0.381	0.619
85	0.064	0.167	0.231	0.769		0.133	0.241	0.375	0.625
90	0.059	0.169	0.227	0.773		0.125	0.245	0.370	0.630
95	0.054	0.171	0.224	0.776		0.117	0.248	0.365	0.635
100	0.050	0.172	0.222	0.778		0.109	0.251	0.361	0.639
Average	**0.145**	**0.139**	**0.284**			**0.254**	**0.190**	**0.444**	

Table 6-A-5—continued

Year after Production	Rocky Mountain, Softwood			
	In Use	All		Total Emissions
		In Landfills	Total Stored	
0	0.704	0.000	0.704	0.296
1	0.640	0.037	0.677	0.323
2	0.615	0.048	0.663	0.337
3	0.592	0.057	0.650	0.350
4	0.572	0.066	0.638	0.362
5	0.552	0.075	0.627	0.373
6	0.535	0.082	0.617	0.383
7	0.510	0.092	0.602	0.398
8	0.489	0.101	0.590	0.410
9	0.472	0.108	0.579	0.421
10	0.457	0.114	0.571	0.429
15	0.404	0.136	0.540	0.460
20	0.368	0.152	0.520	0.480
25	0.338	0.166	0.504	0.496
30	0.312	0.177	0.489	0.511
35	0.288	0.188	0.476	0.524
40	0.266	0.198	0.464	0.536
45	0.247	0.206	0.453	0.547
50	0.229	0.214	0.443	0.557
55	0.212	0.221	0.433	0.567
60	0.197	0.228	0.425	0.575
65	0.183	0.234	0.417	0.583
70	0.170	0.239	0.409	0.591
75	0.159	0.244	0.403	0.597
80	0.148	0.248	0.396	0.604
85	0.138	0.252	0.390	0.610
90	0.129	0.256	0.385	0.615
95	0.121	0.259	0.380	0.620
100	0.113	0.262	0.375	0.625
Average	**0.265**	**0.198**	**0.463**	

Table 6-A-5—continued

Year after Production	Southeast, Softwood								
	In Use	Sawlog		Total Emissions		In Use	Pulpwood		Total Emissions
		In Landfills	Total Stored				In Landfills	Total Stored	
0	0.636	0.000	0.636	0.364		0.553	0.000	0.553	0.447
1	0.578	0.034	0.612	0.388		0.490	0.024	0.514	0.486
2	0.557	0.043	0.600	0.400		0.442	0.040	0.482	0.518
3	0.537	0.052	0.589	0.411		0.399	0.054	0.453	0.547
4	0.519	0.060	0.578	0.422		0.361	0.066	0.427	0.573
5	0.502	0.067	0.569	0.431		0.328	0.076	0.403	0.597
6	0.486	0.074	0.560	0.440		0.298	0.084	0.382	0.618
7	0.465	0.083	0.547	0.453		0.247	0.100	0.347	0.653
8	0.447	0.090	0.537	0.463		0.208	0.111	0.319	0.681
9	0.432	0.096	0.528	0.472		0.178	0.119	0.297	0.703
10	0.418	0.102	0.520	0.480		0.155	0.124	0.279	0.721
15	0.371	0.122	0.494	0.506		0.098	0.132	0.230	0.770
20	0.339	0.137	0.476	0.524		0.079	0.128	0.208	0.792
25	0.311	0.150	0.461	0.539		0.071	0.123	0.194	0.806
30	0.287	0.161	0.448	0.552		0.066	0.118	0.184	0.816
35	0.265	0.171	0.436	0.564		0.062	0.115	0.177	0.823
40	0.245	0.180	0.425	0.575		0.058	0.112	0.170	0.830
45	0.227	0.188	0.415	0.585		0.055	0.110	0.165	0.835
50	0.210	0.195	0.405	0.595		0.052	0.109	0.161	0.839
55	0.195	0.202	0.397	0.603		0.049	0.108	0.157	0.843
60	0.181	0.208	0.389	0.611		0.046	0.108	0.154	0.846
65	0.169	0.213	0.382	0.618		0.044	0.108	0.151	0.849
70	0.157	0.218	0.375	0.625		0.041	0.108	0.149	0.851
75	0.146	0.222	0.369	0.631		0.039	0.108	0.147	0.853
80	0.137	0.226	0.363	0.637		0.037	0.108	0.145	0.855
85	0.127	0.230	0.358	0.642		0.035	0.108	0.143	0.857
90	0.119	0.233	0.353	0.647		0.033	0.109	0.142	0.858
95	0.111	0.236	0.348	0.652		0.031	0.109	0.141	0.859
100	0.104	0.239	0.344	0.656		0.030	0.110	0.140	0.860
Average	**0.243**	**0.180**	**0.423**			**0.082**	**0.109**	**0.191**	

