CHAPTER 4

FOREST LAND

Authors

Harald Aalde (Norway), Patrick Gonzalez (USA), Michael Gytarsky (Russian Federation), Thelma Krug (Brazil), Werner A. Kurz (Canada), Stephen Ogle (USA), John Raison (Australia), Dieter Schoene (FAO), and N.H. Ravindranath (India)

Nagmeldin G. Elhassan (Sudan), Linda S. Heath (USA), Niro Higuchi (Brazil), Samuel Kainja (Malawi), Mitsuo Matsumoto (Japan), María José Sanz Sánchez (Spain), and Zoltan Somogyi (European Commission/Hungary)

Contributing Authors

Jim B. Carle (FAO) and Indu K. Murthy (India)

Contents

Figures

Tables

Boxes

4 FOREST LAND

4.1 INTRODUCTION

This chapter provides methods for estimating greenhouse gas emissions and removals due to changes in biomass, dead organic matter and soil organic carbon on Forest Land and *Land Converted to Forest Land*. It builds on the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (*1996 IPCC Guidelines*) and the Good Practice Guidance for Land Use, Land-Use Change and Forestry (*GPG-LULUCF*). The chapter:

- addresses all five carbon pools identified in Chapter 1 and transfers of carbon between different pools within the same land areas;
- includes carbon stock changes on managed forests due to human activities such as establishing and harvesting plantations, commercial felling, fuelwood gathering and other management practices, in addition to natural losses caused by fire, windstorms, insects, diseases, and other disturbances;
- provides simple (Tier 1) methods and default values and outline approaches for higher tier methods for the estimation of carbon stock changes;
- provides methods to estimate non-CO_2 greenhouse gas emissions from biomass burning (other non-CO_2 emissions such as N_2O emissions from soils are covered in Chapter 11);
- should be used together with generic description of methods and equations from Chapter 2, and the approaches for obtaining consistent area data described in Chapter 3.

The *Guidelines* provide methods for estimating and reporting sources and sinks of greenhouse gases only for managed forests, as defined in Chapter 1. Countries should consistently apply national definitions of managed forests over time. National definitions should cover all forests subject to human intervention, including the full range of management practices from protecting forests, raising plantations, promoting natural regeneration, commercial timber production, non-commercial fuelwood extraction, and abandonment of managed land.

This chapter does not include harvested wood products (HWP) which are covered by Chapter 12 of this Volume.

Managed Forest Land is partitioned into two sub categories and the guidance and methodologies are given separately in two sections:

- Section 4.2 Forest Land Remaining Forest Land
- Section 4.3 Land Converted to Forest Land

Section 4.2 covers the methodology that applies to lands that have been Forest Land for more than the transition period required to reach new soil carbon levels (default is 20 years). Section 4.3 applies to lands converted to Forest Land within that transition period. The 20-year interval is taken as a default length of transition period for carbon stock changes following land-use change. It is *good practice* to differentiate national forest lands by the above two categories. The actual length of transition period depends on natural and ecological circumstances of a particular country or region and may differ from 20 years.

Unmanaged forests, which are brought under management, enter the inventory and should be included in the *Land Converted to Forest Land*. Unmanaged forests which are converted to other land uses enter the inventory under their post conversion land-use categories with the appropriate transition period for the new land-use category.

If there are no data on land conversion and the period involved are available, the default assumption is that all managed forest land belongs to the category *Forest Land Remaining Forest Land* and greenhouse gas (GHG) emissions and removals are estimated using guidance given in Section 4.2.

Relevant carbon pools and non-CO_2 gases

The relevant carbon pools and non-CO_2 gases for which methods are provided are given below:

- Biomass (above-ground and below-ground biomass)
- Dead organic matter (dead wood and litter)
- Soil organic matter
- Non-CO_2 gases (CH_4, CO, N_2O, NO_X)

The selection of carbon pools or non-CO_2 gases for estimation will depend on the significance of the pool and tier selected for each land-use category.

Forest land-use classification

Greenhouse gas emissions and removals per hectare vary according to site factors, forest or plantation types, stages of stand development and management practices. It is *good practice* to stratify Forest Land into various sub categories to reduce the variation in growth rate and other forest parameters and to reduce uncertainty (Box 4.1). As a default, the *Guidelines* use the most recent ecological zone (see Table 4.1 in Section 4.5 and Figure 4.1 in this chapter) and forest cover (see Table 4.2 in Section 4.5 and Figure 4.2 in this chapter) classifications, developed by the Food and Agriculture Organization (FAO, 2001). National experts should use more detailed classifications for their countries, if available and suitable, given the other data requirements.

BOX 4.1
LEVELS OF DETAIL

Stratification of forest types into homogeneous sub-categories, and if possible at regional or sub-regional level within a country, reduces the uncertainty of estimates of greenhouse gas emissions and removals. For simplicity and clarity, this chapter discusses estimation of emissions and removals at national level and for a relatively small number of subcategories of Forest Land. This level of detail is designed to match the available sources of default input data, carbon contents and other assumptions. It is important, however, for users of these Guidelines to understand that they are encouraged to carry out the greenhouse gas emissions inventory calculations at a finer level of detail, if possible. Many countries have more detailed information available about forests and land-use change than were used in constructing default values in this Chapter. These data should be used, if suitable, for the following reasons:

1. Geographic detail at regional rather than national level

Experts may find that greenhouse gas estimation for various regions within a country are necessary to capture important geographic variations in ecosystem types, biomass densities, fractions of cleared biomass which are burnt, etc.

2. Finer detail by subcategory

Experts may subdivide the recommended land-use categories and subcategories to reflect important differences in climate, ecology or species, forest types, land-use or forestry practices, fuelwood gathering patterns, etc.

In all cases, working at finer levels of disaggregation does not change the basic nature of the method of estimations, although additional data and assumptions will generally be required beyond the defaults provided in this Chapter. Once greenhouse gas emissions are estimated, using the most appropriate level of detail determined by the national experts, results should also be aggregated up to the national level and the standard categories requested in these *Guidelines*. This will allow for comparability of results among all participating countries. Generally, the data and assumptions used for finer levels of detail should also be reported to ensure transparency and repeatability of methods.

Terminology

The terminology used in the methods for estimating biomass stocks and changes need to be consistent with the terminologies and definitions used by the Food and Agriculture Organization (FAO). FAO is the main source of activity data and emission factors for forest and other land-use categories in Tier 1 level calculations. Examples of terminology from FAO are: biomass growth, mean annual increment, biomass loss, and wood-removal. The Glossary in Annex 4A.1 includes definitions of these terminologies.

Figure 4.1 **Global ecological zones, based on observed climate and vegetation patterns (FAO, 2001). Data for geographic information systems available at http://www.fao.org.**

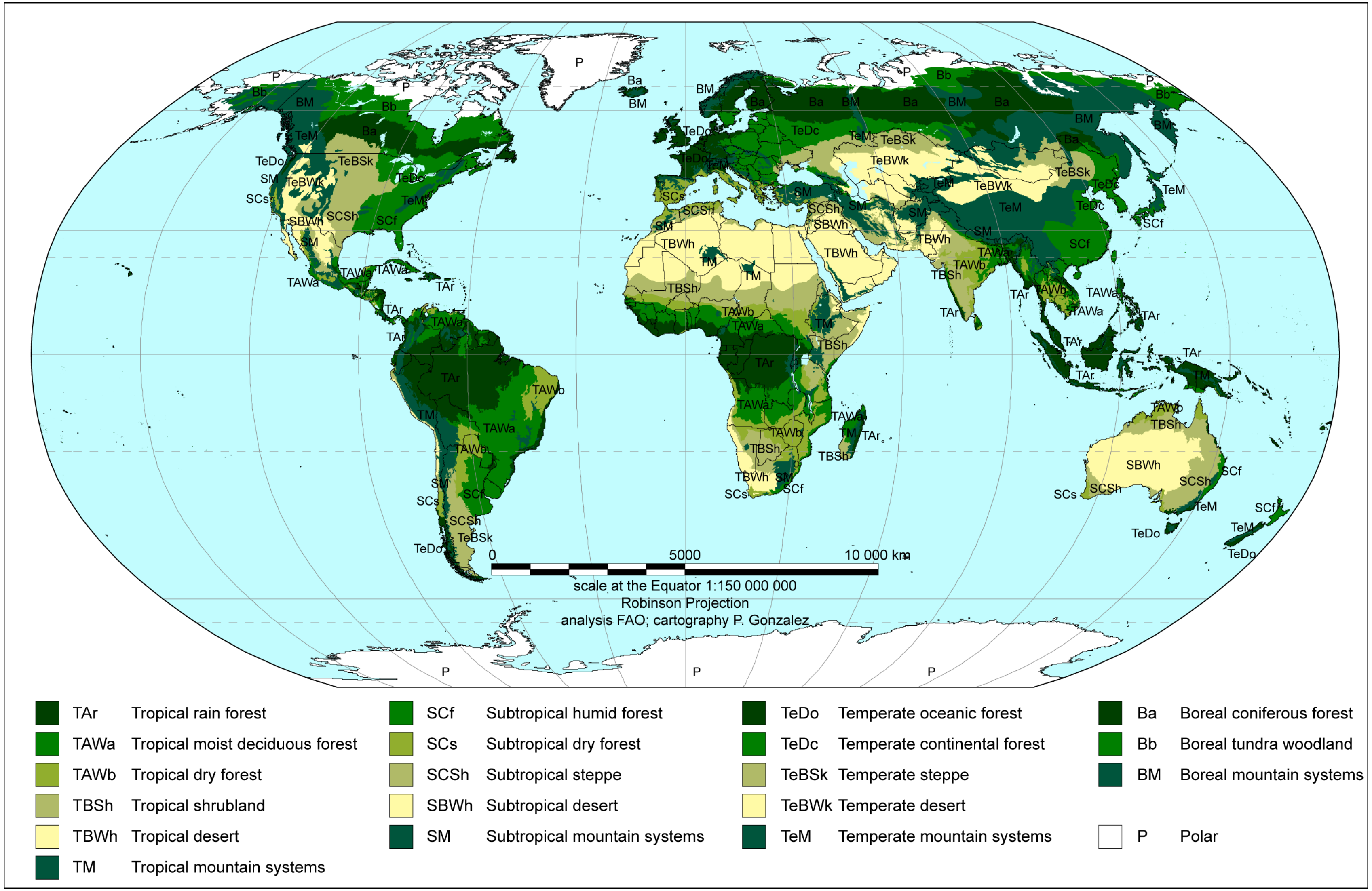
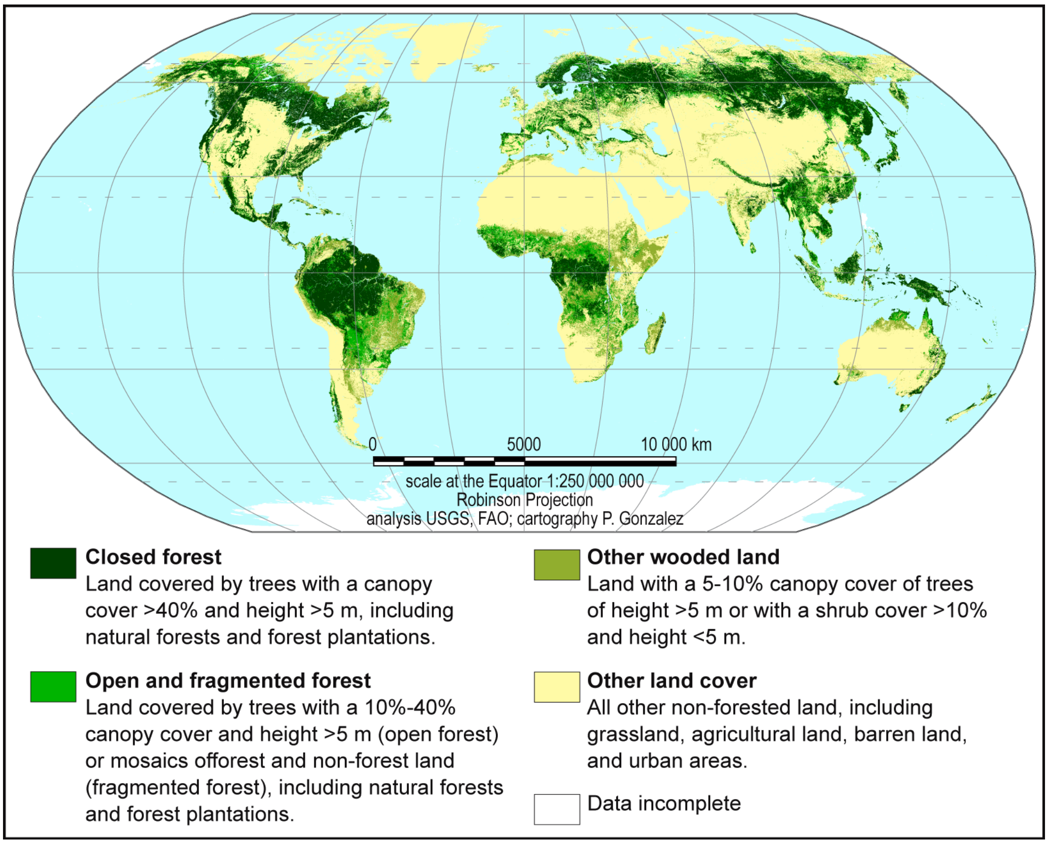


Figure 4.2 **Global forest and land cover 1995. Original spatial resolution of the forest data is 1 km^2 (analysis U.S. Geological Survey (Loveland *et al.*, 2000) and FAO (2001)). Data for geographic information systems available at http://edc.usgs.gov.**



4.2 FOREST LAND REMAINING FOREST LAND

This section deals with managed forests that have been under Forest Land for over 20 years (default), or for over a country-specific transition period. Greenhouse gas inventory for *Forest Land Remaining Forest Land* (FF) involves estimation of changes in carbon stock from five carbon pools (i.e., above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter), as well as emissions of non-CO_2 gases. Methods for estimating greenhouse gas emissions and removals for lands converted to Forest Land in the past 20 years (e.g., from Cropland and Grassland) are presented in Section 4.3. The set of general equations to estimate the annual carbon stock changes on Forest Land are given in Chapter 2.

4.2.1 Biomass

This section presents methods for estimating biomass gains and losses. Gains include total (above-ground and below-ground) biomass growth. Losses are roundwood removal/harvest, fuelwood removal/harvest/gathering, and losses from disturbances by fire, insects, diseases, and other disturbances. When such losses occur, below-ground biomass is also reduced and transformed to dead organic matter (DOM).

4.2.1.1 CHOICE OF METHOD

Chapter 2 describes two methods, namely, *Gain-Loss Method* based on estimates of annual change in biomass from estimates of biomass gain and loss (Equation 2.7) and a *Stock-Difference Method* which estimates the difference in total biomass carbon stock at time t_2 and time t_1 (Equation 2.8).

The biomass gain-loss method is applicable for all tiers although the stock-difference method is more suited to Tiers 2 and 3. This is because, in general, the stock-difference method will provide more reliable estimates for relatively large increases or decreases of biomass or where very accurate forest inventories are carried out. For areas with a mix of stands of different forest types, and/or where biomass change is very small compared to the total amount of biomass, the inventory error under the stock-difference method may be larger than the expected change. Unless periodic inventories give estimates on stocks of dead organic matter, in addition to growing stock, one should be aware that other data on mortality and losses will still be required for estimating the transfer to dead organic matter, harvested wood products and emissions caused by disturbances. Subsequent inventories must also allow identical area coverage in order to get reliable results when using the stock-difference method. The choice of using gain-loss or stock-difference method at the appropriate tier level will therefore be a matter of expert judgment, taking into account the national inventory systems, availability of data and information from ecological surveys, forest ownership patterns, activity data, conversion and expansion factors as well as cost-benefit analysis.

The decision tree as shown in Figure 1.2 in Chapter 1 should be used to guide choice between the Tiers. This promotes efficient use of available resources, taking into account whether the biomass of this category is a significant carbon pool or a key category as described in Volume 1, Chapter 4.

Tier-1 Method (Biomass Gain-Loss Method)

Tier 1 is feasible even when country-specific estimates of activity data and emission/removal factors are not available, and works when changes of the carbon pool in biomass on *Forest Land Remaining Forest Land* are relatively small. The method requires the biomass carbon loss to be subtracted from the biomass carbon gain (Equation 2.7). The annual change in carbon stocks in biomass can be estimated using the gain-loss method, where the annual increase in carbon stocks due to biomass growth and annual decrease in carbon stocks due to biomass losses are estimated:

- The annual increase in biomass carbon stock is estimated using Equation 2.9, where area under each forest sub-category is multiplied by mean annual increment in tonnes of dry matter per hectare per year.
- Since the biomass growth is usually in terms of merchantable volume or above-ground biomass, the below-ground biomass is estimated with a below-ground biomass to above-ground biomass ratio (Equation 2.10). Alternatively, merchantable volume (m^3) can be converted directly to total biomass using biomass conversion and expansion factors ($BCEF_I$), (Equation 2.10).
- If $BCEF_I$ values are not available and if the biomass expansion factor (BEF) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_I = BEF_I \bullet D$$

Biomass Expansion Factors (BEF_I) expand merchantable volume to total aboveground biomass volume to account for non-merchantable components of the tree, stand and forest. BEF_I is dimensionless.

- The average above-ground biomass of forest areas affected by disturbances are given in Tables 4.7 and 4.8; net average annual above-ground biomass growth values are provided in Tables 4.9, 4.10, and 4.12; net volume annual increment values are provided in Tables 4.11A and 4.11B; wood density is given in Tables 4.13 and 4.14; and below-ground biomass to above-ground biomass ratios (R) are given in Table 4.4. Refer to Box 4.2 for detailed explanation on how to convert and expand volumes of growing stock, increment and wood removals to biomass.
- In some ecosystems, basic wood density (D) can influence spatial patterns of forest biomass (Baker *et al.*, 2004b). Tier 1 users who do not have measurements of wood density at the desired sub-strata level can estimate wood density by estimating the proportion of total forest biomass contributed by the 2-3 dominant species and using species-specific wood density values (Tables 4.13 and 4.14) to calculate a weighted average wood density value.
- Annual biomass loss or decrease in biomass carbon stocks is estimated using Equation 2.11, which requires estimates of annual carbon loss due to wood removals (Equation 2.12), fuelwood removal (Equation 2.13) and disturbances (Equation 2.14). Transfer of biomass to dead organic matter is estimated using Equation 2.20, based on estimates of annual biomass carbon lost due to mortality (Equation 2.21), annual carbon transfer to slash (Equation 2.22).
- Biomass estimates are converted to carbon values using carbon fraction of dry matter (Table 4.3).

When either the biomass stock or its change in a category (or sub-category) is significant or a key category, it is *good practice* to select a higher tier methodology for estimation. The choice of Tier 2 or 3 method depends on the types and accuracy of data and models available, level of spatial disaggregation of activity data and national circumstances.

If using activity data collected via Approach 1 (see Chapter 3), and it is not possible to use supplementary data to identify the amount of land converted *from* and *to* Forest Land, the inventory compiler should estimate C stocks in biomass on all Forest Land using the Tier 1 method described above for *Forest Land Remaining Forest Land*.

Tier 2

Tier 2 can be used in countries where country-specific estimates of activity data and emission/removal factors are available or can be gathered at reasonable cost. Tier 2, same as Tier 1, uses Equations 2.7 to 2.14 (excluding Equation 2.8). Species-specific wood density values (Tables 4.13 and 4.14) permit the calculation of biomass from species-specific forest inventory data. It is possible to use the stock-difference method (Equation 2.8) at Tier 2 where the necessary country-specific data are available

Tier 3

Tier 3 approach for biomass carbon stock change estimation allows for a variety of methods, including process-based models. Implementation may differ from one country to another, due to differences in inventory methods, forest conditions and activity data. Transparent documentation of the validity and completeness of the data, assumptions, equations and models used is therefore a critical issue at Tier 3. Tier 3 requires use of detailed national forest inventories when the stock-difference method is used (Equation 2.8). They may be supplemented by allometric equations and models (for example, Chambers *et al.* (2001) and Baker *et al.* (2004a) for the Amazon; Jenkins *et al.* (2004) and Kurz and Apps (2006) for North America; and Zianis *et al.* (2005) for Europe), calibrated to national circumstances that allow for direct estimation of biomass growth.

BOX 4.2

BIOMASS CONVERSION AND EXPANSION FACTORS FOR ASSESSING BIOMASS AND CARBON IN FORESTS[1]

Forest inventories and operational records usually document growing stock, net annual increment or wood removals in m^3 of merchantable volume. This excludes non-merchantable above-ground components such as tree tops, branches, twigs, foliage, sometimes stumps, and below-ground components (roots).

Assessments of biomass and carbon stocks and changes, on the other hand, focus on total biomass, biomass growth and biomass removals (harvest), including non-merchantable components, expressed in tons of dry-weight. Several methods may be used to derive forest biomass and its changes. Above-ground biomass and changes can be derived in two ways, namely:

(i) directly by measuring sample tree attributes in the field, such as diameters and heights, and applying, species-specific allometric equations or biomass tables based on these equations once or periodically.

(ii) indirectly by transforming available volume data from forest inventories, e.g., merchantable volume of growing stock, net annual increment or wood removals (Somogyi *et al.*, 2006).