Table 6-A-5—continued

Year after Production	Southeast, Hardwood								
	Sawlog					Pulpwood			
	In Use	In Landfills	Total Stored	Total Emissions		In Use	In Landfills	Total Stored	Total Emissions
0	0.609	0.000	0.609	0.391		0.591	0.000	0.591	0.409
1	0.552	0.035	0.587	0.413		0.525	0.027	0.552	0.448
2	0.534	0.043	0.577	0.423		0.480	0.043	0.522	0.478
3	0.518	0.051	0.569	0.431		0.439	0.056	0.495	0.505
4	0.503	0.058	0.561	0.439		0.404	0.067	0.471	0.529
5	0.488	0.065	0.553	0.447		0.372	0.077	0.449	0.551
6	0.475	0.071	0.546	0.454		0.344	0.085	0.430	0.570
7	0.457	0.079	0.537	0.463		0.296	0.100	0.397	0.603
8	0.442	0.086	0.528	0.472		0.260	0.111	0.371	0.629
9	0.429	0.092	0.521	0.479		0.231	0.119	0.350	0.650
10	0.418	0.097	0.515	0.485		0.209	0.124	0.334	0.666
15	0.373	0.119	0.492	0.508		0.153	0.134	0.287	0.713
20	0.338	0.136	0.475	0.525		0.132	0.133	0.265	0.735
25	0.309	0.151	0.460	0.540		0.121	0.130	0.251	0.749
30	0.282	0.164	0.446	0.554		0.113	0.127	0.240	0.760
35	0.258	0.176	0.434	0.566		0.106	0.126	0.232	0.768
40	0.236	0.186	0.422	0.578		0.100	0.125	0.225	0.775
45	0.216	0.196	0.412	0.588		0.094	0.125	0.218	0.782
50	0.198	0.204	0.402	0.598		0.089	0.125	0.213	0.787
55	0.181	0.212	0.393	0.607		0.084	0.125	0.209	0.791
60	0.166	0.218	0.384	0.616		0.079	0.126	0.205	0.795
65	0.152	0.224	0.376	0.624		0.075	0.126	0.201	0.799
70	0.139	0.230	0.369	0.631		0.071	0.127	0.198	0.802
75	0.127	0.235	0.362	0.638		0.067	0.128	0.195	0.805
80	0.117	0.239	0.356	0.644		0.063	0.129	0.193	0.807
85	0.107	0.243	0.350	0.650		0.060	0.130	0.190	0.810
90	0.098	0.247	0.345	0.655		0.057	0.131	0.188	0.812
95	0.090	0.250	0.340	0.660		0.054	0.132	0.186	0.814
100	0.083	0.253	0.336	0.664		0.051	0.133	0.185	0.815
Average	**0.231**	**0.187**	**0.417**			**0.119**	**0.123**	**0.242**	

Table 6-A-5—continued

Year after Production	South Central, Softwood								
	In Use	Sawlog		Total Emissions		In Use	Pulpwood		Total Emissions
		In Landfills	Total Stored				In Landfills	Total Stored	
0	0.629	0.000	0.629	0.371		0.570	0.000	0.570	0.430
1	0.569	0.035	0.603	0.397		0.506	0.026	0.532	0.468
2	0.547	0.044	0.591	0.409		0.459	0.041	0.500	0.500
3	0.527	0.053	0.580	0.420		0.417	0.055	0.472	0.528
4	0.509	0.061	0.569	0.431		0.380	0.066	0.447	0.553
5	0.492	0.068	0.560	0.440		0.348	0.076	0.424	0.576
6	0.477	0.075	0.551	0.449		0.319	0.085	0.404	0.596
7	0.455	0.083	0.538	0.462		0.270	0.100	0.370	0.630
8	0.437	0.091	0.527	0.473		0.232	0.111	0.343	0.657
9	0.421	0.097	0.518	0.482		0.202	0.119	0.321	0.679
10	0.408	0.102	0.510	0.490		0.180	0.124	0.304	0.696
15	0.362	0.122	0.484	0.516		0.123	0.133	0.256	0.744
20	0.330	0.136	0.466	0.534		0.103	0.130	0.234	0.766
25	0.303	0.148	0.451	0.549		0.094	0.126	0.220	0.780
30	0.280	0.158	0.439	0.561		0.087	0.122	0.210	0.790
35	0.259	0.168	0.427	0.573		0.082	0.120	0.202	0.798
40	0.240	0.176	0.416	0.584		0.077	0.118	0.195	0.805
45	0.222	0.184	0.406	0.594		0.072	0.117	0.189	0.811
50	0.206	0.191	0.397	0.603		0.068	0.116	0.185	0.815
55	0.192	0.197	0.389	0.611		0.064	0.116	0.181	0.819
60	0.178	0.203	0.381	0.619		0.061	0.116	0.177	0.823
65	0.166	0.208	0.374	0.626		0.058	0.116	0.174	0.826
70	0.155	0.213	0.368	0.632		0.054	0.117	0.171	0.829
75	0.145	0.217	0.362	0.638		0.051	0.117	0.169	0.831
80	0.135	0.221	0.356	0.644		0.049	0.118	0.167	0.833
85	0.126	0.225	0.351	0.649		0.046	0.119	0.165	0.835
90	0.118	0.228	0.346	0.654		0.044	0.119	0.163	0.837
95	0.111	0.231	0.342	0.658		0.042	0.120	0.161	0.839
100	0.104	0.234	0.338	0.662		0.039	0.121	0.160	0.840
Average	**0.239**	**0.176**	**0.415**			**0.099**	**0.116**	**0.215**	

Table 6-A-5—continued

Year after Production	South Central, Hardwood								
	In Use	Sawlog		Total Emissions		In Use	Pulpwood		Total Emissions
		In Landfills	Total Stored				In Landfills	Total Stored	
0	0.587	0.000	0.587	0.413		0.581	0.000	0.581	0.419
1	0.531	0.033	0.564	0.436		0.516	0.027	0.542	0.458
2	0.512	0.042	0.554	0.446		0.470	0.042	0.512	0.488
3	0.495	0.050	0.545	0.455		0.429	0.055	0.484	0.516
4	0.479	0.057	0.536	0.464		0.392	0.067	0.459	0.541
5	0.464	0.064	0.528	0.472		0.360	0.077	0.437	0.563
6	0.450	0.070	0.521	0.479		0.332	0.085	0.417	0.583
7	0.432	0.078	0.510	0.490		0.283	0.100	0.383	0.617
8	0.416	0.085	0.501	0.499		0.246	0.111	0.357	0.643
9	0.403	0.091	0.493	0.507		0.217	0.119	0.336	0.664
10	0.391	0.096	0.487	0.513		0.195	0.124	0.319	0.681
15	0.347	0.116	0.463	0.537		0.138	0.133	0.272	0.728
20	0.314	0.132	0.446	0.554		0.118	0.131	0.250	0.750
25	0.286	0.145	0.432	0.568		0.108	0.128	0.236	0.764
30	0.262	0.157	0.419	0.581		0.101	0.125	0.226	0.774
35	0.239	0.168	0.407	0.593		0.095	0.123	0.217	0.783
40	0.219	0.177	0.396	0.604		0.089	0.121	0.210	0.790
45	0.200	0.186	0.386	0.614		0.084	0.121	0.204	0.796
50	0.183	0.193	0.377	0.623		0.079	0.120	0.199	0.801
55	0.168	0.200	0.368	0.632		0.075	0.121	0.195	0.805
60	0.154	0.206	0.360	0.640		0.070	0.121	0.191	0.809
65	0.141	0.212	0.353	0.647		0.067	0.121	0.188	0.812
70	0.129	0.217	0.346	0.654		0.063	0.122	0.185	0.815
75	0.118	0.222	0.340	0.660		0.060	0.123	0.182	0.818
80	0.108	0.226	0.334	0.666		0.057	0.124	0.180	0.820
85	0.099	0.229	0.329	0.671		0.054	0.124	0.178	0.822
90	0.091	0.233	0.324	0.676		0.051	0.125	0.176	0.824
95	0.084	0.236	0.319	0.681		0.048	0.126	0.174	0.826
100	0.077	0.238	0.315	0.685		0.046	0.127	0.173	0.827
Average	**0.215**	**0.177**	**0.393**			**0.110**	**0.119**	**0.229**	