The latter approach may achieve the transformation by applying biomass regression functions, which usually express biomass of species or species groups (t/ha) or its rate of change, directly as a function of growing stock density (m^3/ha), and age, eco-regions or other variables (Pan *et al.*, 2004).

More commonly than these biomass regression functions, a single, discrete transformation factors[2] is applied to merchantable volume to derive above-ground biomass and its changes:

(i) Biomass Expansion Factors (BEF) expand the dry weight[3] of the merchantable volume of growing stock, net annual increment, or wood removals, to account for non-merchantable components of the tree, stand, and forest. Before applying such BEFs, merchantable volume (m^3) must be converted to dry-weight (tonne) by multiplying with a conversion factor known as basic wood density (D) in (t/m^3). BEFs are dimensionless since they convert between units of weight.

This method gives best results, when the BEFs have actually been determined based on dry weights, and when locally applicable basic wood densities are well known.

(ii) Biomass Conversion and Expansion Factors (BCEF) combine conversion and expansion. They have the dimension (t/m^3) and transform in one single multiplication growing stock, net annual increment, or wood removals (m^3) directly into above-ground biomass, above-ground biomass growth, or biomass removals (t).

BCEFs are more convenient. They can be applied directly to volume-based forest inventory data and operational records without the need of having to resort to basic wood densities. They provide best results, when they have been derived locally, based directly on merchantable volume.

Mathematically, BCEF and BEF are related by:

$$BCEF = BEF \bullet D$$

Application of this equation requires caution because basic wood density and biomass expansion factors tend to be correlated. If the same sample of trees was used to determine D, BEF or BCEF, conversion will not introduce error. If, however, basic wood density is not known with certainty, transforming one into the other might introduce error, as BCEF implies a specific but unknown basic wood density. Ideally, all conversion and expansion factors would be derived or their applicability checked locally.

---

[1] Please see glossary (Annex 4A.1) for definitions of terms.

[2] While these transformation factors are usually applied in discrete form, they can also be expressed and depicted as continuous functions of growing stock density, age, or other variables.

[3] In some applications, biomass expansion factors expand dry-weight of merchantable components to total biomass, including roots, or expand merchantable volume to above-ground or total biomass volume (Somogyi *et al.*, 2006). As used in this document, biomass expansion factors always transform dry-weight of merchantable volume including bark to above-ground biomass, excluding roots.

Both BEF and BCEF tend to decrease as a function of stand age, as growing stock density (volume of growing stock per ha) increases. This is because of the increasing ratio of merchantable volume to total volume. The decrease is rapid at low growing stock densities or for young stands and levels out for older stands and higher stand densities.

The *GPG-LULUCF* provided only average default BEF values, together with wide ranges, and general guidance on how to select applicable values for specific countries from these ranges. To facilitate selection of more reliable default values, this document provides default factors as a function of growing stock density in Table 4.5. Since more comprehensive and more recent data were found in the literature, Table 4.5 contains BCEF defaults only. Countries that possess country-specific basic wood densities and BEF on a consistent basis may apply them to calculate country-specific BCEF using the formula given above.

BCEF or BEF that apply to growing stock and net annual increment are different. In this document, the following symbols are used:

$BCEF_S$: biomass conversion and expansion factor applicable to growing stock; transforms merchantable volume of growing stock into above-ground biomass.

$BCEF_I$: biomass conversion and expansion factor applicable to net annual increment; transforms merchantable volume of net annual increment into above-ground biomass growth.

$BCEF_R$: biomass conversion and expansion factors applicable to wood removals; transforms merchantable biomass to total biomass (including bark). $BCEF_R$ and BEF_R for wood and fuelwood removal will be larger than that for growing stock due to harvest loss (see Annex 4A.1 Glossary). If a country specific value for harvest loss is not known, defaults are 10% for hardwoods and 8% for conifers (Kramer and Akca, 1982). Default conversion and expansion factors for wood removals can be derived by dividing $BCEF_S$ by (1– 0.08) for conifers and (1-0.1) for broadleaves.

It is *good practice* to estimate growing stock biomass, above-ground biomass growth and above-ground biomass removals by strata; to document these strata; and to aggregate results ex post. Methods described above will yield above-ground biomass and its changes. Results must be expanded to total biomass via applicable below-ground biomass to above-ground biomass ratios.

4.2.1.2 CHOICE OF EMISSION FACTORS

The Gain-Loss Method requires the above-ground biomass growth, biomass conversion and expansion factor (BCEF), BEF, and/or basic wood densities according to each forest type and climatic zone in the country, plus emission factors related to biomass loss, including losses due to wood removals, fuelwood removals and disturbances.

Annual biomass carbon gain, ΔC_G

Mean above-ground biomass growth (increment), G_W

Tier 1

Default values of the above-ground biomass growth (G_W) which are provided in Tables 4.9, 4.10 and 4.12 can be used at Tier 1. If available, it is *good practice* to use other regional default values for different forest types more relevant to the country.

Tier 2

Tier 2 method uses more country-specific data to calculate the above-ground biomass growth, G_W from country-specific net annual increment of growing stock (I_V). Tables 4.11a and 4.11b provide default values for I_V. Combined default biomass conversion and expansion factor ($BCEF_I$) of I_v are provided in Table 4.5. Separate data on biomass expansion factor for increment (BEF_I) and basic wood density (D) can also be used to convert the available data to G_W. Tables 4.13 and 4.14 provide default values for basic wood density.

Tier 3

Under Tier 3, process-based estimation will have access to detailed forest inventory or monitoring system with data on growing stock and past and projected net annual increment and functions relating to growing stock or net annual increment directly to biomass and biomass growth. It is also possible to derive net annual increment by process simulation. Specific carbon fraction and basic wood density should also be incorporated.

Forest inventories usually provide conditions of forest growing stock and net annual increment in the year of the inventory. When the year of inventory does not coincide with the year of reporting, interpolated or extrapolated net annual increment or increment estimated by models (i.e., model capable of simulating forest dynamics), should be used along with data on harvesting and disturbances to update inventory data to the year of interest.

Below-ground biomass growth (increment)

Tier 1

Below-ground carbon stock changes, as a default assumption consistent with the *1996 IPCC Guidelines*, can be zero. Alternatively, default values for below-ground biomass to above-ground biomass ratios (R) are to be used to estimate below-ground biomass growth. Default values are provided in Table 4.4. Strictly, these ratios of below-ground biomass to above-ground biomass are only valid for stocks, but no appreciable error is likely to obtain if they are applied to above-ground biomass growth over short periods.

Tier 2

Country-specific below-ground biomass to above-ground biomass ratios should be used to estimate below-ground biomass for different forest types.

Tier 3

For preference, below-ground biomass should be directly incorporated in models for calculating total biomass increment and losses. Alternatively, nationally or regionally determined below-ground biomass to above-ground biomass ratios or regression models (e.g., Li *et al.*, 2003) may be used.

Annual carbon loss in biomass, ΔC_L

Biomass loss due to wood removals, $L_{wood\text{-}removals}$ and $L_{fuelwood}$

When computing carbon loss through biomass removals, the following factors are needed: Wood removal (H), fuelwood removal as trees or parts of trees (FG), basic wood density (D), below-ground biomass to above-ground biomass ratio (R), carbon fraction (CF), BCEF for wood removals. While all wood removals represent a loss for the forest biomass pool, Chapter 12 provides guidance for estimating annual change in carbon stocks in harvested wood products.

Disturbances, $L_{disturbance}$

The estimate of other losses of carbon requires data on areas affected by disturbances ($A_{disturbance}$) and the biomass of these forest areas (B_W). Above ground biomass estimates of forest types affected by disturbance are required, along with below-ground biomass to above-ground biomass ratio and fraction of biomass lost in disturbance.

Chapter 2, Tables 2.4, 2.5 and 2.6 provide fuel biomass consumption values, emission factors, and combustion factors needed for estimating proportion of biomass lost in fires and proportion to be transferred to dead organic matter under higher tiers.

Tier 1

The average biomass varies with the forest types and management practices. The default values are given in Tables 4.7 and 4.8. In the case of fire, both CO_2 and non-CO_2 emissions occur from combusted fuels of above-ground biomass including understory. Fire may consume a high proportion of understory vegetation. In the case of other disturbances, a fraction of above ground biomass is transferred to dead organic matter and under Tier 1, all biomass in area subjected to disturbance is assumed to be emitted in the year of disturbance.

Tier 2

Under Tier 2, biomass changes due to disturbances will be taken into account by forest category, type of disturbance and intensity. Average values for biomass are obtained from country-specific data.

Tier 3

In addition to calculating losses similar to Tier 2, Tier 3 can also adopt models, which typically employ spatially referenced or spatially explicit information on the year and type of disturbance.

4.2.1.3 CHOICE OF ACTIVITY DATA

Area of managed Forest Land

All tiers require information on areas of managed Forest Land according to different forest types, climate, management systems, and regions.

Tier 1

Tier 1 uses data of forest area which can be obtained through national statistics, from forest agencies (which may have information on areas of different management practices), conservation agencies (especially for areas managed for natural regeneration), municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation for avoiding omissions or double counting as specified in Chapter 3. If no country data are available, aggregate information can be obtained from international data sources (FAO, 1995; FAO, 2001; TBFRA, 2000). It is *good practice* to verify, validate, and update the FAO data using national sources.

Tier 2
Tier 2 uses country-defined national data sets, according to different forest types, climate, management systems, and regions, with a resolution sufficient to ensure appropriate representation of land areas in line with provisions of Chapter 3 of this volume. Approach 2 of Chapter 3 is relevant for Tier 2.

Tier 3
Tier 3 uses country-specific data on managed Forest Land from different sources, notably national forest inventories, registers of land use and land-use changes, or remote sensing. These data should give a full accounting of all land-use transitions to Forest Land and disaggregate along climate, soil, and vegetation types. Geo-referenced area under different forest types may be used to track changes in area under different land-use types, using Approach 3 of Chapter 3.

Wood removals
The inventory requires data on wood removals, including fuelwood removals and biomass losses due to disturbances, in order to calculate biomass stock changes and carbon pool transfers. In addition to wood removals for industrial purposes, there may also be wood removals for small scale processing or direct sales to consumers from land owners. This quantity may not be included in official statistics and may need to be estimated by survey. Fuelwood from branches and tops of felled trees must be subtracted from transfers to the dead wood pool. Salvage of wood from areas affected by disturbances must also be subtracted from biomass, to ensure that no double counting occurs in Tier 1 inventories in which the biomass in areas affected by disturbances is already assumed released to the atmosphere.

In using production statistics, users must pay careful attention to the units involved. It is important to check whether the information in the original data is reported in biomass, volumes underbark or overbark to ensure that expansion factors are used only where appropriate and in a consistent way.

Unless restricted to Approach 1 land representation without supplementary data, so that all forest land is counted under *Forest Land Remaining Forest Land*, wood removals from Forest Land being converted to another land use should not be included in losses reported for *Forest Land Remaining Forest Land* since these losses are reported in the new land-use category. If the statistics on wood removals do not provide stratification on lands, then an amount of biomass approximating the biomass loss from lands converted from Forest Land should be subtracted from the total wood removals.

Extraction of roundwood is published in the UNECE/FAO Timber Bulletin and by FAO Yearbook of Forest Products. The latter is based primarily on data provided by the countries. In the absence of official data, FAO provides an estimate based on the best information available. Usually, the FAO yearbook appears with a two-year time lag.

Tier 1
FAO data can be used as a Tier 1 default for H in Equation 2.12 in Chapter 2. The roundwood data include all wood removed from forests which are reported in cubic meters underbark. The underbark data need conversion to overbark before using $BCEF_R$. Conversion from underbark to overbark volumes is done by using bark percentages.

Tier 2
Country-specific data should be used.

Tier 3
Country-specific wood removals data from different forest categories should be used at the spatial resolution chosen for reporting

Fuelwood removal
Estimation of carbon losses due to fuelwood removal requires annual volume of fuelwood removed (FG) and basic wood density (D). Fuelwood is produced in different ways in countries and varies from ordinary timber harvesting, to using parts of trees, to gathering of dead wood. Fuelwood constitutes the largest component of biomass loss for many countries, thus reliable estimates are needed for such countries. . If possible, fuelwood removal from *Forest Land Remaining Forest Land* and that coming from Forest Land conversion to other uses should be separated.

Tier 1
FAO provides statistics on fuelwood and charcoal removals for all countries. FAO statistics are based on what is provided by the concerned ministries/ departments in the countries and in some cases may not account fully for the entire fuelwood and charcoal removal due to the limitations of national data collection and reporting systems. Thus, under Tier 1, FAO statistics can be used directly but should be checked for completeness by the national

source of data for the FAO such as the Ministry of Forests or Agriculture or any statistical organization. FAO or any national estimates should be supplemented from regional surveys or local studies on fuelwood consumption, since fuelwood is collected from multiple sources; forests, timber processing residues, farms, homesteads, village commons, etc. If more complete information is available nationally, it should be used.

Tier 2
Country-specific data should be used, if available. Regional surveys of fuelwood removals can be used to verify and supplement the national or FAO data source. At the national level, aggregate fuelwood removals can be estimated by conducting regional level surveys of rural and urban households at different income levels, industries and establishments.

Tier 3
Fuelwood removals data from national level studies should be used at the resolution required for the Tier 3 model, including the non-commercial fuelwood removals. Fuelwood removal should be linked to forest types and regions.

Different methods of fuelwood removal from *Forest Land Remaining Forest Land* should be accounted at regional or disaggregated level through surveys. The source of fuelwood should be identified to ensure that no double counting occurs.

Disturbances
A database on rate and impact of natural disturbances by type, for all European countries (Schelhaas *et al.*, 2001), can be found at: http://www.efi.fi/

A UNEP database on global burnt area can be found at: http://www.grid.unep.ch/

However, one should note that the UNEP database is only valid for year 2000. In many countries inter-annual variability in burnt area is large, so these figures will not provide a representative average. Many countries maintain their own disturbance statistics e.g., Stocks *et al.* (2002) which can be employed in Tier 2 or Tier 3 approaches (Kurz and Apps, 2006).

The FRA2005 (FAO, 2005) should also be examined for data on disturbances.

4.2.1.4 CALCULATION STEPS FOR TIER 1

The following summarizes steps for estimating change in carbon stocks in biomass (ΔC_B) using the default methods:

Step 1: Using guidance from Chapter 3 (approaches in representing land areas), categorise the area (A) of *Forest Land Remaining Forest Land* into forest types of different climatic or ecological zones, as adopted by the country. As a point of reference, Annex 3A.1 of *GPG-LULUCF* (IPCC, 2003) provides national-level data of forest area and annual change in forest area by region and by country as a means of comparison. Alternatively FAO also periodically provides area data;

Step 2: Estimate the annual biomass gain in *Forest Land Remaining Forest Land* (ΔC_G) using estimates of area and biomass growth, for each forest type and climatic zone in the country available using Equations 2.9 and 2.10 in Chapter 2;

Step 3: Estimate the annual carbon loss due to wood removals ($L_{wood\text{-}removals}$) using Equation 2.12 in Chapter 2;

Step 4: Estimate annual carbon loss due to fuelwood removal ($L_{fuelwood}$) using Equation 2.13 in Chapter 2;

Step 5: Estimate annual carbon loss due to disturbance ($L_{disturbance}$) using Equation 2.14 in Chapter 2, avoid double counting of losses already covered in wood removals and fuelwood removals;

Step 6: From the estimated losses in Steps 3 to 5, estimate the annual decrease in carbon stocks due to biomass losses (ΔC_L) using Equation 2.11 in Chapter 2;

Step 7: Estimate the annual change in carbon stocks in biomass (ΔC_B) using Equation 2.7 in Chapter 2.

Example. The following example shows Gain-Loss Method (Tier 1) calculations of annual change in carbon stocks in biomass (ΔC_B), using Chapter 2, Equation 2.7 ($\Delta C_B = (\Delta C_G - \Delta C_L)$), for a hypothetical country in temperate continental forest zone of Europe (Table 4.1, Section 4.5):

- the area of *Forest Land Remaining Forest Land* (A) within the country is 100,000 ha (see Chapter 3 for area categorization);
- it is a 25-year-old pine forest, average above-ground growing stock volume is 40 m^3 ha^{-1};
- the merchantable round wood harvest over bark (H) is 1,000 m^3 yr^{-1};
- whole trees fuel wood removal (FG_{trees}) is 500 m^3 yr^{-1};
- area of insect disturbance is 2,000 ha yr^{-1} with above-ground biomass affected 4.0 tonne d.m. ha^{-1}.

Annual gain in biomass (ΔC_G) is a product of mean annual biomass increment (G_{TOTAL}), area of land (A) and carbon fraction of dry matter (CF); Equation 2.9 in Chapter 2 ($\Delta C_G = \sum_{ij} (A \bullet G_{TOTAL} \bullet CF)$. G_{TOTAL} is calculated using Chapter 2, Equation 2.10 for given values of annual above-ground biomass growth (G_W), below-ground biomass to above-ground biomass ratio (R), and default data tables in Section 4.5.

For the hypothetical country,

G_W = 4.0 tonnes d.m. ha^{-1} yr^{-1} (Table 4.9);

R = 0.29 tonne d.m. (tonne d.m.)$^{-1}$ for above-ground biomass of 50 to 150 t ha^{-1} (Table 4.4 with reference to Table 4.7 for above ground biomass);

G_{TOTAL} = 4.0 tonnes d.m. ha^{-1} yr^{-1} ● (1 + 0.29) = 5.16 tonnes d.m. ha^{-1} yr^{-1} (Equation 2.10); and

CF = 0.47 tonne C (tonne d.m.)$^{-1}$ (Table 4.3).

Consequently, (Equation 2.9): ΔC_G = 100,000 ha ● 5.16 tonnes d.m. ha^{-1} yr^{-1} ● 0.47 tonne C (tonne dm)$^{-1}$ = 242,520 tonnes C yr^{-1}.

Biomass loss (ΔC_L) is a sum of annual loss due to wood removals ($L_{wood\text{-}removals}$), fuel wood gathering ($L_{fuelwood}$) and disturbances ($L_{disturbance}$), Equation 2.11 in Chapter 2.

Wood removal ($L_{wood\text{-}removals}$) is calculated with Equation 2.12, Chapter 2, merchantable round wood over bark (H), biomass conversion expansion factor ($BCEF_R$), bark fraction in harvested wood (BF), below-ground biomass to above-ground biomass ratio (R), carbon fraction of dry matter (CF) and default tables, Section 4.5.

For the hypothetical country,

$BCEF_R$ = 1.11 tonnes d.m. m^{-3} (Table 4.5 with reference to growing stock volume 40 m^3 ha^{-1});

BF = 0.1 tonne d.m. (tonne d.m.)$^{-1}$. R = 0.29 tonne d.m. (tonne d.m.)$^{-1}$ for above-ground biomass 50 to 150 t ha^{-1} (Table 4.4, for above-ground biomass refer to Table 4.7); and

CF = 0.47 tonne C (tonne d.m.)$^{-1}$ (Table 4.3).

$L_{wood\text{-}removals}$ = 1,000 m^3 yr^{-1} ● 1.11 tonnes d.m. m^{-3} (1 + 0.29 + 0.1) ● 0.47 tonne C (tonne d.m.)$^{-1}$

= 725.16 tonnes C yr^{-1} (Equation 2.12).

Fuelwood removal ($L_{fuelwood}$) is calculated using Equation 2.13, Chapter 2, wood removals as whole trees (FG_{trees}), biomass conversion expansion factor ($BCEF_R$), below-ground biomass to above-ground biomass ratio (R), carbon fraction of dry matter (CF) and default tables in Section 4.5. For the hypothetical country,

$BCEF_R$ = 1.11 tonnes d.m. m^{-3} (Table 4.5 with reference to growing stock volume 40 m^3 ha^{-1});

R = 0.29 tonne d.m. (tonne dm)$^{-1}$ for above-ground biomass 50 to 150 t ha^{-1} (Table 4.4, for above-ground biomass refer to Table 4.7); and

CF = 0.47 tonne C (tonne dm)$^{-1}$ (Table 4.3).

$L_{fuelwood}$ = 500 m^3 yr^{-1} ● 0.75 tonne d.m. m^{-3} (1 + 0.29) ● 0.47 tonne C (tonne d.m.)$^{-1}$

= 336.50 tonne C yr^{-1} (Equation 2.13).

Annual carbon loss in biomass due to disturbances ($L_{disturbance}$) is calculated using Equation 2.14, Chapter 2, area of disturbances ($A_{disturbance}$), average above-ground biomass affected (B_W), below-ground biomass to above-ground biomass ratio (R), carbon fraction of dry matter (CF), fraction of biomass lost in disturbance (fd) and default tables in Section 4.5. For the hypothetical country,

R = 0.29 tonne d.m. (tonne dm)$^{-1}$ for above-ground biomass 50 to 150 t ha^{-1} (Table 4.4, for above-ground biomass refer to Table 4.7);

CF = 0.47 tonne C (tonne dm)$^{-1}$ (Table 4.3); and fd = 0.3

$L_{disturbance}$ = 2,000 ha yr^{-1} ● 4.0 tonnes d.m. ha^{-1} (1 + 0.29) ● 0.47 tonne C (tonne dm)$^{-1}$ ● 0.3

= 1,455.12 tonnes C yr^{-1} (Equation 2.14)

Annual decrease in carbon stocks due to biomass losses (ΔC_L),

ΔC_L = 725.16 tonnes C yr^{-1} + 336.50 tonnes C yr^{-1} + 1,455.12 tonnes C yr^{-1}

= 2,516.78 tonnes C yr^{-1} (Equation 2.11)

Annual change in carbon stocks in biomass (ΔC_B)

Using Chapter 2, Equation 2.7 ($\Delta C_B = (\Delta C_G - \Delta C_L)$),

ΔC_B = 242,520 tonnes C yr^{-1} – 2,516.78 tonnes C yr^{-1} = 240,003.22 tonnes C yr^{-1}

4.2.1.5 UNCERTAINTY ASSESSMENT

This section considers source-specific uncertainties relevant to inventory estimates made for *Forest Land Remaining Forest Land*. Estimating country-specific and/or disaggregated values requires more accurate information on uncertainties than given below. Volume 1, Chapter 3 provides information on uncertainties associated with sample-based studies. The literature available on uncertainty estimates on emission factors and activity data is limited.

Emission and removal factors

FAO (2006) provides uncertainty estimates for forest carbon factors; basic wood density (10 to 40%); annual increment in managed forests of industrialized countries (6 %); growing stock (industrialized countries 8%, non-industrialized countries 30%); combined natural losses for industrialized countries (15%); wood and fuelwood removals (industrialized countries 20%).

In Finland, the uncertainty of basic wood density of pine, spruce and birch trees is under 20% in studies of Hakkila (1968, 1979). The variability between forest stands of the same species should be lower or at most the same as for individual trees of the same species. In Finland, the uncertainty of biomass expansion factors for pine, spruce, and birch was approximately 10% (Lehtonen *et al.*, 2003).

In eight Amazon tropical forest inventory plots, combined measurement errors led to errors of 10-30% in estimates of basal area change over periods of less than 10 years (Phillips *et al.*, 2002).

The major sources of uncertainty of wood density and biomass expansion factors are stand age, species composition, and structure. To reduce uncertainty, countries are encouraged to develop country- or region-specific biomass expansion factors and BCEFs that fit their conditions. In case country- or regional-specific values are unavailable, the sources of default parameters should be checked and their correspondence with specific conditions of a country should be examined.

The causes of variation of annual increment include climate, site growth conditions, and soil fertility. Artificially regenerated and managed stands are less variable than natural forests. The major ways to improve accuracy of estimates are associated with application of country-specific or regional increment stratified by forest type. If the default values of increment are used, the uncertainty of estimates should be clearly indicated and documented. Tier 3 approaches can use growth curves stratified by species, ecological zones, site productivity and management intensity. Similar approaches are routinely used in timber supply planning models and this information can be incorporated into carbon accounting models (e.g., Kurz *et al.*, 2002).

Data on commercial fellings are relatively accurate, although they may be incomplete or biased due to illegal fellings and underreporting due to tax regulations. Traditional wood that is gathered and used directly, without being sold, is not likely to be included in any statistics. Countries must carefully consider these issues. The amount of wood removed from forests after storm breaks and pest outbreaks varies both in time and volume. No default data can be provided on these types of losses. The uncertainties associated with these losses can be estimated from the amount of damaged wood directly withdrawn from the forest or using data on damaged wood subsequently used for commercial and other purposes. If fuelwood gathering is treated separately from fellings, the relevant uncertainties might be high, due to high uncertainty associated with traditional gathering.

Activity data
Area data should be obtained using the guidance in Chapter 3 or from FAO (2000). Industrialized countries estimated an uncertainty in forest area estimates of approximately 3% (FAO, 2000).

4.2.2 Dead organic matter

The general description of methods for estimating changes in carbon stocks in dead organic matter (DOM) pools (litter and dead wood) has been provided in Chapter 2.

This section focuses on methods for estimating carbon stock changes in dead organic matter pools for *Forest Land Remaining Forest Land*. Tier 1 methods assume that the net carbon stock changes in DOM pools are zero because the simple input and output equations used in Tier 1 methods are not suitable to capture the DOM pool dynamics. Countries that want to quantify DOM dynamics need to develop Tier 2 or 3 methodologies. The countries where DOM is a key category should adopt higher tiers and estimate DOM changes.

The dead wood (DW) pool contains carbon in coarse woody debris, dead coarse roots, standing dead trees, and other dead material not included in the litter or soil carbon pools. Estimating the size and dynamics of the dead wood pool poses many practical limitations, particularly related to field measurements. The uncertainties associated with estimates of the rate of transfer from the DW pool to the litter and soil pools, and emissions to the atmosphere are generally high. The amount of dead wood is highly variable between stands, both in managed (Duvall and Grigal, 1999; Chojnacky and Heath, 2002) and unmanaged lands (Spies *et al.*, 1988). Amounts of dead wood depend on the time since last disturbance, the type of the last disturbance, losses during disturbances, the amount of biomass input (mortality) at the time of the disturbance (Spies *et al.*, 1988), natural mortality rates, decay rates, and management (Harmon *et al.*, 1986).

Net litter accumulation rates can be estimated using the stock-difference method or the gain-loss method. The latter requires an estimate of the balance of the annual amount of litterfall (which includes all leaves, twigs and small branches, fruits, flowers, roots, and bark) minus the annual rate of litter decomposition. In addition, disturbances can add and remove carbon from the litter pool, influencing the size and composition of the litter pool. The litter dynamics during the early stages of stand development depend on the type and intensity of the last disturbance. Where disturbance has transferred biomass to DOM pools (e.g., wind-throw or insect kill), litter pools can be decreasing until losses are compensated by litter inputs. Where disturbance has removed litter (e.g., wildfire), litter pools can be increasing in the early stages of stand development if litter input exceeds decay. Management such as timber harvesting, slash burning, and site preparation alter litter properties (Fisher and Binkley, 2000), but there are few studies clearly documenting the effects of management on litter carbon (Smith and Heath, 2002).

4.2.2.1 CHOICE OF METHOD

The decision tree in Figure 2.3 in Chapter 2 provides guidance in the selection of the appropriate tier level for the implementation of estimation procedures. The choice of method is described jointly for dead wood and Litter since the equations are identical for both, but the estimates are calculated separately for each of the two pools.

The estimation of changes in carbon stocks in DOM pool requires estimates of changes in carbon stocks of dead wood and litter pools (refer to Equation 2.17 of Chapter 2).

Tier 1
The Tier 1 method assumes that the dead wood and litter carbon stocks are in equilibrium so that the changes in carbon stock in the DOM pools are assumed to be zero. Countries experiencing significant changes in forest types, disturbance or management regimes in their forests are encouraged to develop domestic data to quantify the impacts from these changes using Tier 2 or 3 methodologies and to report the resulting stock changes and non-CO_2 emissions.

Tiers 2 and 3
Two general methods are available for estimating the carbon stock changes in dead wood and litter. Similar methods exist for the estimation of biomass carbon stock changes, and the choice of method for estimating DOM changes may be affected by the choice of method for biomass carbon stock change estimation.

Gain-Loss Method: The Gain-Loss method uses a mass balance of inputs to and losses from the dead wood and litter pools to estimate stock changes over a specified period. This involves estimating the area of managed *Forest Land Remaining Forest Land* and the average annual transfer of carbon stock into and out of dead wood and litter pools (Equation 2.18 in Chapter 2). To reduce uncertainty, the area under *Forest Land Remaining*

Forest Land can be further stratified by climate or ecological zones, and classified by forest type, productivity, disturbance regime, management practice, or other factors that affect dead wood and litter carbon pool dynamics. Estimation of the net balance requires calculation on a per hectare basis of the annual transfers into the dead wood and litter pools from stem mortality, litterfall and turnover, and the losses from decomposition. In addition, in areas subject to management activities or natural disturbances, dead wood and litter will be added in the form of biomass residues, and transferred through harvest (salvage of standing dead trees), burning or other mechanisms.

It is *good practice* that the stratification of Forest Land adopted for DOM be identical to that used for the estimation of changes in biomass carbon stocks (Section 4.2.1).

Stock-Difference Method: This involves estimating the area of managed *Forest Land Remaining Forest Land*, determining the dead wood and litter carbon stocks at two points of time and the calculation of the difference between the two carbon stock estimates (Equation 2.19 in Chapter 2). The annual carbon stock change for the inventory year is obtained by dividing the change in carbon stock by the period (years) between the two measurements. Method 2 is only feasible for countries which have forest inventories based on sample plots. Calculating carbon stock changes as the difference of carbon stocks at two points in time requires that the area at time t1 and t2 is identical to ensure that reported carbon stocks are not the result of changes in area.

For Tiers 2 and 3 methods, both options, are data intensive and require field measurements and models for their implementation. Such models can build on the knowledge and information compiled for the simulation of forest dynamics as used in the timber supply planning process (e.g. Kurz *et al.*, 2002, and Kurz and Apps, 2006).

4.2.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

By default, it is assumed that the carbon stocks in the DOM pools in *Forest Land Remaining Forest Land* are stable. Carbon-dioxide emissions originating from dead wood and litter pools during wildfire are assumed to be zero, and accumulation of carbon in dead wood and litter pools during regrowth is also not counted. Non- CO_2 emissions from wildfire, including CH_4 and CO are estimated in Tier 1.

Tiers 2 and 3

The parameter f_{BLol} is the fraction of total biomass left to decay on the ground, see Chapter 2, Equation 2.20. Resolution and accuracy of the transferred carbon will correspond to the expansion factors applied in calculating losses.

Tier 2 estimation of f_{Blol} requires national data on average proportions of carbon left after disturbances. When national data are incomplete, Chapter 2 provides two tables:

- Default values of combustion factor to be used as $(1- f_{BL})$ in case the country has good growing stock biomass data; in this case the proportion lost is used; see Table 2.6
- Default values of biomass removals to be used as $[M_B \bullet (1- f_{BL})]$ in case the growing stock biomass data are not reliable. M_B is the mass of fuel available for combustion (see Table 2.4 and Equation 2.27 in Chapter 2).

Country-specific values for transfer of carbon in live trees that are harvested to harvest residues can be derived from national expansion factors, taking into account the forest type (coniferous/broadleaved/ mixed), the rate of biomass utilization, harvesting practices and the amount of damaged trees during harvesting operations. Both harvest and natural disturbances add biomass to dead wood and litter pools. Other management practices (such as burning of harvest residues) and wildfire remove carbon from dead wood and litter pools. If the area under each management practice and type of forest affected by disturbance are known, then disturbance matrices (see Chapter 2, Table 2.1; Kurz *et al.*, 1992) can be used to define for each disturbance type the proportion of each biomass, dead organic matter, and soil carbon pool that is transferred to other pools, to the atmosphere, or removed from the forest during harvest.

Tier 3 estimation of f_{Blol}, will require more detailed knowledge of the proportion of rapid emissions from disturbances such as fires and windstorms. Data should be obtained by on-site measurements or from studies of similar disturbances. Disturbance matrices (see Chapter 2, Table 2.1) have been developed to define, for each disturbance type, the proportion of biomass (and all other carbon pools) that is transferred to other carbon pools, released to the atmosphere, or transferred to harvested wood products (Kurz *et al.*, 1992). Disturbance matrices ensure conservation of carbon when calculating the immediate impacts of harvest or disturbances on ecosystem carbon.

Tier 3 methods rely on more complex forest carbon accounting models that track the rates of input and losses from dead organic matter pools for each forest type, productivity, and age-class. Where comprehensive forest inventories exist, that include re-measurement of dead organic matter pools, estimates of carbon stock changes can also be derived using the stock-difference approach described in Equation 2.19 in Chapter 2. It is *good practice* that inventory-based approaches with periodic sampling follow the principles set out in Chapter 3, Annex 3A.3. Inventory-based approaches can be coupled with models to capture the dynamics of all forest carbon pools. Tier 3 methods provide estimates of greater certainty than lower tiers and feature a greater link between the dynamics of biomass and dead organic matter carbon pools. Other important parameters in modelling dead wood and litter carbon budgets are decay rates, which may vary with the forest type and climatic conditions, and forest management practices (e.g., controlled broadcast burning or thinning and other forms of partial harvest).

4.2.2.3 CHOICE OF ACTIVITY DATA

Countries using a Tier 1 method require no activity data for estimation of changes in carbon stock in DOM in *Forest Land Remaining Forest Land*.

Countries using higher tiers require activity data on the areas of *Forest Land Remaining Forest Land* classified by major forest types, management practices, and disturbance regimes. Total forest area and all other activity data should be consistent with that reported under other sections of this chapter, notably under biomass section of *Forest Land Remaining Forest Land* (Section 4.2.1). Country-specific activity data on the area annually affected by harvest and disturbances can be derived from national monitoring programs. The assessment of changes in carbon stock in DOM is greatly facilitated if this information can be used in conjunction with national soil and climate data, vegetation inventories, and other geophysical data.

Data sources will vary according to a country's forest management system. Data can be compiled from individual contractors or companies, regulation bodies and governmental agencies responsible for forest inventory and management, and from research institutions. Data formats vary widely, and include, among others, activity reports submitted regularly within incentive programs or as required by regulations, forest management inventories and from monitoring programs using remotely sensed imagery (Wulder *et al.*, 2004).

4.2.2.4 CALCULATION STEPS FOR TIER 1

Since Tier 1 assumes no change in DOM for *Forest Land Remaining Forest Land*, guidance on calculations steps is not relevant.

4.2.2.5 UNCERTAINTY ASSESSMENT

Tier 1 by definition assumes stable carbon stocks so formal uncertainty analysis is not appropriate. In fact the assumption is almost never true at the stand level and unlikely to be true in general, although the resulting error could be small for a forested landscape because increases in some stands could be off-set by decreases in others, but for the entire landscape or country, dead organic matter pools can be either increasing or decreasing. An understanding of the types of changes that are occurring in the forests of a country can provide some qualitative insight into the direction of change in dead organic matter pools. For example, in some countries biomass growing stocks are increasing because harvest and disturbance losses are smaller than growth increments. It is likely that dead organic matter pools are also increasing, even if the rate of increase cannot be known unless a Tier 2 or 3 estimation method is used.

Countries that use methods that assume all carbon losses occur in the year of disturbance are likely to overestimate disturbance losses in the years of above-average disturbances, and underestimate true emissions in years of below-average disturbances. Countries with fairly constant harvest or disturbance rates that rely on such methods are likely to be closer to the actual net carbon stock changes.

The uncertainty of estimates using higher Tier methods must be evaluated for each country using expert judgment. It is fair to assume that the uncertainty in the estimates of changes of carbon stock in dead organic matter is generally larger than that of the estimates of changes in carbon stock in biomass since, in most countries, considerably more data are available on biomass stocks than on dead organic matter stocks. Moreover, models that describe biomass dynamics are generally more advanced than models of dead organic matter dynamics.

Given the increased importance of understanding the non-timber components of forest ecosystems, many countries have revised their inventory procedures. More data on dead organic matter carbon stocks and their dynamics are becoming available, which will allow inventory agencies to better identify, quantify and reduce uncertainties in dead organic matter estimates in the years to come.

4.2.3 Soil carbon

This section elaborates on estimation procedures and *good practices* for estimating change in forest soil C stocks. It does not include forest litter, which is a dead organic matter pool. Separate guidance is provided for two types of forest soils: 1) mineral forest soils, and 2) organic forest soils.

The organic C content of mineral forest soils (to 1 m depth) typically varies between 20 to over 300 tonnes C ha^{-1} depending on the forest type and climatic conditions (Jobbagy and Jackson, 2000). Globally, mineral forest soils contain approximately 700 Pg C (Dixon *et al.*, 1994), but soil organic C pools are not static due to differences between C inputs and outputs over time. Inputs are largely determined by the forest productivity, the decomposition of litter and its incorporation into the mineral soil and subsequent loss through mineralization/respiration (Pregitzer, 2003). Other losses of soil organic C occur through erosion or the dissolution of organic C that is leached to groundwater or loss through overland flow. A large proportion of input is from above-ground litter in forest soils so soil organic matter tends to concentrate in the upper soil horizons, with roughly half of the soil organic C in the upper 30 cm layer. The C held in the upper profile is often the most chemically decomposable, and the most directly exposed to natural and anthropogenic disturbances. This section only deals with soil C and does not address decomposing litter (i.e., dead organic matter, see Section 4.2.2).

Human activities and other disturbances such as changes in forest type, productivity, decay rates and disturbances can alter the C dynamics of forest soils. Different forest management activities, such as rotation length; choice of tree species; drainage; harvest practices (whole tree or sawlog, regeneration, partial cut or thinning); site preparation activities (prescribed fires, soil scarification); and fertilization, affect soil organic C stocks (Harmon and Marks, 2002; Liski *et al.*, 2001; Johnson and Curtis, 2001). Changes in disturbance regimes, notably in the occurrence of severe forest fires, pest outbreaks, and other stand-replacing disturbances are also expected to alter the forest soil C pool (Li and Apps, 2002; de Groot *et al.,* 2002). In addition, drainage of forest stands on organic soils reduces soil C stocks.

General information and guidelines on estimating changes soil C stocks are found in Chapter 2, Section 2.3.3, and needs to be read before proceeding with the specific guidelines dealing with forest soil C stocks. Changes in soil C stocks associated with forests are computed using Equation 2.24 in Chapter 2, which combines the change in soil organic C stocks for mineral soils and organic soils; and stock change for soil inorganic C pools (Tier 3 only). This section elaborates on estimation procedures and *good practices* for estimating change in forest soil C organic stocks (Note: It does not include forest litter, i.e., dead organic matter). Separate guidance is provided for two types of forest soils: 1) mineral forest soils, and 2) organic forest soils. See Section 2.3.3.1 for general discussion on soil inorganic C (no additional information is provided in the Forest Land discussion below).

To account for changes in soil C stocks associated with *Forest Land Remaining Forest Land*, countries need to have, at a minimum, estimates of the total Forest Land area at the beginning and end of the inventory time period, stratified by climate region and soil type. If land-use and management activity data are limited, Approach 1 activity data (see Chapter 3) can be used as the basis for a Tier 1 approach, but higher Tiers are likely to need more detailed records or knowledge of country experts about the approximate distribution of forest management systems. Forest Land classes must be stratified according to climate regions and major soil types, which can be accomplished with overlays of suitable climate and soil maps.

4.2.3.1 CHOICE OF METHOD

Inventories can be developed using Tier 1, 2 or 3 approaches, and countries may choose to use different tiers for mineral and organic soils. Decision trees are provided for mineral soils (Figure 2.4) and organic soils (Figure 2.5) in Chapter 2 to assist inventory compilers with selection of the appropriate tier for their soil C inventory.

Mineral soils

In spite of a growing body of literature on the effect of forest types, management practices and other disturbances on soil organic C, the available evidence remains largely site- and study-specific, but eventually may be generalized based on the influence of climatic conditions, soil properties, the time scale of interest, taking into consideration sampling intensity and effects across different soil depth increments (Johnson and Curtis, 2001; Hoover, 2003; Page-Dumroese *et al.*, 2003). However, the current knowledge remains inconclusive on both the magnitude and direction of C stock changes in mineral forest soils associated with forest type, management and other disturbances, and cannot support broad generalizations.

Tier 1

Due to incomplete scientific basis and resulting uncertainty, it is assumed in the Tier 1 method that forest soil C stocks do not change with management. Furthermore, if using Approach 2 or 3 activity data (see Chapter 3), it is not necessary to compute C stock changes for mineral soils (i.e., change in SOC stocks is 0).

If using activity data collected via Approach 1 (see Chapter 3), and it is not possible to identify the amount of land converted *from* and *to* Forest Land, then the inventory compiler should estimate soil C stocks for Forest Land using the areas at and the end of the year for which the inventory is being estimated, and the difference estimates the uptake or less of forest soil. The changes in soil C stocks for Forest Land are summed with the changes in stocks for other land uses to estimate the influence of land-use change. If the compiler does not compute a stock for Forest Land, it is likely to create systematic errors in the inventory. For example, land converted from Forest Land to Cropland or Grassland will have a soil C stock estimated in the final year of the inventory, but will have no stock in the first year of the inventory (when it was forest). Consequently, conversion to Cropland or Grassland is estimated as a gain in soil C because the soil C stocks are assumed to be 0 in the Forest Land, but not in Cropland and Grassland. This would introduce a bias into the inventory estimates. SOC_0 and SOC_{0-T} are estimated for the top 30 cm of the soil profile using Equation 2.25 (Chapter 2). Note that areas of exposed bedrock in Forest Land are not included in the soil C stock calculation (assume a stock of 0).

Tier 2

Using Equation 2.25 (Chapter 2) soil organic C stocks are computed based on reference soil C stocks and country-specific stock change factors for forest type (F_I), management (F_{MG}) and natural disturbance regime (F_D). Note that the stock change factor for natural disturbance regime (F_D) is substituted for the land-use factor (F_{LU}) in Equation 2.25. In addition, country-specific information can be incorporated to better specify reference C stocks, climate regions, soil types, and/or the land management classification system.