Table 6-A-5—continued

Year after Production	Other West, Hardwood			
	In Use	All		Total Emissions
		In Landfills	Total Stored	
0	0.568	0.000	0.568	0.432
1	0.516	0.028	0.544	0.456
2	0.494	0.038	0.532	0.468
3	0.473	0.046	0.520	0.480
4	0.455	0.054	0.509	0.491
5	0.438	0.061	0.499	0.501
6	0.422	0.068	0.490	0.510
7	0.399	0.077	0.476	0.524
8	0.381	0.084	0.465	0.535
9	0.365	0.090	0.455	0.545
10	0.352	0.095	0.447	0.553
15	0.307	0.113	0.421	0.579
20	0.277	0.126	0.403	0.597
25	0.253	0.136	0.389	0.611
30	0.232	0.146	0.377	0.623
35	0.212	0.154	0.366	0.634
40	0.195	0.162	0.356	0.644
45	0.179	0.169	0.347	0.653
50	0.164	0.175	0.339	0.661
55	0.151	0.181	0.331	0.669
60	0.138	0.186	0.324	0.676
65	0.127	0.190	0.318	0.682
70	0.117	0.195	0.312	0.688
75	0.108	0.198	0.306	0.694
80	0.099	0.202	0.301	0.699
85	0.091	0.205	0.296	0.704
90	0.084	0.208	0.292	0.708
95	0.078	0.210	0.288	0.712
100	0.072	0.213	0.284	0.716
Average	**0.195**	**0.161**	**0.357**	

Table 6-A-6: Regional Factors to Estimate Carbon in Roundwood Logs, Bark on Logs, and Fuelwood

Region[a]	Timber Type	Roundwood Category	Ratio of Roundwood to Growing-Stock Volume that is Roundwood[b]	Ratio of Carbon in Bark to Carbon in Wood[c]	Fraction of Growing-Stock Volume that is Roundwood[d]	Ratio of Fuelwood to Growing-Stock Volume that is Roundwood[b]
Northeast	SW	Sawlog	0.991	0.182	0.948	0.136
		Pulpwood	3.079	0.185		
	HW	Sawlog	0.927	0.199	0.879	0.547
		Pulpwood	2.177	0.218		
North Central	SW	Sawlog	0.985	0.182	0.931	0.066
		Pulpwood	1.285	0.185		
	HW	Sawlog	0.960	0.199	0.831	0.348
		Pulpwood	1.387	0.218		
Pacific Coast	SW	Sawlog	0.965	0.181	0.929	0.096
		Pulpwood	1.099	0.185		
	HW	Sawlog	0.721	0.197	0.947	0.957
		Pulpwood	0.324	0.219		
Rocky Mountain	SW	Sawlog	0.994	0.181	0.907	0.217
		Pulpwood	2.413	0.185		
	HW	Sawlog	0.832	0.201	0.755	3.165
		Pulpwood	1.336	0.219		
South	SW	Sawlog	0.990	0.182	0.891	0.019
		Pulpwood	1.246	0.185		
	HW	Sawlog	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 et al. (2003a), 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, FIA Program's database of forest surveys (FIADB)(Alerich et al., 2005; USDA Forest Service, 2005). Carbon mass is calculated for boles from stump to 4-inch (10.2 cm) 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).

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