Tier 3

Tier 3 approaches will require considerable knowledge and data allowing for the development of an accurate and comprehensive domestic estimation methodology, including evaluation of model results and implementation of a domestic monitoring scheme and/or modelling tool. The basic elements of a country-specific approach are (adapted from Webbnet Land Resource Services Pty ltd, 1999):

- Stratification by climatic zones, major forest types and management regimes coherent with those used for other C pools in the inventory, especially biomass;
- Determination of dominant soil types in each stratum;
- Characterization of corresponding soil C pools, identification of determinant processes in SOC input and output rates and the conditions under which these processes occur; and
- Determination and implementation of suitable methods to estimate carbon stock changes from forest soils for each stratum on an operational basis, including model evaluation procedures; methodological considerations are expected to include the combination of monitoring activities – such as repeated forest soil inventories - and modelling studies, and the establishment of benchmark sites. Further guidance on good soil monitoring practices is available in the scientific literature (Kimble *et al.*, 2003, Lal *et al.*, 2001, McKenzie *et al.*, 2000). It is *good practice* for models developed or adapted for this purpose to be peer-reviewed, and validated with observations representative of the ecosystems under study and independent from the calibration data.

Organic soils

Tier 1

Currently, only C emissions due to drainage of forest organic soils are addressed in the Tier 1 method due to data limitations and lack of sufficient knowledge that constrain the development of a more refined default methodology. Using Equation 2.26 (Chapter 2), drained forest organic soils are stratified by climate type, and then multiplied by a climate-specific emission factor to derive an estimate of annual C emissions. Areas converted to Forest Land can be included in the total area estimate, in using Approach 1 land representation, without supplementary data, to be able to identify land-use changes.

Tier 2

For Tier 2, the same basic equation is used as in Tier 1 (Equation 2.26), but country-specific information is incorporated to better specify emission factors, climate regions, and/or develop a forest classification scheme, relevant for organic soils.

Tier 3

Tier 3 methodology involves the estimation of CO_2 emissions associated with management of forested organic soils, including all anthropogenic activities likely to alter the hydrological regime, surface temperature, and vegetation composition of forested organic soils; and major disturbances such as fires.

4.2.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTORS

Mineral soils

Tier 1

It is not necessary to compute the stock estimates for *Forest Land Remaining Forest Land* with Approach 2 or 3 activity data (see Chapter 3). If using Approach 1 activity data, stock change factors, including input, management and disturbance regime, are equal to 1 using the Tier 1 approach. Consequently, only reference C stocks are needed to apply the method, and those are provided in Table 2.3 of Chapter 2.

Tier 2

In a Tier 2 approach, stock change factors are derived based on a country-specific classification scheme for management, forest types, and natural disturbance regimes. A Tier 2 approach should also include the derivation of country-specific reference C stocks, and a more detailed classification of climate and soils than the default categories provided with the Tier 1 method.

It is *good practice* to focus on the factors that have the largest overall effect, taking into account the impact on forest SOC and the extent of affected forests. Management practices can be coarsely labeled as intensive (e.g., plantation forestry) or extensive (e.g., natural forest); these categories can also be redefined according to national circumstances. The development of stock change factors is likely to be based on intensive studies at experimental sites and sampling plots involving replicated, paired site comparisons (Johnson *et al.*, 2002; Olsson *et al.*, 1996; see also the reviews by Johnson and Curtis, 2001; and Hoover, 2003). In practice, it may not be possible to separate the effects of a different forest types, management practices and disturbance regimes, in which case some stock change factors can be combined into a single modifier. If a country has well-documented data for different forest types under different management regimes, it might be possible to derive soil organic C estimates directly without using reference C stocks and adjustment factors. However, a relationship to the reference C stocks must be established so that the impact of land-use change can be computed without artificial increases or decreases in the C stocks due to a lack of consistency in the methods across the various land-use categories (i.e., Forest Land, Cropland, Grassland, Settlements, and Other Land).

Inventories can also be improved by deriving country-specific reference C stocks (SOC_{ref}), compiled from published studies or surveys. Such values are typically obtained through the development and/or compilation of large soil profile databases (Scott *et al.*, 2002; Siltanen *et al.*, 1997). Additional guidance for deriving stock change factors and reference C stocks is provided in Section 2.3.3.1 (Chapter 2).

Tier 3

Constant stock change rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Section 2.3.3.1 (Chapter 2) for further discussion.

Organic soils

Tier 1

Default emission factors are provided in Table 4.6 of Section 4.5, to estimate the loss of C associated with drainage of organic soils.

Tier 2

Tier 2 approaches involve the derivation of emission factors from country-specific data. The main consideration is whether forests types or management in addition to climate regions will be subdivided into finer classes. These decisions will depend on experimental data that demonstrate significant differences in C loss rates. For example, drainage classes can be developed for various forest management systems. In addition, management activities may disrupt the C dynamics of the underlying organic soils. Harvest, for example, may cause a rise in the water table due to reduced interception, evaporation and transpiration (Dubé *et al.*, 1995).

Tier 3

Constant emission rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Section 2.3.3.1 (Chapter 2) for further discussion.

4.2.3.3 CHOICE OF ACTIVITY DATA

Mineral soils

Tier 1

For the Tier 1 approach, it is assumed that forest soil C stocks do not change with management, and therefore it is not necessary to classify forest into various types, management classes or natural disturbance regimes. However, if using Approach 1 activity data (see Chapter 3), environmental data will be needed to classify the country into climate regions and soil types in order to apply the appropriate reference C stocks to Forest Land. A detailed description of the default climate classification scheme is given in Chapter 3, Annex 3A.5. If the information needed to classify climate types is not available from national databases, there are international sources of climate data such as United Nations Environmental Program. Data will also be needed to classify soils into the default categories provided in Chapter 3, and if national data are not available to map the soil types, international soils data provide a reasonable alternative, such as the FAO Soils Map of the World.

Tier 2

Activity data for the Tier 2 approach consist of the major forest types, management practices, disturbance regimes and the areas to which they apply. It is preferable for the data to be linked with the national forest inventory, where one exists, and/or with national soil and climate databases. Typical changes include: conversion of unmanaged to managed forest; conversion of native forest into a new forest type; intensification of forest management activities, such as site preparation, tree planting and rotation length changes; changes in harvesting practices (bole vs. whole-tree harvesting; amount of residues left on-site); frequency of disturbances (pest and disease outbreaks, flooding, fires, etc). Data sources will vary according to a country's forest management system, but could include individual contractors or companies, statutory forest authorities, research institutions and agencies responsible for forest inventories. Data formats vary widely, and include, among others, activity reports, forest management inventories and remote sensing imagery.

In addition, Tier 2 should involve a finer stratification of environmental data than the Tier 1 approach, including climate regions and soil types, which would likely be based on national climate and soils data. If a finer classification scheme is utilized in a Tier 2 inventory, reference C stocks will also need to be derived for the more detailed set of climate regions and soil types, and the land management data will need to be stratified based on the country-specific classification.

Tier 3

For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed data on the combinations of climate, soil, topographic and management data are needed, relative to the Tiers 1 and 2 methods, but the exact requirements will be dependent on the model or measurement design.

Organic soils

Tier 1

Forests are not stratified into various systems using Tier 1 methods. However, land areas do need to be stratified by climate region and soil type (see Chapter 3 for guidance on soil and climate classification) so that organic soils may be identified and the appropriate default emission factor applied.

Tier 2

Tier 2 approaches may involve a finer stratification of management, forest type or disturbance regime, in a manner consistent with the country-specific emission factors for organic soils. For example, forest systems will need to be stratified by drainage if management factors are derived by drainage class. However it is *good practice* for the classification to be based on empirical data that demonstrates significant differences in rates of C change for the proposed categories. In addition, Tier 2 approaches should involve a finer stratification of climate regions.

Tier 3

For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed data on the combinations of climate, soil, topographic and management data are needed, relative to the Tiers 1 and 2 methods, but the exact requirements will be dependent on the model or measurement design.

4.2.3.4 CALCULATION STEPS FOR TIER 1

Mineral soils

Since Tier 1 assumes no change in mineral soil C stocks for *Forest Land Remaining Forest Land*, guidance on calculations steps are not provided.

Organic soils

Step 1: Estimate the area of drained organic soils under managed forest in each climatic region of the country for each year or for the last year in each time period of the inventory (e.g., emissions over an inventory time period between 1990 and 2000 would be based on the land-use in 2000, assuming land-use and management are only known for these two years during the inventory time period).

Step 2: Select the appropriate emission factor (EF) for annual losses of CO_2 (from Table 4.6).

Step 3: Estimate total emissions by summing the product of area (A) multiplied by the emission factor (EF) for all climate zones.

4.2.3.5 UNCERTAINTY ASSESSMENT

Three broad sources of uncertainty exists in soil C inventories: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in reference soil C stocks if using Tier 1 or 2 approaches (mineral soils only); and 3) uncertainties in the stock change/emission factors for Tier 1 or 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with Tier 3 measurement-based inventories. In general, precision of an inventory is increased (i.e., smaller confidence ranges) with more sampling to estimate values for the three broad categories. In addition, reducing bias (i.e., improve accuracy) is more likely through the development of a higher Tier inventory that incorporates country-specific information.

For Tier 1, uncertainties are provided with the reference C stocks in the first footnote of Table 2.3 (Chapter 2), and emission factor uncertainties for organic soils are provided in Table 4.6, Section 4.5. Uncertainties in land-use and management data will need to be addressed by the inventory compiler, and then combined with uncertainties for the default factors and reference C stocks (mineral soils only) using an appropriate method, such as simple error propagation equations. Refer to Section 4.2.1.5 for uncertainty estimate for land area estimates. However, it is *good practice* for the inventory compiler to derive uncertainties from country-specific activity data instead of using a default level.

Default reference C stocks for mineral soils and emission factors for organic soils can have inherently high uncertainties, particularly bias, when applied to specific countries. Defaults represent globally averaged values of land-use and management impacts or reference C stocks that may vary from region-specific values (Powers *et al.*, 2004; Ogle *et al.*, 2006). Bias can be reduced by deriving country-specific factors using Tier 2 method or by developing a Tier 3 country-specific estimation system. The underlying basis for higher Tier approaches will be research in the country or neighbouring regions that address the effect of land use and management on soil C. In addition, it is *good practice* to further minimize bias by accounting for significant within-country differences in land-use and management impacts, such as variation among climate regions and/or soil types, even at the expense of reduced precision in the factor estimates (Ogle *et al.*, 2006). Bias is considered more problematic for reporting stock changes because it is not necessarily captured in the uncertainty range (i.e., the true stock change may be outside of the reported uncertainty range if there is significant bias in the factors).

Uncertainties in land-use activity statistics may be improved through a better national system, such as developing or extending a ground-based survey with additional sample locations and/or incorporating remote sensing to provide additional coverage. It is *good practice* to design a classification that captures the majority of land-use and management activity with a sufficient sample size to minimize uncertainty at the national scale.

For Tier 2 methods, country-specific information is incorporated into the inventory analysis for purposes of reducing bias. For example, Ogle *et al.* (2003) utilized country-specific data to construct probability distribution functions for US specific factors, activity data and reference C stocks for agricultural soils. It is *good practice* to evaluate dependencies among the factors, reference C stocks or land-use and management activity data. In particular, strong dependencies are common in land-use and management activity data because management practices tend to be correlated in time and space. Combining uncertainties in stock change/emission factors, reference C stocks and activity data can be done using methods such as simple error propagation equations or Monte-Carlo procedures.

Tier 3 models are more complex and simple error propagation equations may not be effective at quantifying the associated uncertainty in resulting estimates. Monte Carlo analyses are possible (Smith and Heath, 2001), but can be difficult to implement if the model has many parameters (some models can have several hundred parameters) because joint probability distribution functions must be constructed quantifying the variance as well as covariance among the parameters. Other methods are also available such as empirically-based approaches (Monte *et al.*, 1996), which use measurements from a monitoring network to statistically evaluate the relationship between measured and modelled results (Falloon and Smith, 2003). In contrast to modelling, uncertainties in measurement-based Tier 3 inventories can be determined from the sample variance, measurement error and other relevant sources of uncertainty.

4.2.4 Non-CO_2 greenhouse gas emissions from biomass burning

Both uncontrolled (wildfires) and managed (prescribed) fires can have a major impact on the non-CO_2 greenhouse gas emissions from forests. In *Forest Land Remaining Forest Land*, emissions of CO_2 from biomass burning also need to be accounted for because they are generally not synchronous with rates of CO_2 uptake. This is especially important after stand replacing wildfire, and during cycles of shifting cultivation in tropical regions.

Where the type of forest changes (e.g., conversion of natural forests to plantation forests), there may be net emissions of CO_2 from biomass burning during the initial years, in particular if significant woody biomass is burnt during the conversion. Over time, however, the impacts are not as great as those that result from *Forest Land Converted to Cropland or Grassland.* Fire emissions during land-use conversion are reported in the new land-use category unless restricted Approach 1 land area representation is being used without supplementary data to enable land use conversions to be identified explicitly, in which case fire emissions from Forest Land should all be included in the *Forest Land Remaining Forest Land* category.

The general method for estimating greenhouse gas emissions in *Forest Land Remaining Forest Land*, and in *Land Converted to Forest Land* is described in Equation 2.27 in Chapter 2. Default tables for Tier 1 approach or components of a Tier 2 approach are provided in that Section 2.4 of Chapter 2.

4.2.4.1 CHOICE OF METHOD

It is *good practice* that countries choose the appropriate Tier for reporting greenhouse gas emissions from fire, based on the decision tree in Figure 2.6 in Chapter 2. Where fire is a key category, emphasis should be on using a Tier 2 or Tier 3 approach. For prescribed fires, country-specific data are required to generate reliable estimates of emissions, since activity data, in general, are poorly reflected in global data sets. In Forest Land, both the CO_2 emissions due to biomass burning and the CO_2 removals resulting from vegetation regrowth need to be accounted for when estimating the net carbon flux.

4.2.4.2 CHOICE OF EMISSIONS FACTORS

The mass of fuel available for combustion (M_B of Equation 2.27) is critical for estimating the non-CO_2 emissions. Default data to support estimation of emissions under a Tier 1 approach are given in Tables 2.4 to 2.6 in Chapter 2. Countries need to judge how their vegetation types correspond with the broad vegetation categories described in the default tables. Guidance for this is provided in Chapter 3 (*Consistent Representation of Lands*). Countries using Tier 2 are likely to have national data at disaggregated level on M_B, according to forest types and management systems. Tier 3 estimation requires spatial estimates of M_B according to different forest types, regions and management systems. Tier 3 estimation methods can also distinguish fires burning at different intensities, resulting in different amounts of fuel consumption.

4.2.4.3 CHOICE OF ACTIVITY DATA

Estimates of area burnt in *Forest Land Remaining Forest Land* are needed. A global database exists that covers the area burnt annually by fires but this will not provide reliable data for the area burnt annually by prescribed fires in individual countries. It is *good practice* to develop national estimates of the area burnt and the nature of the fires especially how they affect forest carbon dynamics (e.g., effects on tree mortality) to improve the reliability of national inventories. Countries using Tier 2 are likely to have access to national estimates. Tier 3 estimation requires regional and forest type specific estimates of area subjected to fire and fire intensity.

Summary of steps for calculating greenhouse gas emissions from biomass burning using Equation 2.27 in Chapter 2:

Step 1: Using guidance from Chapter 3 (approaches in representing land-use areas), categorise the area of *Forest Land Remaining Forest Land* into forest types of different climatic or ecological zones, as adopted by the country for Equation 2.27. Obtain estimates of A (area burnt) from global database or from national sources.

Step 2: Estimate the mass of fuel (M_B) available for combustion, in tonnes/ha, which includes biomass, litter and dead wood.

Step 3: Select combustion factor C_f (default values are in Table 2.6, Chapter 2).

Step 4: Multiply M_B and C_f to provide an estimate of the amount of fuel combusted. If M_B or C_f is unknown, defaults for the product of M_B and C_f are given in Table 2.4.

Step 5: Select emission factors G_{ef} (default factors are in Table 2.5, Chapter 2).

Step 6: Multiply parameters A, M_B, C_f, (or M_B and C_f, Table 2.4) and G_{ef} to obtain the quantity of greenhouse gas emission from biomass burning. Repeat the steps for each greenhouse gas.

4.2.4.4 UNCERTAINTY ASSESSMENT

Country-specific uncertainty estimates are to be estimated for *Forest Land Remaining Forest Land*. These result from the product of the uncertainties associated with activity data (area burnt) and the emission factors. It is *good practice* to provide error estimates (e.g., ranges, standard errors) and not to use country-specific data (for example, if it is of a limited nature) or approaches, unless this leads to a reduction in uncertainties compared with a Tier 1 approach.

4.3 LAND CONVERTED TO FOREST LAND

This section provides methodological guidance on annual estimation of emissions and removals of greenhouse gases, which occur on lands converted to Forest Land from different land-uses, including Cropland, Grassland, Wetlands, Settlements, and Other land, through afforestation and reforestation, either by natural or artificial regeneration (including plantations). The emissions and removals on abandoned lands, which are regenerating to forest due to human activities, should be also estimated under this section. It substitutes the method described under categories 5A, 5C, and 5D of the *IPCC Guidelines*. Land is converted to Forest Land by afforestation and reforestation, either by natural or artificial regeneration (including plantations). The anthropogenic conversion includes promotion of natural re-growth (e.g., by improving the water balance of soil by drainage), establishment of plantations on non-forest lands or previously unmanaged Forest land, lands of settlements and industrial sites, abandonment of croplands, pastures or other managed lands, which re-grow to forest. Unmanaged forests are not considered as anthropogenic greenhouse gas sources or sinks, and are excluded from inventory calculations. Where these unmanaged forests are affected by human activities such as planting, thinning, promotion of natural regeneration or others, they change status and become managed forests, reported under the category *Land Converted to Forest Land*, whose greenhouse gas emissions and removals should be included in the inventory and estimated with the use of the guidance in this section. Land conversion may result in an initial loss of carbon due to changes in biomass, dead organic matter, and soil carbon. But natural regeneration or plantation practices lead to carbon accumulation and that is related to changes in the area of plantations and their biomass stocks.

Converted areas are considered Forest Land, if, following conversion, they correspond to definition of forest adopted by the country. *Land Converted to Forest Land* is covered in this section of the national greenhouse gas inventory until the time the soil carbon in new forests reach a stable level. A default period of 20 years[4] is suggested. Forest ecosystems may require a certain time to return to the level of biomass, stable soil and litter pools of undisturbed state. With this in mind and as a practical matter, the default 20-year time interval is suggested. Countries also have an option to extend the length of transition period. After 20 years or other time interval chosen, the converted lands become forest, i.e., the land areas are transferred from the *Land Converted to Forest Land* category to *Forest Land Remaining Forest Land* (Section 4.2), where areas still becoming established can be treated as a separate stratum if necessary. Logging followed by regeneration or re-growth should be considered under *Forest Land Remaining Forest Land* category, since no land-use change is involved.

Some abandoned lands may be too infertile, saline, or eroded for forest re-growth to occur. In this case, either the land remains in its current state or it may further degrade and lose organic matter. Those lands that remain constant with respect to carbon flux can be ignored. However, in some countries, the degradation of abandoned lands may be a significant problem and could be an important source of CO_2. Where lands continue to degrade, both above-ground biomass and soil carbon may decline rapidly, e.g., due to erosion. The carbon in eroded soil could be re-deposited in rivers, lakes or other lands downstream. For countries with significant areas of such lands, this issue should be considered in a more refined calculation.

Classification of land: *Land Converted to Forest Land* can be classified based on climate domain and ecological zones and forest crown cover classes. The carbon stock varies with climate, biome or forest type, species mix, management practices, etc. It is *good practice* to stratify lands into homogenous sub-categories (see Chapter 3) to reduce uncertainty in estimates of greenhouse gas emissions.

The estimation of emissions and removals of carbon from land-use conversion to Forest Land is divided into three sub-sections: Change in Carbon Stocks in Biomass (Section 4.3.1), Change in Carbon Stocks in Dead Organic Matter (Section 4.3.2) and Change in Carbon Stocks in Soils (Section 4.3.3). The annual changes in carbon stocks on *Land Converted to Forest Land* are calculated using Equations 2.2 and 2.3 of Chapter 2 on the

[4] It is clear that most forest ecosystems will take longer than 100 years to return to the level of biomass, soil and litter pools in undisturbed state; however human-induced activities can enhance the rate of return to stable state of carbon stocks. With this in mind and as a practical matter, the default 20-year time interval is suggested to capture the establishment of the forest ecosystems. Countries also have the option to extend the length of the transition period, though a consistent transition period will be required for the land use matrix system of land area representation to work properly.

basis of annual changes in carbon stocks in biomass, dead organic matter (including dead wood and litter) and soil. Changes in carbon stock in *Land Converted to Forest Land* are estimated using:

- annual change in carbon stocks in above- and below-ground biomass
- annual change in carbon stocks in dead organic matter that includes dead wood and litter
- annual change in carbon stocks in soils

The approach for calculation of non-CO_2 emissions is described in Section 4.3.4 based on methods given in Chapter 2.

Application of these methods will only be possible if using Approach 2 or 3 land area representation as set out in Chapter 3, or Approach 1 data with supplementary data to enable land-use conversions to be identified. The actions to be taken in this case have already been identified in Section 4.2 above (*Forest Land Remaining Forest Land*).

4.3.1 Biomass

This section presents methodological guidance for calculation of emissions and removals of CO_2 by changes in biomass on *Land Converted to Forest Land*. It substitutes the methodology provided for reporting on "Changes in Forest and Other Woody Biomass Stocks" and "Abandonment of Managed Lands" categories of the *IPCC Guidelines* as applied to newly established forests.

4.3.1.1 CHOICE OF METHOD

This section presents methodological guidance for calculation of emissions and removals of CO_2 by changes in above-ground and below-ground biomass on *Land Converted to Forest Land*. Based on key category analysis, activity data and resources available, three tier methods are suggested to estimate changes in biomass stocks. The decision tree in Figure 1.3 in Chapter 1 illustrates *good practice* approach for choosing the method to calculate CO_2 emissions and removals in biomass on *Land Converted to Forest Land*.

Tier 1
Annual change in carbon stocks in biomass is estimated with the use of Equation 2.7 in Chapter 2. Tier 1 follows the default approach. It implies the use of default parameters provided in Section 4.5. This approach can be also applied, if the data on previous land uses are not available, which may be the case, when areas are estimated using Approach 1 from Chapter 3. It implies the use of default parameters in Tables 4.1 through 4.14.

Annual increase in carbon stocks in biomass, ΔC_G. The calculations of ΔC_G should be made according to Equation 2.9 in Chapter 2. As the growth rate of trees strongly depends on management regime, a distinction should be made between intensively (e.g., plantation forestry) and extensively (naturally re-growing stands with reduced or minimum human intervention) managed forests. The intensively and extensively managed forests can be further stratified based on climate, species, management practices, etc. Hence, the annual increase in carbon stocks can be estimated separately for intensively and extensively managed forests, using Equation 2.9 twice. First, for intensively managed forests using relevant area (A_I) and the relevant mean annual biomass growth (G_{Total}) for intensively managed forests and second, for extensively managed forests by using appropriate area (A_E) and mean annual biomass growth (G_{Total}) data for extensively managed forests. G_{TOTAL} is calculated using Equation 2.10, Chapter 2, and default data tables in Section 4.5. The intensively managed and extensively managed forests can be further stratified based on climate, species, forest management practices, etc. The default data for extensively and intensively managed forests from the tables should be chosen with regard to tree species composition and climatic region. The default data for extensively and intensively managed forests should be taken from Section 4.5, correspondingly.

Annual decrease in carbon stocks in biomass due to losses, ΔC_L. Biomass loss due to wood removal ($L_{wood\text{-}removals}$), fuelwood removal ($L_{fuelwood}$) and disturbances ($L_{disturbance}$) attributed to *Land Converted to Forest Land*, is estimated using Equation 2.11 in Chapter 2.

The loss of biomass due to wood removal ($L_{wood\text{-}removals}$) is estimated with the use of Equation 2.12, of Chapter 2, and default values of basic wood density and the data on round wood logging, biomass conversion expansion factor, below-ground biomass to above-ground biomass ratio (R) and carbon fraction of dry matter (CF), provided in Section 4.5 tables. The biomass loss due to fuelwood removal ($L_{fuelwood}$) is estimated using Equation 2.13, fuelwood collecting data and relevant $BCEF_R$ for growing stock, R and CF from default tables in Section 4.5. The ($L_{disturbance}$) could be estimated using Equation 2.14, in Chapter 2, area of disturbance, average growing stock biomass of land areas affected by disturbances and appropriate R and CF from default tables in Section 4.5.

The ΔC_L should be assumed 0, if no data on losses are available (for Equation 2.11). To prevent double accounting or omission, consistent reporting of biomass loss should be maintained in Sections 4.2.1 and 4.3.1.

Tier 2

The Tier 2 method is similar to Tier 1, but it uses nationally derived data and more disaggregated activity data and allows for more precise estimates of changes in carbon stocks in biomass. The net annual CO_2 removals are calculated as a sum of increase in biomass due to biomass growth on converted lands, changes due to actual conversion (difference between biomass stocks before and after conversion) and losses on converted lands (Equations 15 and 16, Chapter 2).

In addition to default values, the application of Tier 2 (Equation 2.15) requires national data on: i) area annually converted to forest; ii) average annual growth in carbon stocks in biomass per ha on converted lands, obtained e.g., from forest inventories (no default data can be provided); iii) change in biomass carbon when non-forest land becomes Forest Land; and iv) emissions due to loss of biomass on converted land. The approach may require data on previous land uses as well as knowledge of land-use change matrix (see Table 3.4 in Chapter 3) and carbon stocks on those lands.

$\Delta \mathbf{C_G}$ should be estimated using Equation 2.9, where the area (A) of *Land Converted to Forest Land* should be considered separately along with respective mean annual increments for intensively and extensively managed forests (further categorized based on species, climate, etc.) and summed up. Average annual increment in biomass for managed forests is calculated in accordance with Tier 2 method as in Section 4.2.1, *Forest Land Remaining Forest Land* and Equation 2.10, Chapter 2, based on country-specific data on average annual biomass growth in merchantable volume per ha on land converted to forests (obtained e.g., from forest inventories) and on basic wood density, biomass conversion and expansion factors and below-ground to above-ground biomass ratio.

$\Delta \mathbf{C_{CONVERSION}}$ accounts for the initial change in biomass stocks resulting from the land-use conversion, e.g., part of biomass may be withdrawn through land clearing, restocking or other human-induced activities applied on land prior to artificial or natural regeneration. These changes in carbon stocks in biomass are calculated with the use of Equation 2.16 in Chapter 2. This requires estimates of biomass stocks on land type *i* before (B_{BEFORE_i}) and after (B_{AFTER_i}) the conversion in tonnes d.m. ha^{-1}, area of land-use *i* converted to Forest Land ($\Delta A_{TO\_FOREST_i}$) in a certain year, and the carbon fraction of dry matter (CF).

The calculation of $\Delta C_{CONVERSION}$ may be applied separately to account for different carbon stocks occurring on specific types of land (ecosystems, site types, etc.) before the transition. The $\Delta A_{TO\_FOREST_i}$ refers to the particular inventory year for which the calculations are made.

$\Delta \mathbf{C_L}$ is estimated using Equation 2.11 in Chapter 2. Biomass loss due to wood removal ($L_{wood\text{-}removals}$), fuelwood removal ($L_{fuelwood}$), and disturbances ($L_{disturbance}$) should be estimated with the use of Equations 2.12 to 2.14, in Chapter 2. Inventory compilers are encouraged to develop country-specific wood density and BEF or BCEF values for growing stock increment and harvests to apply them in Equation 2.12 (for Tier 2 calculations). Chapter 2 describes the method for calculation of biomass losses from fuelwood gathering ($L_{fuelwood}$) and disturbances ($L_{disturbance}$). The ΔC_L should be assumed 0, if no data on losses are available. It is *good practice* to ensure consistent reporting on biomass losses between Sections 4.2.2 and 4.2.3 to avoid over- and underestimates due to double counting or omissions.

Tier 3

Tier 3 should be used when land conversion to Forest Land is a key category and leading to a significant change of carbon stocks. It can follow the same equations and steps as Tier 2 or can use more complex methods and models, but in either case, it can make use of substantial national methods and country-specific data. The Equations 2.15 and 2.16 can be expanded on the basis of finer geographical scale and sub-division to forest type, species, and land type before conversion. Country-defined methodologies may be based on regular forest inventory or geo-referenced data and (or) models for accounting for changes in biomass. National activity data can have high resolution and be available for all categories of converted lands and forest types established on them. It is *good practice* to describe and document the methodology in accordance with Volume 1, Chapter 8 (Reporting Guidance and Tables).

Transfer of biomass to dead organic matter

During the process of conversion of land to Forest Land as well as during the process of extraction of biomass through felling, the non-commercial component of the biomass is left on the forest floor or transferred to dead organic matter. Refer to Section 4.3.2 for description of the method and the assumptions about the fate of dead organic matter.

4.3.1.2 CHOICE OF EMISSION FACTORS

Annual increase in carbon stocks in biomass, ΔC_G

The calculations distinguish between two broad management practices: intensive (e.g., plantation forestry with site preparation, planting of selected species and fertilization) and extensive (natural regeneration with minimum human intervention). These categories can also be refined according to national circumstances, for example based on stand origin (e.g., natural or artificial regeneration, restocking, promotion of natural re-growth, etc.), climate, species, management practice, etc.

Tier 1

The methods for calculation of total biomass require above-ground and below-ground biomass pools (for pool descriptions, refer to Chapter 1). The tables in Section 4.5 represent default values of average annual growth in above-ground biomass for intensively (plantations) and extensively (naturally regenerated) managed forests, biomass conversion and expansion factors, below-ground biomass to above-ground biomass ratio and carbon fraction of dry matter (CF). The below-ground biomass to above-ground biomass ratio should be used to account for below-ground biomass in total biomass estimations. Basic wood density and biomass expansion factors, which allow for calculation of ΔC_G as described in Section 4.2.1 *Forest Land Remaining Forest Land*. It is *good practice* to explore any regional or otherwise relevant default values to the country.

Tier 2

It is *good practice* to determine, wherever possible, annual increment values, below-ground biomass to above-ground biomass, basic wood density, and biomass conversion and expansion factors appropriate for national conditions and use them in calculations under Tier 2. These categories can also be refined according to national circumstances, for example based on stand origin (natural or artificial regeneration, restocking, promotion of natural re-growth, etc.), climate, species composition, and management regime. The further stratifications may refer to tree species composition, management regime, stand age, climatic region and soil type, etc. Countries are encouraged to obtain specific biomass increment and expansion factors through research efforts. Additional guidance is provided in Section 4.2.1.

Tier 3

The increment in biomass carbon stocks can be estimated based on country-specific annual biomass growth and carbon fraction in biomass data that come from forest inventories, sample plots, research and (or) models. The inventory compilers should ensure that the models and forest inventory data have been appropriately documented and described in line with the requirements highlighted in Volume 1, Chapter 8.

Change in biomass stocks on land before and after conversion, $\Delta C_{CONVERSION}$

The calculations of biomass stocks before and after conversion should be made with the use of values consistent with other land uses. For example, comparable values of carbon stock should be used to estimate initial carbon stock for Grassland converted to Forest Land and for changes in biomass for *Grassland Remaining Grassland*.

Tier 1

No estimate of $\Delta C_{CONVERSION}$ is required for Tier 1 calculations.

Tier 2

It is *good practice* to obtain and use, wherever possible, country-specific data on biomass stocks on land before and after conversion. The estimates should be consistent with those used in calculations of carbon stock changes in Cropland, Grassland, Wetlands, Settlements and Other Land, and should be obtained from national agencies or surveys. Tier 2 may imply the use of a combination of country-specific and default data. For default biomass stock values on land before the conversion, refer to other sections of this Volume.

Tier 3

Estimates and calculations should be performed based on forest inventory and or model data. Forest inventory, models and data should be documented in line with procedures outlined in Volume 1, Chapter 8.

Change in carbon stocks in biomass due to losses, ΔC_L

Wood removal, fuelwood removal, and natural disturbances such as windfall, fires, and insect outbreaks result in loss of carbon on *Land Converted to Forest Land* that should be reported in accordance with *good practice* approach provided in Section 4.2.1. The *good practice* approach provided in Section 4.2.1 for estimating losses of carbon is fully applicable and should be used for appropriate calculations under Section 4.2.2. If changes in carbon stocks are derived from regular forest inventories, the losses from wood removal and disturbances will be covered without a need to report on them separately. It is *good practice* to ensure consistent reporting on losses of biomass between Sections 4.2.1 and 4.2.2 to avoid double counting or omissions.

The data on logging of round wood should be taken from national sources or FAO. It should be noted that FAO data on logging is in merchantable round wood over bark. Bark fraction in harvested wood (BF) should be applied to account for bark in wood removals with harvest. If logging is significant in the country, the inventory compilers are encouraged to use national harvest data or derive country-specific BF values.

In most countries, information on area disturbed is not likely to be available by the two sub-categories, *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* sub-categories. Given that the latter is, in most cases, much smaller than the former, all disturbances can be applied to *Forest Land Remaining Forest Land*, or the disturbed area can be pro-rated in proportion to the two land sub-categories.

Fuelwood consumption data are not normally reported separately for *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. Then it is likely that the default fuelwood data is likely to be reported in *Forest Land Remaining Forest Land*. The reporting of fuelwood should be cross-checked between the two land sub-categories to avoid double counting by checking with reporting of fuelwood in *Forest Land Remaining Forest Land*.

4.3.1.3 CHOICE OF ACTIVITY DATA

Area of land converted to forest, ΔA_{TO_FOREST}

All tiers require information on areas converted to Forest Land over the 20 years prior to the inventory year. After 20 years or other time interval chosen, the lands converted to Forest Land, as defined in the country, should be transferred to and accounted for under Section 4.2 (*Forest Land Remaining Forest Land*). The same area data should be used for Sections 4.3.2 (Change in Carbon Stocks in Dead Organic Matter), Section 4.3.3 (Change in Carbon Stocks in Soils), and Section 4.3.4 (Non-CO_2 Greenhouse Gas Emissions). If possible, these areas should be further disaggregated to take into consideration major soil types and biomass densities on land before and after conversion. Box 4.3 gives examples of a *good practice* approach in identification of lands converted to Forest Land. Subject to national data availability, the inventory compilers can also choose *good practice* approach on the basis of approaches provided in Chapter 3.

Different biomass growth rates should be used for calculations of biomass stocks for forests naturally re-growing on abandoned lands and for forest plantations. To undertake calculations under Tiers 2 and 3, inventory compilers are encouraged to obtain information on types of previous land uses for lands converted to Forest Land.

Tier 1

Activity data can be obtained through national statistics, from forestry agencies (information on areas of different management practices), conservation agencies (naturally regenerated areas), municipalities, survey and mapping agencies. Expert judgment may be used to assess whether new forests are predominantly intensively or extensively managed, if no recorded data are available. If the data on intensively and extensively managed areas of forests become available, these should be used for further partitioning areas to obtain more accurate estimates. Cross-checks should be applied to ensure complete and consistent representation of data to avoid omissions or double counting. If no country data are available, aggregate information can be obtained from international data sources (FAO, 2001; TBFRA, 2000).

Tier 2

Areas under different land uses subjected to conversion during a given year or over a period of years should be available. They can come from national data sources and a land-use change matrix or its equivalent that covers all possible transitions to Forest Land. Country-defined national data sets should have a resolution sufficient to ensure appropriate representation of land areas in line with provisions of Chapter 3 of this Volume. It is important to estimate area converted to forest through natural regeneration and plantation approach.

Tier 3

National activity data on land conversion to Forest Land through natural and artificial regeneration should be available from different sources, notably national forest inventories, registers of land use and land-use changes and remote sensing, as described in Chapter 3 of this Volume. These data should give a full accounting of all land-use transitions to Forest Land and can be further disaggregated along climate, soil, and vegetation types. Area under plantations is usually available according to species and age of the stand.

BOX 4.3
EXAMPLES OF *GOOD PRACTICE* APPROACH IN IDENTIFICATION OF LANDS CONVERTED TO FOREST LAND

National land management systems can allow for identification of land-use changes, and the land census systems implemented in many countries also enables consistent representation and timely tracking changes in land use. The national inventory compilers should take the data from land management systems or censuses and use them as the basis for identification of converted lands. The land conversion data may be obtained directly from companies, private owners, ministries and agencies, which undertake particular activities over converted lands.

In some countries, special accounting systems have been designed to estimate emissions and removals over converted lands. The Australia National Carbon Accounting System (NCAS) <http://www.greenhouse.gov.au/> is an example of a *good practice* approach in identification of land conversion. The NCAS is a sophisticated model-based tool that comprises data from resource census, field studies, and remote sensing. It operates at high spatial and temporal scales. The NCAS addresses all sectors of activity in land systems, including carbon pools and all greenhouse gases as affected by human-induced activities. It allows for tracking afforestation and reforestation activities within the territory of the country along with estimating emissions and removals relevant to them. As soon as the new data enter the NCAS, the inventory data are updated continuously. Design and implementation of the NCAS and its components has been subjected to extensive peer review and Quality Assurance/Quality Control regime (AGO, 2002).

Similar systems are being developed in New Zealand (Stephens *et al.,* 2005; Trotter *et al.,* 2005), Canada (Kurz and Apps, 2006), and other countries. The use of such land management systems contributes to development of high quality inventories and reduces the levels of uncertainty within the sector.

4.3.1.4 CALCULATION STEPS FOR TIER 1

The following summarizes steps for estimating change in carbon stocks in biomass (ΔC_B) using the default methods

Step 1: Estimate area converted to Forest Land (during the period 20 years before the year of the inventory) from other land-use categories such as Cropland, Grassland, and Settlements. Refer to Chapter 3 for detailed approaches for estimating *Land Converted to Forest Land*.

Step 2: Disaggregate the area converted to Forest Land according to intensively managed forest (through plantation forestry) and extensively managed forest (through natural regeneration) based on the approach used for conversion.

Step 3: Calculate the initial biomass loss associated with the land conversion, $\Delta C_{CONVERSION}$ (Equation 2.16). This can be stratified by land conversion methods.

Step 4: Estimate the annual increase in carbon stocks in biomass due to growth on *Land Converted to Forest Land* (ΔC_G), for intensively managed forests at species and other sub-category level, using Equations 2.9 and 2.10 in Chapter 2. Estimate annual increment of biomass at species and other sub-category level.

Step 5: Estimate the annual increase in carbon stocks in biomass growing on *Land Converted to Forest Land* (ΔC_G), for extensively managed forests at species and other sub-category level, using Equations 2.9 and 2.10 in Chapter 2.

Step 6: Estimate annual loss or decrease in biomass ($L_{wood\text{-}removals}$) due to commercial fellings (industrial wood and sawn logs) using Equation 2.12 in Chapter 2.

Step 7: Estimate biomass loss due to fuelwood removal ($L_{fuelwood}$) on *Land Converted to Forest Land* using Equation 2.13 in Chapter 2.

Step 8: Estimate annual carbon loss due to disturbance or other losses ($L_{disturbance}$) using Equation 2.14 in Chapter 2.

Step 9: Estimate the total loss of biomass carbon due to wood removal, fuelwood removal, and disturbance (ΔC_L) using Equation 2.11 in Chapter 2.

Step 10: Estimate the annual change in carbon stock in biomass (ΔC_B) on *Land Converted to Forest Land* using Equation 2.15 in Chapter 2.

Example. The following example shows Gain-Loss method (Tier 1) calculations of annual change in carbon stocks in biomass (ΔC_B in Equation 2.7, Chapter 2) for a hypothetical country in temperate continental forest zone of Europe (Table 4.1, Section 4.5). The area of non-forest land converted to Forest Land (A) within the country is 1,000 ha (see Chapter 3 for area categorization). The new forest is intensively managed 9-year-old pine plantation, average above-ground growing stock volume is 10 m^3 ha^{-1}. Thinning removed 100 m^3 yr^{-1} of merchantable round wood over bark (H); 50 m^3 yr^{-1} of whole trees (FG_{trees}) were removed as fuel wood. The area of insect disturbance ($A_{disturbance}$) is 50 ha yr^{-1} with 1.0 tonne d.m. ha^{-1} of above-ground biomass affected (B_W).

Annual gain in biomass (ΔC_G) is a product of mean annual biomass increment (G_{TOTAL}), area of land converted to Forest Land (A) and carbon fraction of dry matter (CF), Equation 2.9, Chapter 2.

G_{TOTAL} is calculated using annual above-ground biomass increment (G_W), below-ground biomass to above-ground biomass ratio (R), (Equation 2.10, Chapter 2) and default data tables, Section 4.5.

For the hypothetical country,

G_W = 4.0 tonnes d.m. ha^{-1} yr^{-1} (Table 4.12); and

R = 0.40 tonne d.m. (tonne d.m.)$^{-1}$ for above-ground biomass <50 t ha^{-1} (Table 4.4, with reference to Table 4.8 for above-ground biomass).

G_{TOTAL} = 4.0 tonnes d.m. ha^{-1} yr^{-1} ● (1 + 0.40) = 5.6 tonnes d.m. ha^{-1} yr^{-1} (Equation 2.10)

CF = 0.47 tonne C (tonne d.m.)$^{-1}$ (Table 4.3)

ΔC_G (Equation 2.9): = 1,000 ha ● 5.6 tonnes d.m. ha^{-1} yr^{-1} ● 0.47 tonne C (tonne d.m.)$^{-1}$

= 2,632 tonnes C yr^{-1}

Biomass loss (ΔC_L) is a sum of annual loss due to wood removals ($L_{wood-removals}$), fuelwood removal ($L_{fuelwood}$) and disturbances ($L_{disturbance}$), Equation 2.11, Chapter 2.

Wood removals ($L_{wood-removals}$) is calculated using Equation 2.12 in Chapter 2 with merchantable round wood over bark (H), biomass conversion expansion factor ($BCEF_R$), bark fraction in harvested wood (BF), below-ground biomass to above-ground biomass ratio (R), carbon fraction of dry matter (CF), and default tables in Section 4.5. For the hypothetical country,

$BCEF_R$ = 2.0 tonnes d.m. m^{-3} (Table 4.5, with reference to volume of growing stock 10 m^3 ha^{-1});

Default BEF = 0.1 tonne d.m. (tonne d.m.)$^{-1}$;

R = 0.40 tonne d.m. (tonne d.m.)$^{-1}$ for above-ground biomass <50 t ha^{-1} (Table 4.4, for above-ground biomass refer to Table 4.8); and

CF = 0.47 tonne C (tonne d.m.)$^{-1}$ (Table 4.3).

$L_{wood-removals}$ = 100 m^3 yr^{-1} ● 2 tonnes d.m. m^{-3} (1 + 0.40 + 0.1) ● 0.47 tonne C (tonne d.m.)$^{-1}$

= 141 tonnes C yr^{-1} (Equation 2.12)

Fuelwood removal ($L_{fuelwood}$) is calculated using Equation 2.13, Chapter 2 with wood removals as whole trees (FG_{trees}), biomass conversion expansion factor ($BCEF_R$), below-ground biomass to above-ground biomass ratio (R), carbon fraction of dry matter (CF), and default tables in Section 4.5. For the hypothetical country,

$BCEF_R$ = 2.0 tonnes d.m. m^{-3} (Table 4.5, with reference to growing stock volume 10 m^3 ha^{-1});

R = 0.40 tonne d.m. (tonne d.m.)$^{-1}$ for above-ground biomass <50 t ha^{-1} (Table 4.4, with reference to Table 4.8 for above-ground biomass); and

CF = 0.47 tonne C (tonne d.m.)$^{-1}$ (Table 4.3).

$L_{fuelwood}$ = 50 m^3 yr^{-1} ● 2.0 tonnes d.m. m^{-3} (1 + 0.40) ● 0.47 tonne C (tonne d.m.)$^{-1}$

= 65.80 tonnes C yr^{-1} (Equation 2.13)

Annual carbon loss in biomass due to disturbances ($L_{disturbance}$) is calculated using Equation 2.14, Chapter 2 with area of disturbances ($A_{disturbance}$), average above-ground biomass affected (B_W), below-ground biomass to above-ground biomass ratio (R), carbon fraction of dry matter (CF), fraction of biomass lost in disturbance (fd), and default tables in Section 4.5. For the hypothetical country,

fd = 0.3;

R = 0.40 tonne d.m. (tonne d.m.)$^{-1}$ for above-ground biomass <50 t ha^{-1} (Table 4.4, with reference to Table 4.8 for above-ground biomass); and

CF = 0.47 tonne C (tonne d.m.)$^{-1}$ (Table 4.3).

$L_{disturbance}$ = 50 ha yr^{-1} ● 1.0 tonne d.m. ha^{-1} (1 + 0.40) ● 0.47 tonne C (tonne d.m.)$^{-1}$ ● 0.3
= 9.87 tonnes C yr^{-1} (Equation 2.14)

Annual decrease in carbon stocks due to biomass losses (ΔC_L),

ΔC_L = 141.00 tonnes C yr^{-1} + 65.80 tonnes C yr^{-1} + 9.87 tonnes C yr^{-1}
= 216.67 tonnes C yr^{-1} (Equation 2.11)

Annual change in carbon stocks in biomass (ΔC_B)

Using Chapter 2, Equation 2.7 ($\Delta C_B = (\Delta C_G - \Delta C_L)$),

ΔC_B = 2,632 tonnes C yr^{-1} – 216.67 tonnes C yr^{-1} = 2,415.33 tonnes C yr^{-1} (Equation 2.7)

4.3.1.5 UNCERTAINTY ASSESSMENT

The emission factors required for estimating carbon stock changes for *Land Converted to Forest Land* are nearly identical to those required for *Forest Land Remaining Forest Land*, but refer to lands converted to forests within 20 years of the inventory year (default period of conversion). The discussion on uncertainty for *Forest Land Remaining Forest Land* also applies here. The uncertainty involved in the estimation of biomass stocks on land before and after conversion is likely to be high. This uncertainty can be reduced by conducting sample field studies in dominant land-use categories subjected to conversion to Forest Land. The uncertainty is likely to be low for the wood removal (industrial round wood), since national statistics are likely to be maintained on commercial harvests, although sometimes it may be difficult to separate commercial harvests due to deforestation from those that come from *Forest Land Remaining Forest Land*. However, the uncertainty is likely to be high for fuelwood removal and gathering and biomass loss due to disturbance. The uncertainty involved for commercial and traditional methods should be reduced by conducting sample surveys in different socio-economic and climatic regions.

The critical activity data required for estimating carbon stock changes include the area of land converted and loss rates of biomass during the initial conversion and thereafter. The level of uncertainty for area under intensive and extensive plantations is likely to be low since most countries maintain records of the area afforested and reforested. The uncertainty should be reduced by developing a land-use change matrix of *Forest Land Remaining Forest Land* and for different categories of *Land Converted to Forest Land*, based on remote sensing or other monitoring techniques. A combination of remote sensing and ground surveys could have an uncertainty as low as 10-15%.

4.3.2 Dead organic matter

In this section, changes in carbon stock in dead organic matter pools are discussed for the land-use category *Land Converted to Forest Land*. Cropland, Grassland, Settlements, and other land-use categories can be potentially converted to Forest Land through planting or natural regeneration. It is likely that most non-forest land will not have significant dead wood or litter carbon pools. Accordingly, the Tier 1 assumption is that carbon stocks in dead wood and litter pools in non-forest land are zero, and that carbon in dead organic matter pools increases linearly to the value of mature forests over a specified time period (default = 20 years). The Tier 1 assumption for the conversion of unmanaged to managed Forest Land is that the dead organic matter carbon stocks in unmanaged forests are similar to those of managed forests and that no carbon stock changes need to be reported. In reality, other things being equal, dead organic matter carbon stocks in unmanaged forests are higher than those in managed forests because harvest removes woody biomass that would otherwise contribute to long-term dynamics of DOM pools (Kurz *et al.*, 1998) and it is *good practice* that countries with high rates of conversion of unmanaged to managed forests use higher Tier methods to estimate the resulting changes in DOM carbon stocks.

Methods to estimate emissions and removals of carbon in dead organic matter pools following conversion of land to Forest Land require estimates of the carbon stocks just prior to and just following the conversion, and estimates of the areas of lands converted during the inventory period. Some of the non-forest land-use categories, such as Wetlands, Settlements, Cropland and Grassland can have significant carbon stock in the DOM pools. It is *good practice* to assess whether the assumption of zero DOM pool sizes is justified for lands converted to Forest Land. Higher Tier methods can specify the initial DOM pool sizes (e.g., in some land-use categories dead wood and litter pools are non-zero) and quantify the length of the transition period (default = 20 years) during which DOM pools are changing as a result of a transition to Forest Land.

4.3.2.1 CHOICE OF METHOD

The general methods for estimating changes in carbon stock in dead organic matter pools have been described in Chapter 2, Section 2.3.2. The decision tree in Figure 1.3 in Chapter 1 provides guidance in the selection of the appropriate tier level for the implementation of estimation procedures. Dead wood and litter carbon stock estimates often differ significantly depending on previous land use, forest type, and regeneration type.

Tier 1

For *Land Converted to Forest Land*, the Tier 1 assumption is that dead wood and litter pools increase linearly from zero (in the non-forest land-use category) to the default values for the climate region over a period of T years (the current default is 20 years for both litter and dead wood carbon pools). Human activities such as fuelwood collection and some silvicultural practices such as frequent thinnings can greatly affect the rate of carbon accumulation in dead wood and litter pools. It is *good practice* to assess whether the default pool sizes and the assumed transitions periods are reasonable given a country's climatic and management regimes. The 20-year default period is appropriate for litter pools but likely too short for dead wood pools, particularly in colder regions with slow growing vegetation. If the time required to accumulate DOM pools is longer than the default period, then the Tier 1 assumptions may overestimate the rates of carbon accumulation. Where the area involved in land-use conversion to forests is large, it is *good practice* to develop national estimates of the rates of litter and dead wood carbon accumulation in lands converted to Forest Land.

Tiers 2 and 3

Changes in carbon stock in dead wood and litter pools under a Tier 2 or Tier 3 can be estimated using the two methods outlined in Chapter 2 (Equations 2.18 and 2.19 in Chapter 2). It is *good practice* to stratify areas converted to Forest Land according to the prior land use, the methods used during the conversion (e.g., site preparation, treatment of residual biomass), and the productivity and characteristics of the forest that is regrowing. All of these factors influence the magnitude and rate of change of carbon stock in the DOM pools on *Land Converted to Forest Land*.

Countries using higher Tier methods are also encouraged to select more appropriate transition periods for litter and dead wood carbon stocks. Litter pools can stabilize relatively quickly as inputs balance outputs. Dead wood pools generally require much longer transition periods from non-forest to forest conditions. Moreover, both litter and dead wood carbon stock sizes are affected by many factors and countries using higher Tiers are encouraged to select DOM stock values at maturity that adequately reflect national circumstances. Countries using Tier 3 modeling approaches will obtain estimates of dead organic matter stocks based on the simulated balance of input and losses.

4.3.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

Countries using a Tier 1 method require data on the default dead wood and litter carbon stocks in the six land-use categories in different climatic regions, as defined in Table 3.1, Chapter 3. The Tier 1 assumption is that carbon stocks in litter and dead wood pools in all non-forest land-use categories are zero. For lands converted to Forest Land, the carbon stocks in dead wood and litter pools are assumed to increase linearly over the transition period T (default is 20 years for both litter and dead wood C stocks). Thus, the annual rate of increase is estimated as the ratio between the difference in carbon stocks in the DOM pools in the non-forest and forest categories, and the number of years in the transition period T.

Tiers 2 and 3

The higher Tier methods described in Chapter 4, Section 4.2 *Forest Land Remaining Forest Land* are equally applicable to *Land Converted to Forest Land*. Additional emission and removal factors are required where the impacts of the land-use conversion practices (e.g., site preparation and slash burning) are to be estimated. Additional requirements may arise if the assumption that carbon stocks in dead wood and litter pools of non-forest land-use categories are zero cannot be justified, such as in some agro-forestry systems, in settlements with substantial forest cover, and in other circumstances. This may pose special challenges because forest inventories typically do not include such areas and other data sources need to be identified or measurement programs implemented.

4.3.2.3 CHOICE OF ACTIVITY DATA

The Tier 1 method requires activity data on the annual rate of conversion to Forest Land. Activity data should be consistent with those used for estimating changes in carbon stock in biomass on *Land Converted to Forest Land*, according to the general principles set out in Chapter 3. Activity data can be obtained from national statistics, from forest management agencies, conservation agencies, municipalities, survey and mapping agencies. Where reporting programs are used, it is *good practice* to implement verification procedures and cross-checks to ensure complete and consistent representation of *Land Converted to Forest Land*, to avoid omissions or double counting. Data should be disaggregated according to the general climatic categories and forest types.

Inventories using higher Tiers will require more comprehensive information on the establishment of new forests, with refined soil classes, climate, and spatial and temporal resolution.

All changes in dead organic matter pools occurring over the number of years (T) selected as the transition period should be included. Lands where the transitions occurred more than T years ago are transferred to and reported under the category *Forest Land Remaining Forest Land*.

4.3.2.4 CALCULATION STEPS FOR TIER 1

The following summarizes steps for estimating change in carbon stocks in dead organic matter using the default methods

Step 1: Estimate area converted to Forest Land (during the period 20 years prior to the year of inventory) from other land-use categories such as Cropland, Grassland and Settlements. Refer to Chapter 3 for detailed approaches for estimating *Land Converted to Forest Land*.

Step 2: The Tier 1 assumption is that dead organic matter (dead wood and litter) carbon stocks on non-forest land are zero. If national data on dead wood and litter carbon stocks in non-forest land are available, disaggregate the area converted to Forest Land according to the land-use category of origin, e.g., Grassland, Cropland, etc., using the same categories for which dead organic matter estimates are available. Default values for litter carbon stocks in Forest Land are provided in Table 2.2. Statistically valid, regional default estimates for dead wood carbon stocks in forests are not available.

Step 3: Estimate the average annual increment of dead organic matter stocks, separately for dead wood and litter, by dividing the difference in pre- and post-conversion carbon stocks by the time period of transition (Equation 2.23 in Chapter 2). The default Tier 1 assumption is that non-forest dead organic matter carbon stocks are zero and that the period of transition is 20 years.

Step 4: Estimate the annual change in carbon stock in dead organic matter on *Land Converted to Forest Land* by multiplying the average annual increment (Step 3) by the area of lands converted to Forest Land over the past 20 (default) years.

4.3.2.5 UNCERTAINTY ASSESSMENT

In general, the magnitude of uncertainty in dead organic matter pools is larger than the uncertainty in biomass estimates because much less data are typically available for DOM pools compared to biomass pools. Uncertainties in area estimates made using the approaches suggested in Chapter 3 are indicated in Table 3.7 and uncertainties in assessing dead organic matter carbon stock changes may be several times larger than the uncertainty of biomass stock change estimates using default coefficients.

Although relatively few estimates of uncertainty, in changes in carbon stock in DOM pools, are available in the literature or elsewhere, several sources of uncertainty can be identified for the estimates of changes in carbon stock in dead organic matter pools on *Land Converted to Forest Land*. First, the assumption that carbon stocks in DOM are zero in non-forest land is not always justified. Underestimating the true initial DOM stock size will lead to overestimates of the true accumulation rates. Second, the default values for litter and dead wood carbon stock sizes are likely to be biased by being based upon estimates from land that was Forest Land for a long period of time. Thus the stock sizes at the end of the transition period may be overestimated, again, leading to overestimates of the accumulation rates. Third, the default transition period may be too long for litter carbon stocks, leading to underestimates of the true accumulation rates. For the dead wood pool, however, the current default assumption of a 20-year transition period is likely to be too short. Thus, the rate of carbon accumulation in the dead wood pool may be overestimated.

4.3.3 Soil carbon

Land conversions on mineral soils generally either maintain similar levels of C storage or create conditions that increase soil C stocks, particularly if the land was previously managed for annual crop production (Post and Kwon, 2000). However, under certain circumstances, Grassland conversion to Forest Land has been shown to cause small C losses in mineral soils for several decades following conversion (Davis and Condron, 2002; Paul *et al.*, 2002). Emissions of C from organic soils will vary depending on the previous use and level of drainage. Specifically, conversion from Cropland will tend to decrease emissions; conversions from Grassland will likely maintain similar emission rates; while conversion from Wetlands often increases C emissions.

General information and guidelines on estimating changes soil C stocks are found in Section 2.3.3 in Chapter 2 (including equations), and need to be read before proceeding with guidelines dealing with forest soil C stocks. The total change in soil C stocks for *Land Converted to Forest Land* is computed using Equation 2.24 (Chapter 2), which combines the change in soil organic C stocks for mineral soils and organic soils; and carbon stock changes for inorganic soil C pools (Tier 3 only). This section provides specific guidance for estimating soil organic C stock changes; see Section 2.3.3.1 (Chapter 2) for general discussion on soil inorganic C (no additional information is provided in the Forest Land discussion below).

To account for changes in soil C stocks associated with *Land Converted to Forest Land*, countries need to have, at a minimum, estimates of the areas of *Land Converted to Forest Land* during the inventory time period, stratified by climate region and soil type. If land-use and management data are limited, Approach 1 activity data can be used as a starting point, along with knowledge of country experts of the approximate distribution of land-use types being converted. If previous lands uses and conversions for *Land Converted to Forest Land* are unknown, SOC stocks changes can still be computed using the methods provided in *Forest Land Remaining Forest Land*, but the land base will likely be different for forests in the current year relative to the initial year in the inventory. It is critical, however, that the total land area across all land-use sectors be equal over the inventory time period (e.g., if 5 Million ha is converted from Cropland and Grassland to Forest Land during the inventory time period, then Forest Land will have an additional 5 Million ha in the last year of the inventory, while Cropland and Grassland will have a corresponding loss of 5 Million ha in the last year), and the total change will be estimated when summing SOC stocks across all land uses. *Land Converted to Forest Land* is stratified according to climate regions and major soil types, which could either be based on default or country-specific classifications. This can be accomplished with overlays of climate and soil maps, coupled with spatially-explicit data on the location of land conversions.

Inventories can be developed using Tier 1, 2 or 3 approaches, with each successive Tier requiring more detail and resources than the previous. It is possible that countries will use different tiers to prepare estimates for the separate components in this source category (i.e., soil organic C stocks changes in mineral soils and organic soils; and stock changes associated with soil inorganic C pools).

4.3.3.1 CHOICE OF METHOD

Inventories can be developed using Tier 1, 2 or 3 approaches and countries may choose different tiers for mineral and organic soils. Decision trees are provided for mineral (Figure 2.4) and organic soils (Figure 2.5) in Section 2.3.3.1 (Chapter 2) to assist inventory compilers with selection of the appropriate tier for their soil C inventory.

Mineral soils

Tier 1

Change in soil organic C stocks can be estimated for mineral soils with land-use conversion to Forest Land using Equation 2.25 (Chapter 2). For Tier 1, the initial (pre-conversion) soil organic C stock ($SOC_{(0-T)}$) and C stock in the last year of the inventory time period (SOC_0) are determined from the common set of reference soil organic C stocks (SOC_{REF}) and default stock change factors (F_{LU}, F_{MG}, F_I) as appropriate for describing land use and management both pre- and post-conversion. Note that area of exposed bedrock in Forest Land or the previous land use are not included in the soil C stock calculation (assume a stock of 0). Annual rates of stock changes are calculated as the difference in stocks (over time) divided by the time dependence (D) of the stock change factors (default is 20 years).

Tier 2

The Tier 2 approach for mineral soils also uses Equation 2.25 (Chapter 2), but involves country or region-specific reference C stocks and/or stock change factors and possibly more disaggregated land-use activity and environmental data.

Tier 3

Tier 3 approaches will involve more detailed and country-specific models and/or measurement-based approaches along with highly disaggregated land-use and management data. It is *good practice* that Tier 3 approaches estimating soil C change from land-use conversions to Forest Land, employ models, monitoring networks and/or data sets that are capable of representing transitions over time from other land uses, including Grassland, Cropland, and possibly Settlements or other land uses. It is important that models be evaluated with independent observations from country or region-specific field locations that are representative of the interactions of climate, soil and forest type/management on post-conversion change in soil C stocks.

Organic soils

Tier 1 and Tier 2

Land Converted to Forest Land on organic soils within the inventory time period is treated the same as *Forest Land Remaining Forest Land* on organic soils. C losses for the newly converted Forest Land are computed using Equation 2.26 (Chapter 2) if the soils are drained. Additional guidance on the Tiers 1 and 2 approaches are given in Section 4.3.3.1.

Tier 3

Similar to mineral soils, a Tier 3 approach will involve country-specific models and/or measurement-based approaches along with highly disaggregated land-use and management data (see mineral soils above for additional discussion).

4.3.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTORS

Mineral soils

Tier 1

For native unmanaged land, as well as for managed Forest Land, Settlements and nominally managed Grassland with low disturbance regimes, soil C stocks are assumed equal to the reference values (i.e., land use, disturbance (forests only), management and input factors equal 1), but it will be necessary to apply the appropriate stock change factors to represent other systems which may be converted to Forest Land, such as improved and degraded Grassland, as well as all Cropland systems. See the appropriate land-use section for default stock change factors (Forest Land in 4.2.3.2, Cropland in Section 5.2.3.2, Grassland in 6.2.3.2, Settlements in 8.2.3.2, and Other Land in 9.3.3.2). Default reference C stocks are found in Table 2.3 (Chapter 2).

Tier 2

Estimation of country-specific stock change factors is probably the most important development associated with the Tier 2 approach. Differences in soil organic C stocks among land uses are computed relative to a reference condition. If default reference C stocks are used, the reference condition is native vegetation that is neither degraded nor improved through land-use and management practices. Stock change factors for land-use conversion to native forests will be equal to 1 if the forest represents the reference condition. However, stock change factors will need to be derived for *Land Converted to Forest Land* that do not represent the reference condition, accounting for the influence of disturbance (F_D), input (F_I) and management (F_{MG}), which are then used to further refine the C stocks of the new forest system. See the appropriate section for specific information regarding the derivation of stock change factors for other land-use sectors (Cropland in 5.2.3.2, Grassland in Section 6.2.3.2, Settlements in 8.2.3.2, and Other Land in 9.3.3.2).

Reference C stocks can also be derived from country-specific data in a Tier 2 approach. However, reference values should be consistent across the land uses (i.e., Forest Land, Cropland, Grassland, Settlements, Other Land), and thus must be coordinated among the various teams conducting soil C inventories for AFOLU.

Tier 3

Constant stock change rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Section 2.3.3.1 (Chapter 2) for further discussion.

Organic soils

Tier 1 and Tier 2

Land Converted to Forest Land on organic soils within the inventory time period is treated the same as *Forest Land Remaining Forest Land* on organic soils, i.e., they have a constant emission factor applied to them, based on climate regime. Tier 1 emission factors are given in Table 4.6 (Section 4.5), while Tier 2 emission factors are derived from country or region-specific data.

Tier 3
Constant emission rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Section 2.3.3.1 in Chapter 2 for further discussion.

4.3.3.3 CHOICE OF ACTIVITY DATA

Mineral soils

Tier 1 and Tier 2
For purposes of estimating soil carbon stock change, area estimates of *Land Converted to Forest Land* should be stratified according to major climate regions and soil types. This can be based on overlays with suitable climate and soil maps and spatially-explicit data of the location of land conversions. Detailed descriptions of the default climate and soil classification schemes are provided in Chapter 3. Specific information is provided in the each of the land-use sections regarding treatment of land-use/management activity data (Forest Land in Section 4.2.3.3, Cropland in 5.2.3.3, Grassland in 6.2.3.3, Settlements in 8.2.3.3, and Other Land in 9.3.3.3).

One critical issue in evaluating the impact of *Land Converted to Forest Land* on soil organic C stocks is the type of land-use and management activity data. Activity data gathered using Approach 2 or 3 (see Chapter 3 for discussion about Approaches) provide the underlying basis for determining the previous land use for *Land Converted to Forest Land*. In contrast, aggregate data (Approach 1, Chapter 3) only provide the total amount of area in each land use and do not form a basis for determining specific transitions. Therefore, the previous land use before conversion to Forest Land will be unknown. This is not problematic using Tier 1 or 2 methods because the calculation is not dynamic and assumes a step change from one equilibrium state to another. With aggregate data (Approach 1), changes in soil organic C stocks may be computed separately for each land-use sector and then combined to obtain the total stock change. Some of the stock changes will result from less or more land area in a particular sector, but such changes in the land base will be counter-balanced by a concomitant increase or decrease in land area for another sector. Using this approach, it will be necessary for coordination among each sector to ensure the total land base is remaining constant over time, given that some land area will be lost and gained within individual sectors during each inventory year due to land-use change.

Tier 3
For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed data on the combinations of climate, soil, topographic and management data are needed, relative to Tier 1 or 2 method, but the exact requirements will be dependent on the model or measurement design.

Organic soils

Tier 1 and Tier 2
Land Converted to Forest Land on organic soils within the inventory time period is treated the same as *Forest Land Remaining Forest Land* on organic soils; see Section 4.2.3.3.

Tier 3
Similar to mineral soils, Tier 3 approaches will likely require more detailed data on the combinations of climate, soil, topographic and management data, relative to Tier 1 or 2 methods, but the exact requirements will be dependent on the model or measurement design.

4.3.3.4 CALCULATION STEPS FOR TIER 1

Mineral soils
The steps for estimating SOC_0 and $SOC_{(0-T)}$ and net soil C stock change per ha of *Land Converted to Forest Land* are as follows:

Step 1: Determine the land-use and management by mineral soil types and climate regions for land at the beginning of the inventory period, which can vary depending on the time step of the activity data (0-T; e.g., 5, 10 or 20 years ago).

Step 2: Select the native reference C stock value (SOC_{REF}), based on climate and soil type from Table 2.3, for each area of land being inventoried. The reference C stocks are the same for all land-use categories to ensure that erroneous changes in the C stocks are not computed due to differences in reference stock values among sectors.

Step 3: Select the land-use factor (F_{LU}), management factor (F_{MG}) and C input levels (F_I) representing the land-use and management system present before conversion to forest. Values for F_{LU}, F_{MG} and F_I are given in the respective section for the land-use sector (Cropland in Chapter 5, and Grassland in Chapter 6).

Step 4: Multiply these values by the reference soil C stock to estimate of 'initial' soil organic C stock ($SOC_{(0-T)}$) for the inventory time period.

Step 5: Estimate SOC_0 by repeating step 1 to 4 using the same native reference C stock (SOC_{REF}), but with land-use, management and input factors that represent conditions in the last (year 0) inventory year. For Tier 1, all stock change factors are assumed equal to 1 for Forest Land (although for Tier 2, different values for these factors under newly converted Forest Land should be used, based on country-specific data).

Step 6: Estimate the average annual change in soil C stock for the area over the inventory time period, $\Delta C_{CC_{Mineral}}$, (see Equation 2.25 in Chapter 2).

Step 7: Repeat Steps 1 to 6 if there are additional inventory time periods (e.g., 1990 to 2000, 2001 to 2010, etc.).

A numerical example is given below for afforestation of cropland soil.

Example: An area of 100,000 ha of cropland was planted to forest. The soil type is an Ultisol in a tropical moist climate, which has a native reference stock, SOC_{Ref} (0-30 cm), of 47 tonnes C ha^{-1} (Table 2.3). The previous land use was annual row crops, with conventional tillage, no fertilization and where crop residues are removed, so that the soil carbon stock at the beginning of the inventory time period (in this example, 5 yrs earlier in 1995) was ($SOC_{Ref} \bullet F_{LU} \bullet F_{MG} \bullet F_I$) = 47 tonnes C ha^{-1} ● 0.48 ● 1 ● 0.92 = 20.8 tonnes C ha^{-1} (see Table 5.5, Chapter 5, for stock change factor for cropland). Under Tier 1, managed forest is assumed to have the same soil C stock as the reference condition (i.e. all stock change factors are equal to 1). Thus, the average annual change in soil C stock for the area over the inventory time period is estimated as (47 tonnes C ha^{-1} – 20.8 tonnes C ha^{-1}) / 20 yrs = 1.3 tonnes C ha^{-1} yr^{-1}. For the area reforested there is an increase of 131,000 tonnes C yr^{-1}. (Note: 20 years is the time dependence of the stock change factor, i.e., factor represents annual rate of change over 20 years)

Organic soils

Calculation steps are the same as described in Section 4.2.3.4 above.

4.3.3.5 UNCERTAINTY ASSESSMENT

Uncertainty analyses for *Land Converted to Forest Land* are fundamentally the same as *Forest Land Remaining Forest Land*. Three broad sources of uncertainty exists: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in reference soil C stocks if using Tier 1 or 2 approaches (mineral soils only); and 3) uncertainties in the stock change/emission factors for Tier 1 or 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with a Tier 3 measurement-based inventories. See the uncertainty section in *Forest Land Remaining Forest Land* for additional discussion (Section 4.2.3.5).

4.3.4 Non-CO_2 greenhouse gas emissions from biomass burning

The guidance to estimate non-CO_2 greenhouse gas emissions from biomass burning or fire on *Land Converted to Forest Land* is discussed in Section 4.2.4. General guidance is also provided in Chapter 2, Section 2.4.

Guidance for estimating N_2O emissions from forest soils is provided in Chapter 11.

4.4 COMPLETENESS, TIME SERIES, QA/QC, AND REPORTING AND DOCUMENTATION

4.4.1 Completeness

Completeness is a requirement for greenhouse gas inventories, and it is *good practice* to address all forest carbon gains and losses including harvested wood products. Greenhouse gas inventory for Forest Land should include all land under Forest Land and all land-use categories converted to Forest Land. For completeness, it is *good practice* to include all the carbon pools and non-CO_2 greenhouse gases. Chapter 11, Section 11.2 provides advice on N_2O emission from drained organic soils. The forest area used for calculation for different carbon pools should be the same. Emissions from organic soils and emissions or removals attributed to land-use change on mineral soils should be estimated. Higher tiers include additional impacts of management and natural disturbance regimes on mineral soil C stocks or emissions from organic soils, by incorporating country-specific information. A complete accounting of emissions and removals of CO_2 associated with *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*, or from the effects of biomass burning in managed (and unmanaged, when applicable) Forest Land is necessary. It is *good practice* that all losses from biomass carbon pools that result in transfers to dead organic matter pools are first accounted as changes to biomass carbon stocks. It is *good practice* that countries using Tier 1 estimation methods do not account for carbon emissions from DOM pools during fire or other disturbances because all DOM pool additions are assumed to have been released in the year of addition. Consequently, Tier 1 methods also preclude the accounting of DOM pool increases following natural disturbances.

4.4.2 Developing a consistent times series

It is *good practice* to develop a consistent time series of inventories of anthropogenic emissions and removals of greenhouse gases for all AFOLU categories using the guidance in Volume 1, Chapter 5. Because activity data may only be available every few years, achieving time series consistency may require interpolation or extrapolation from longer time series or trends, possibly using information on changes in forest policies and incentive schemes where drivers are needed.

Consistent accounting over time of land areas included in biomass and soil C emissions and removals inventory requires that activity data for all land-use categories be stratified by a common definition of climate and soil types. Thus, areas subject to land-use change will not be lost or double-counted due to accounting errors resulting from inconsistent definitions for climate and forest types and soil strata within other land-use categories. To estimate emissions and removals of greenhouse gases, whether by Tier 1, 2 or 3, ideally the same protocol (sampling strategy, method, etc.) should be applied consistently every year in the time series, at the same level of disaggregation, and, where country-specific data are used, it is *good practice* to use the same coefficients and methods for equivalent calculations at all points in the time series.

However, as inventory capacity and information and data sources availability improve over time, new sources and sink categories should be included, or moving to higher tier, the methods and data used to calculate estimates can be updated and refined. In these circumstances, consistent recalculation of historical emissions and removals is a *good practice*. In some cases, if some historical data are missing, then they may need to be estimated from other data sources. For example, the *2006 IPCC Guidelines* now require estimation of emissions of CO_2 and non-CO_2 from forests, which were not included under the 1966 Guidelines (refer to Chapter 1). The level of knowledge and detail of emission estimates for soils will also improve over time, necessitating recalculation of historic inventories to take account of new data and/or methods. Often, changes in forest soils cannot be detected at time scale finer than a decade; it will be necessary to interpolate between measurements in order to obtain annual estimates of emissions and removals. Changes in forest types, practices and disturbances need to be tracked for long time periods determined for example by soil carbon dynamics or forest rotation periods where these are specifically tracked in detailed model calculations.

Where countries use Tier 1 methods, estimates of DOM stock changes are only provided in the case of land-use change to or from Forest Land. It is *good practice* to recalculate the entire time series of data if either the default values for litter and dead wood carbon pools or the lengths of the transition periods are changed. It is also *good practice* to recalculate the entire time series of estimates if revisions to activity data, such as the rate of land-use change, have occurred. As more ground plot and other sample data on dead wood and litter carbon stocks become available in the future, countries are likely to improve the models used in higher Tier estimation procedures. It is *good practice* to use the same model parameter values (such as litterfall rates, decay rates, disturbance impacts) for the entire time series and to recalculate the entire time series if one or more of the model parameters have changed. Failure to do so may result in artificial sources or sinks, for example as a result of decay rate modifications.

4.4.3 Quality Assurance and Quality Control

The characteristics of the greenhouse gas inventory estimate of Forest Land can have different level of precision, accuracy and levels of bias. Moreover, the estimates are influenced by the quality and consistency of data and information available in a country, as well as gaps in knowledge. In addition, depending on the tier level used by a country, estimates can be affected by different sources of errors, such as sampling errors, assessment errors, classification errors in remote sensing imagery, and modeling errors that can propagate to the total estimation.

It is *good practice* to execute quality control checks through Quality Assurance (QA) and Quality Control (QC) procedures, and expert review of the emission estimation procedures. Additional quality control checks as outlined in Tier 2 procedures in Volume 1, Chapter 6, and quality assurance procedures may also be applicable, particularly if higher Tier methods are used to estimate emissions. It is *good practice* to supplement the general QA/QC related to data processing, handling, and reporting and documenting, with source-specific category procedures. QA/QC procedures should be documented separately for *Forest Land Remaining Forest Land* and for *Land Converted to Forest Land*.

Agencies which collect data are responsible for reviewing the data collection methods, checking the data to ensure that they are collected and aggregated or disaggregated correctly, and cross-checking the data with other data sources and with previous years to ensure that the data are realistic, complete and consistent over time. FAO data needs to cross checked with other national sources for accuracy and consistency. The basis for the estimates (e.g., statistical surveys or ´desk estimates´) must be reviewed and described as part of the QC process. Documentation is a crucial component of the review process because it enables reviewers to identify inaccuracy, gaps and suggest improvements. Documentation and transparency in reporting is most important for highly uncertain source categories and to give reasons for divergences between country-specific factors and default or factors used by other countries. Countries with similar (ecological) conditions are encouraged to collaborate in the refinements of methods, emissions factors and uncertainty assessment.

Activity data check: The inventory agency should, where possible, check data comprising of all managed land areas, using independent sources and compare them. For many countries, FAO database could be the main source and in such a case the data must be cross-checked with other sources. Any differences in area records should be documented for the purposes of review. Activity data area totals should be summed across all land-use categories to ensure that total area involved in the inventory and its stratification across climate and soil types remains constant over time. This ensures that Forest Land areas are neither 'created' nor 'lost' over time, which would result in major errors in the inventory. When using country-specific data (such as data on standing biomass and biomass growth rates, carbon fraction in above-ground biomass and biomass expansion factors, and synthetic fertilizer consumption estimates), the inventory agency should compare them to the IPCC default values or the Emission Factor Database (EFDB) and note the differences.

The country-specific parameters should be of high quality, preferably peer-reviewed experimental data, adequately described, and documented. The agencies performing the inventory are encouraged to ensure that *good practice* methods have been used and the results peer-reviewed. Assessments on test areas can be used to validate the reliability of figures reported.

Internal and external review: The review processes as set out in Volume 1, Chapter 8 should be undertaken by experts preferably not directly involved in the inventory development. The inventory agency should utilize experts in greenhouse gas removals and emissions in AFOLU to conduct expert peer-review of the methods and data used. Given the complexity and uniqueness of the parameters used in calculating country-specific factors for some categories, selected specialists in the field should be involved in such reviews. If soil factors are based on direct measurements, the inventory agency should review the measurements to ensure that they are representative of the actual range of environmental and soil management conditions, and inter-annual climatic variability, and were developed according to recognized standards. The QA/QC protocol in effect at the sites should also be reviewed and the resulting estimates compared between sites and with default-based estimates.

It is *good practice* that countries using Tier 1 methods review and, if necessary, revise the default assumptions for carbon stocks in litter and dead wood pools which are required for estimation of carbon losses following deforestation. Countries that use higher tier methods are encouraged to calculate intermediate indicators of the models used to develop estimates of DOM stock changes. For example, QA/QC procedures could compare estimates of stock sizes, litterfall inputs, decay losses, etc., against literature values and other peer-reviewed publications. Where possible, it is also *good practice* to compare model estimates against field measurements and other data sources. One QA/QC check that is easily implemented in modelling systems is to calculate an internal mass balance to ensure that the model neither produces nor loses carbon that is not reported as a source or a sink. For example, conservation of mass requirements include that losses from biomass pools are either accounted as input to the DOM pools, are transferred outside of the forest ecosystem or released to the atmosphere (in case of fire). Further, harvest data can be used to check transfer (stop loss) estimates produced by models. A second QA/QC procedure that can be implemented in countries that use higher Tier estimation methods is to establish upper and lower bounds for DOM pools stratified by regions, forest type, and soil type (organic vs. mineral soils). Any values, reported in inventories or estimated by models that fall outside these bounds can be investigated further.

4.4.4 Reporting and Documentation

General requirements for reporting and documentation are set out in Volume 1, Chapter 8. In general it is *good practice* to archive and document all data and information (such as figures, statistics, sources of assumptions, modeling approaches, uncertainty analyses, validation studies, inventory methods, research experiments, measurements arising from field site studies, associated protocols, and other basic data) applied to produce the national emissions/removals inventory. Elaborations on carbon pool definitions should be reported, and definitions relevant to determining the extent of the managed land included in the inventory, together with evidence that these definitions have been applied consistently over time provided.

Documentation is needed for demonstrating completeness, consistency of time series data and methods for interpolating between samples, methods and years, and for recalculating and avoidance of double counting as well as for performing QA/QC. As inventory compilers decide to progress through higher tier levels, whose calculation methods and data are not described in the present volume or characterized by more disaggregated approaches, additional documentation is required to support the use of more advanced and accurate methodologies, country-defined parameters, and high resolution maps and data sets. However, at all tier levels, explanation is needed for decisions regarding choice of methodology, coefficients, and activity data. The aim is to facilitate reconstruction of estimates by independent third parties, but it may prove impractical to include all documentation necessary in national inventory report. The inventory should therefore include summaries of approaches and methods used, and references to source of data such that the reported emissions estimates are transparent and steps adopted in their calculation may be retraced.

Emission factors: Sources of the emission or removal factors that were used (specific IPCC default values or otherwise) have to be quoted. If country- or region- or forest type-specific emission factors were used, and if new methods (other than the default IPCC methods) were used, the scientific basis of these emission factors and methods should be completely described and documented. This includes defining the input parameters and describing the process by which these emission factors and methods are derived, as well as describing sources and magnitudes of uncertainties. Inventory agencies using country-specific emission factors should provide information on the basis of selection of a different factor, describe how it was derived, compare it to other published emission factors, explain any significant differences, and attempt to place bounds on uncertainty.

Activity data: Sources of all activity data, such as areas, soil types and characteristics and vegetation covers, used in the calculations should be provided (i.e., complete citations for statistical databases from which data were drawn). Reference to the metadata for the databases are useful, including information on dates and frequency of data collection, sampling procedures, analytical procedures used to obtain soil characteristics and minimum detectable change in organic carbon, and estimates of accuracy and precision. When activity data were not obtained directly from databases, the information and assumptions that were used to derive the activity data should be provided, as well as estimates of the uncertainty associated to the derived activity data. This applies in particular when scaling up procedures are used to derive large-scale estimates; in these cases the statistical procedures should be described along with the associated uncertainty.

Results of model simulations: If inventory agencies used data output from models in their estimation procedures, the rationale for model selection and use should be provided. It is a *good practice* to provide complete citations of peer-reviewed publications in which the model is described, and modelling results are interpreted and validated. Detailed information should be provided to enable reviewers to assess the model's validity, including the general modeling approach, key model assumptions, input and output data, parameter values and parameterization procedures, confidence intervals of model outputs, and the outcome of any sensitivity analysis conducted on the output. In addition, computer source code for models should be permanently archived for future reference, along with all the input and output files.

Analysis of emissions: Significant fluctuations in emissions between years should be explained. A distinction should be made between changes in activity levels and changes in emission coefficients from year to year, and the reasons for these changes documented. If different emission factors are used for different years, the reasons for this should be explained and documented.

4.5 TABLES

TABLE 4.1
CLIMATE DOMAINS (FAO, 2001), CLIMATE REGIONS (CHAPTER 3), AND ECOLOGICAL ZONES (FAO, 2001)

Climate domain		Climate region	Ecological zone		
Domain	**Domain criteria**		**Zone**	**Code**	**Zone criteria**
Tropical	all months without frost; in marine areas, temperature >18°C	Tropical wet	Tropical rain forest	TAr	wet: ≤ 3 months dry, during winter
		Tropical moist	Tropical moist deciduous forest	TAwa	mainly wet: 3-5 months dry, during winter
		Tropical dry	Tropical dry forest	TAWb	mainly dry: 5-8 months dry, during winter
			Tropical shrubland	TBSh	semi-arid: evaporation > precipitation
			Tropical desert	TBWh	arid: all months dry
		Tropical montane	Tropical mountain systems	TM	altitudes approximately >1000 m, with local variations
Sub-tropical	≥ 8 months at a temperature >10°C	Warm temperate moist	Subtropical humid forest	SCf	humid: no dry season
		Warm temperate dry	Subtropical dry forest	SCs	seasonally dry: winter rains, dry summer
			Subtropical steppe	SBSh	semi-arid: evaporation >precipitation
			Subtropical desert	SBWh	arid: all months dry
		Warm temperate moist or dry	Subtropical mountain systems	SM	altitudes approximately 800 m-1000 m
Temp-erate	4-8 months at a temperature >10°C	Cool temperate moist	Temperate oceanic forest	TeDo	oceanic climate: coldest month >0°C
			Temperate continental forest	TeDc	continental climate: coldest month <0°C
		Cool temperate dry	Temperate steppe	TeBSk	semi-arid: evaporation > precipitation
			Temperate desert	TeBWk	arid: all months dry
		Cool temperate moist or dry	Temperate mountain systems	TeM	altitudes approximately >800 m
Boreal	≤ 3 months at a temperature >10°C	Boreal moist	Boreal coniferous forest	Ba	coniferous dense forest dominant
		Boreal dry	Boreal tundra woodland	Bb	woodland and sparse forest dominant
		Boreal moist or dry	Boreal mountain systems	BM	altitudes approximately >600 m
Polar	all months <10°C	Polar moist or dry	Polar	P	all months <10°C

Climate domain: Area of relatively homogenous temperature regime, equivalent to the Köppen-Trewartha climate groups (Köppen, 1931).

Climate region: Areas of similar climate defined in Chapter 3 for reporting across different carbon pools.

Ecological zone: Area with broad, yet relatively homogeneous natural vegetation formations that are similar, but not necessarily identical, in physiognomy.

Dry month: A month in which Total Precipitation (mm) ≤ 2 x Mean Temperature (ºC).

TABLE 4.2
FOREST AND LAND COVER CLASSES

Forest or land cover class	Definition
Forest	Land spanning more than 0.5 hectare with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use. Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 meters *in situ*. Areas under reforestation that have not yet reached but are expected to reach a canopy cover of 10 percent and tree height of 5 meters are included, as are temporarily unstocked areas, resulting from human intervention or natural causes, which are expected to regenerate. Includes: areas with bamboo and palms provided that height and canopy cover criteria are met; forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest; windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 hectare and width of more than 20 meters; plantations primarily used for forestry or protective purposes, such as rubber-wood plantations and cork oak stands. Excludes: tree stands in agricultural production systems, for example in fruit plantations and agroforestry systems. The term also excludes trees in urban parks and gardens.
Other wooded land	Land not classified as "Forest", spanning more than 0.5 hectare; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds *in situ*; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use.
Other land	All land that is not classified as Forest or Other Wooded Land. Includes: agricultural land, meadows and pastures, built-up areas, barren land, etc; areas classified under the subcategory 'Other Land with tree cover'.
Other land with tree cover	Land classified as Other Land, spanning more than 0.5 hectare with a canopy cover of more than 10 percent of trees able to reach a height of 5 meters at maturity. Includes: groups of trees and scattered trees in agricultural landscapes, parks, gardens, and around buildings (provided that the area, height and canopy cover criteria are met); tree plantations established mainly for other purposes than wood, such as fruit orchards and palm plantations.

Source: FAO, 2006. Global Forest Resources Assessment 2005 – progress towards sustainable forest management. FAO Forestry Paper No. 147. Rome.

TABLE 4.3 CARBON FRACTION OF ABOVEGROUND FOREST BIOMASS			
Domain	**Part of tree**	**Carbon fraction, (CF) [tonne C (tonne d.m.)$^{-1}$]**	**References**
Default value	All	0.47	McGroddy *et al.*, 2004
Tropical and Subtropical	All	0.47 (0.44 - 0.49)	Andreae and Merlet, 2001; Chambers *et al.*, 2001; McGroddy *et al.*, 2004; Lasco and Pulhin, 2003
	wood	0.49	Feldpausch *et al.*, 2004
	wood, tree d < 10 cm	0.46	Hughes *et al.*, 2000
	wood, tree d ≥ 10 cm	0.49	Hughes *et al.*, 2000
	foliage	0.47	Feldpausch *et al.*, 2004
	foliage, tree d < 10 cm	0.43	Hughes *et al.*, 2000
	foliage, tree d ≥ 10 cm	0.46	Hughes *et al.*, 2000
Temperate and Boreal	All	0.47 (0.47 - 0.49)	Andreae and Merlet, 2001; Gayoso *et al.*, 2002; Matthews, 1993; McGroddy *et al.*, 2004
	broad-leaved	0.48 (0.46 - 0.50)	Lamlom and Savidge, 2003
	conifers	0.51 (0.47 - 0.55)	Lamlom and Savidge, 2003

TABLE 4.4
RATIO OF BELOW-GROUND BIOMASS TO ABOVE-GROUND BIOMASS (R)

Domain	Ecological zone	Above-ground biomass	R [tonne root d.m. (tonne shoot d.m.)$^{-1}$]	References
Tropical	Tropical rainforest		0.37	Fittkau and Klinge, 1973
	Tropical moist deciduous forest	above-ground biomass <125 tonnes ha^{-1}	0.20 (0.09 - 0.25)	Mokany *et al*., 2006
		above-ground biomass >125 tonnes ha^{-1}	0.24 (0.22 - 0.33)	Mokany *et al*., 2006
	Tropical dry forest	above-ground biomass <20 tonnes ha^{-1}	0.56 (0.28 - 0.68)	Mokany *et al*., 2006
		above-ground biomass >20 tonnes ha^{-1}	0.28 (0.27 - 0.28)	Mokany *et al*., 2006
	Tropical shrubland		0.40	Poupon, 1980
	Tropical mountain systems		0.27 (0.27 - 0.28)	Singh *et al.*, 1994
Subtropical	Subtropical humid forest	above-ground biomass <125 tonnes ha^{-1}	0.20 (0.09 - 0.25)	Mokany *et al*., 2006
		above-ground biomass >125 tonnes ha^{-1}	0.24 (0.22 - 0.33)	Mokany *et al*., 2006
	Subtropical dry forest	above-ground biomass <20 tonnes ha^{-1}	0.56 (0.28 - 0.68)	Mokany *et al*., 2006
		above-ground biomass >20 tonnes ha^{-1}	0.28 (0.27 - 0.28)	Mokany *et al*., 2006
	Subtropical steppe		0.32 (0.26 - 0.71)	Mokany *et al*., 2006
	Subtropical mountain systems		no estimate available	
Temperate	Temperate oceanic forest, Temperate continental forest, Temperate mountain systems	conifers above-ground biomass < 50 tonnes ha^{-1}	0.40 (0.21 - 1.06)	Mokany *et al*., 2006
		conifers above-ground biomass 50-150 tonnes ha^{-1}	0.29 (0.24 - 0.50)	Mokany *et al*., 2006
		conifers above-ground biomass > 150 tonnes ha^{-1}	0.20 (0.12 - 0.49)	Mokany *et al*., 2006
		Quercus spp. above-ground biomass >70 tonnes ha^{-1}	0.30 (0.20 - 1.16)	Mokany *et al*., 2006
		Eucalyptus spp. above-ground biomass < 50 tonnes ha^{-1}	0.44 (0.29 - 0.81)	Mokany *et al*., 2006
		Eucalyptus spp. above-ground biomass 50-150 tonnes ha^{-1}	0.28 (0.15 - 0.81)	Mokany *et al*., 2006
		Eucalyptus spp. above-ground biomass > 150 tonnes ha^{-1}	0.20 (0.10 - 0.33)	Mokany *et al*., 2006
		other broadleaf above-ground biomass < 75 tonnes ha^{-1}	0.46 (0.12 - 0.93)	Mokany *et al*., 2006
		other broadleaf above-ground biomass 75-150 tonnes ha^{-1}	0.23 (0.13 - 0.37)	Mokany *et al*., 2006
		other broadleaf above-ground biomass >150 tonnes ha^{-1}	0.24 (0.17 - 0.44)	Mokany *et al*., 2006
Boreal	Boreal coniferous forest, Boreal tundra woodland, Boreal mountain systems	above-ground biomass <75 tonnes ha^{-1}	0.39 (0.23 - 0.96)	Li *et al*., 2003; Mokany *et al*., 2006
		above-ground biomass >75 tonnes ha^{-1}	0.24 (0.15 - 0.37)	Li *et al*., 2003; Mokany *et al*., 2006

TABLE 4.5
DEFAULT BIOMASS CONVERSION AND EXPANSION FACTORS (BCEF), TONNES BIOMASS (M^3 OF WOOD VOLUME)$^{-1}$

BCEF for expansion of merchantable growing stock volume to above-ground biomass ($BCEF_S$), for conversion of net annual increment ($BCEF_I$) and for conversion of wood and fuelwood removal volume to above-ground biomass removal ($BCEF_R$)

Climatic zone	Forest type	BCEF	Growing stock level (m^3)			
			<20	21-50	51-100	>100
Boreal	pines	$BCEF_S$	**1.2** (0.85-1.3)	**0.68** (0.5-0.72)	**0.57** (0.52-0.65)	**0.5** (0.45-0.58)
		$BCEF_I$	0.47	0.46	0.46	0.463
		$BCEF_R$	1.33	0.75	0.63	0.55
	larch	$BCEF_S$	**1.22** (0.9-1.5)	**0.78** (0.7-0.8)	**0.77** (0.7-0.85)	**0.77** (0.7-0.85)
		$BCEF_I$	0.9	0.75	0.77	0.77
		$BCEF_R$	1.35	0.87	0.85	0.85
	firs and spruces	$BCEF_S$	**1.16** (0.8-1.5)	**0.66** (0.55-0.75)	**0.58** (0.5-0.65)	**0.53** (0.45-0.605)
		$BCEF_I$	0.55	0.47	0.47	0.464
		$BCEF_R$	1.29	0.73	0.64	0.59
	hardwoods	$BCEF_S$	**0.9** (0.7-1.2)	**0.7** (0.6-0.75)	**0.62** (0.53-0.7)	**0.55** (0.5-0.65)
		$BCEF_I$	0.65	0.54	0.52	0.505
		$BCEF_R$	1.0	0.77	0.69	0.61

TABLE 4.5 (CONTINUED)
DEFAULT BIOMASS CONVERSION AND EXPANSION FACTORS (BCEF), TONNES BIOMASS (M^3 OF WOOD VOLUME)$^{-1}$

BCEF for expansion of merchantable growing stock volume to above-ground biomass ($BCEF_S$), for conversion of net annual increment ($BCEF_I$) and for conversion of wood and fuelwood removal volume to above-ground biomass removal ($BCEF_R$)

Climatic zone	Forest type	BCEF	Growing stock level (m^3)				
Temperate			<20	21-40	41-100	100 -200	>200
	hardwoods	$BCEF_S$	**3.0** (0.8-4.5)	**1.7** (0.8-2.6)	**1.4** (0.7-1.9)	**1.05** (0.6-1.4)	**0.8** (0.55-1.1)
		$BCEF_I$	1.5	1.3	0.9	0.6	0.48
		$BCEF_R$	3.33	1.89	1.55	1.17	0.89
	pines	$BCEF_S$	**1.8** (0.6 -2.4)	**1.0** (0.65 -1.5)	**0.75** (0.6-1.0)	**0.7** (0.4-1.0)	**0.7** (0.4-1.0)
		$BCEF_I$	1.5	0.75	0.6	0.67	0.69
		$BCEF_R$	2.0	1.11	0.83	0.77	0.77
	other conifers	$BCEF_S$	**3.0 (**0.7-4.0)	**1.4** (0.5-2.5)	**1.0** (0.5-1.4)	**0.75** (0.4-1.2)	**0.7** (0.35-0.9)
		$BCEF_I$	1.0	0.83	0.57	0.53	0.60
		$BCEF_R$	3.33	1.55	1.11	0.83	0.77
Mediterranean, dry tropical, subtropical			<20	21-40	41-80	>80	
	hardwoods	$BCEF_S$	**5.0** (2.0-8.0)	**1.9** (1.0-2.6)	**0.8** (0.6-1.4)	**0.66** (0.4-0.9)	
		$BCEF_I$	1.5	0.5	0.55	0.66	
		$BCEF_R$	5.55	2.11	0.89	0.73	
	conifers	$BCEF_S$	**6.0** (3.0-8.0)	**1.2** (0.5-2.0)	**0.6** (0.4-0.9)	**0.55** (0.4-0.7)	
		$BCEF_I$	1.5	0.4	0.45	0.54	
		$BCEF_R$	6.67	1.33	0.67	0.61	

TABLE 4.5 (CONTINUED)
DEFAULT BIOMASS CONVERSION AND EXPANSION FACTORS (BCEF), TONNES BIOMASS (M^3 OF WOOD VOLUME)$^{-1}$

BCEF for expansion of merchantable growing stock volume to above-ground biomass ($BCEF_S$), for conversion of net annual increment ($BCEF_I$) and for conversion of wood and fuelwood removal volume to above-ground biomass removal ($BCEF_R$)

Climatic zone	Forest type	BCEF	Growing stock level (m^3)							
			<10	11-20	21-40	41-60	61-80	80-120	120-200	>200
Humid tropical	conifers	$BCEF_S$	**4.0** (3.0-6.0)	**1.75** (1.4-2.4)	**1.25** (1.0-1.5)	**1.0** (0.8-1.2)	**0.8** (0.7-1.2)	**0.76** (0.6-1.0)	**0.7** (0.6-0.9)	**0.7** (0.6-0.9)
		$BCEF_I$	2.5	0.95	0.65	0.55	0.53	0.58	0.66	0.70
		$BCEF_R$	4.44	1.94	1.39	1.11	0.89	0.84	0.77	0.77
	natural forests	$BCEF_S$	**9.0** (4.0-12.0)	**4.0** (2.5-4.5)	**2.8** (1.4-3.4)	**2.05** (1.2-2.5)	**1.7** (1.2-2.2)	**1.5** (1.0-1.8)	**1.3**(0.9-1.6)	**0.95** (0.7-1.1)
		$BCEF_I$	4.5	1.6	1.1	0.93	0.9	0.87	0.86	0.85
		$BCEF_R$	10.0	4.44	3.11	2.28	1.89	1.67	1.44	1.05

Note: Lower values of the ranges for $BCEF_S$ apply if growing stock definition includes branches, stem tops and cull trees; upper values apply if branches and tops are not part of growing stock, minimum top diameters in the definition of growing stock are large, inventoried volume falls near the lower category limit or basic wood densities are relatively high. Continuous graphs, functional forms and updates with new studies can be found at the forest- and climate- change website at: http://www.fao.org/forestry/

Average BCEF for inhomogeneous forests should be derived as far as possible as weighted averages. It is good practice to justify the factors chosen. To apply $BCEF_I$, an estimate of the current average growing stock is necessary. It can be derived from FRA 2005 at http://www.fao.org/forestry/

$BCEF_R$ values are derived by dividing $BCEF_S$ by 0.9

Sources*:* *Boreal forests*: Alexeyev V.A. and R.A. Birdseye, 1998; Fang J. and Z.M. Wang, 2001; *temperate forests*: Fang J. *et al.*, 2001; Fukuda M. *et al*., 2003; Schroeder P. *et al*., 1997; Snowdon P. *et.al*., 2000; Smith J. *et. al*., 2002; Brown S., 1999; Schoene D. and A. Schulte, 1999; Smith J. *et al.*, 2004; *Mediterranean forests*: Vayreda *et al*., 2002; Gracia *et al*., 2002; *tropical forests*: Brown S. *et al*., 1989; Brown S. and A. Lugo, 1992; Brown S., 2002; Fang J.Y., 2001.

TABLE 4.6 EMISSION FACTORS FOR DRAINED ORGANIC SOILS IN MANAGED FORESTS		
Climate	Emission factors (tonnes C ha^{-1} yr^{-1})	
	Values	Ranges
Tropical	1.36	0.82 – 3.82
Temperate	0.68	0.41 – 1.91
Boreal	0.16	0.08 – 1.09
Source: *GPG-LULUCF*, Table 3.2.3		

TABLE 4.7 ABOVE-GROUND BIOMASS IN FORESTS				
Domain	**Ecological zone**	**Continent**	**Above-ground biomass (tonnes d.m. ha^{-1})**	**References**
Tropical	Tropical rain forest	Africa	310 (130-510)	IPCC, 2003
		North and South America	300 (120-400)	Baker *et al*., 2004a; Hughes *et al*., 1999
		Asia (continental)	280 (120-680)	IPCC, 2003
		Asia (insular)	350 (280-520)	IPCC, 2003
	Tropical moist deciduous forest	Africa	260 (160-430)	IPCC, 2003
		North and South America	220 (210-280)	IPCC, 2003
		Asia (continental)	180 (10-560)	IPCC, 2003
		Asia (insular)	290	IPCC, 2003
	Tropical dry forest	Africa	120 (120-130)	IPCC, 2003
		North and South America	210 (200-410)	IPCC, 2003
		Asia (continental)	130 (100-160)	IPCC, 2003
		Asia (insular)	160	IPCC, 2003
	Tropical shrubland	Africa	70 (20-200)	IPCC, 2003
		North and South America	80 (40-90)	IPCC, 2003
		Asia (continental)	60	IPCC, 2003
		Asia (insular)	70	IPCC, 2003
	Tropical mountain systems	Africa	40-190	IPCC, 2003
		North and South America	60-230	IPCC, 2003
		Asia (continental)	50-220	IPCC, 2003
		Asia (insular)	50-360	IPCC, 2003
Subtropical	Subtropical humid forest	North and South America	220 (210-280)	IPCC, 2003
		Asia (continental)	180 (10-560)	IPCC, 2003
		Asia (insular)	290	IPCC, 2003
	Subtropical dry forest	Africa	140	Sebei *et al*., 2001
		North and South America	210 (200-410)	IPCC, 2003
		Asia (continental)	130 (100-160)	IPCC, 2003
		Asia (insular)	160	IPCC, 2003
	Subtropical steppe	Africa	70 (20-200)	IPCC, 2003
		North and South America	80 (40-90)	IPCC, 2003
		Asia (continental)	60	IPCC, 2003
		Asia (insular)	70	IPCC, 2003
	Subtropical mountain systems	Africa	50	Montès *et al*., 2002
		North and South America	60-230	IPCC, 2003
		Asia (continental)	50-220	IPCC, 2003
		Asia (insular)	50-360	IPCC, 2003

TABLE 4.7 (CONTINUED)
ABOVE-GROUND BIOMASS IN FORESTS

Domain	Ecological zone	Continent	Above-ground biomass (tonnes d.m. ha^{-1})	References
Temperate	Temperate oceanic forest	Europe	120	-
		North America	660 (80-1200)	Hessl *et al*., 2004; Smithwick *et al*., 2002
		New Zealand	360 (210-430)	Hall *et al*., 2001
		South America	180 (90-310)	Gayoso and Schlegel, 2003; Battles *et al*., 2002
	Temperate continental forest	Asia, Europe (≤20 y)	20	IPCC, 2003
		Asia, Europe (>20 y)	120 (20-320)	IPCC, 2003
		North and South America (≤20 y)	60 (10-130)	IPCC, 2003
		North and South America (>20 y)	130 (50-200)	IPCC, 2003
	Temperate mountain systems	Asia, Europe (≤20 y)	100 (20-180)	IPCC, 2003
		Asia, Europe (>20 y)	130 (20-600)	IPCC, 2003
		North and South America (≤20 y)	50 (20-110)	IPCC, 2003
		North and South America (>20 y)	130 (40-280)	IPCC, 2003
Boreal	Boreal coniferous forest	Asia, Europe, North America	10-90	Gower *et al*., 2001
	Boreal tundra woodland	Asia, Europe, North America (≤20 y)	3-4	IPCC, 2003
		Asia, Europe, North America (>20 y)	15-20	IPCC, 2003
	Boreal mountain systems	Asia, Europe, North America (≤20 y)	12-15	IPCC, 2003
		Asia, Europe, North America (>20 y)	40-50	IPCC, 2003

TABLE 4.8
ABOVE-GROUND BIOMASS IN FOREST PLANTATIONS

Domain	Ecological zone	Continent	Above-ground biomass (tonnes d.m. ha^{-1})	References
Tropical	Tropical rain forest	Africa broadleaf > 20 y	300	IPCC, 2003
		Africa broadleaf ≤ 20 y	100	IPCC, 2003
		Africa Pinus sp. > 20 y	200	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	60	IPCC, 2003
		Americas Eucalyptus sp.	200	IPCC, 2003
		Americas Pinus sp.	300	IPCC, 2003
		Americas Tectona grandis	240	Kraenzel *et al*., 2003
		Americas other broadleaf	150	IPCC, 2003
		Asia broadleaf	220	IPCC, 2003
		Asia other	130	IPCC, 2003
	Tropical moist deciduous forest	Africa broadleaf > 20 y	150	IPCC, 2003
		Africa broadleaf ≤ 20 y	80	IPCC, 2003
		Africa Pinus sp. > 20 y	120	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	40	IPCC, 2003
		Americas Eucalyptus sp.	90	Stape *et al*., 2004
		Americas Pinus sp.	270	IPCC, 2003
		Americas Tectona grandis	120	IPCC, 2003
		Americas other broadleaf	100	IPCC, 2003
		Asia broadleaf	180	IPCC, 2003
		Asia other	100	IPCC, 2003

TABLE 4.8 (CONTINUED)
ABOVE-GROUND BIOMASS IN FOREST PLANTATIONS

Domain	Ecological zone	Continent	Above-ground biomass (tonnes d.m. ha^{-1})	References
	Tropical dry forest	Africa broadleaf > 20 y	70	IPCC, 2003
		Africa broadleaf ≤ 20 y	30	IPCC, 2003
		Africa Pinus sp. > 20 y	60	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	20	IPCC, 2003
		Americas Eucalyptus sp.	90	Stape *et al*., 2004
		Americas Pinus sp.	110	IPCC, 2003
		Americas Tectona grandis	90	IPCC, 2003
		Americas other broadleaf	60	IPCC, 2003
		Asia broadleaf	90	IPCC, 2003
		Asia other	60	IPCC, 2003
	Tropical shrubland	Africa broadleaf	20	IPCC, 2003
		Africa Pinus sp. > 20 y	20	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	15	IPCC, 2003
		Americas Eucalyptus sp.	60	IPCC, 2003
		Americas Pinus sp.	60	IPCC, 2003
		Americas Tectona grandis	50	IPCC, 2003
		Americas other broadleaf	30	IPCC, 2003
		Asia broadleaf	40	IPCC, 2003
		Asia other	30	IPCC, 2003
	Tropical mountain systems	Africa broadleaf > 20 y	60-150	IPCC, 2003
		Africa broadleaf ≤ 20 y	40-100	IPCC, 2003
		Africa Pinus sp. > 20 y	30-100	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	10-40	IPCC, 2003
		Americas Eucalyptus sp.	30-120	IPCC, 2003
		Americas Pinus sp.	60-170	IPCC, 2003
		Americas Tectona grandis	30-130	IPCC, 2003
		Americas other broadleaf	30-80	IPCC, 2003
		Asia broadleaf	40-150	IPCC, 2003
		Asia other	25-80	IPCC, 2003
Subtropical	Subtropical humid forest	Americas Eucalyptus sp.	140	IPCC, 2003
		Americas Pinus sp.	270	IPCC, 2003
		Americas Tectona grandis	120	IPCC, 2003
		Americas other broadleaf	100	IPCC, 2003
		Asia broadleaf	180	IPCC, 2003
		Asia other	100	IPCC, 2003
	Subtropical dry forest	Africa broadleaf > 20 y	70	IPCC, 2003
		Africa broadleaf ≤ 20 y	30	IPCC, 2003
		Africa Pinus sp. > 20 y	60	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	20	IPCC, 2003
		Americas Eucalyptus sp.	110	IPCC, 2003
		Americas Pinus sp.	110	IPCC, 2003
		Americas Tectona grandis	90	IPCC, 2003
		Americas other broadleaf	60	IPCC, 2003
		Asia broadleaf	90	IPCC, 2003
		Asia other	60	IPCC, 2003

TABLE 4.8 (CONTINUED)
ABOVE-GROUND BIOMASS IN FOREST PLANTATIONS

Domain	Ecological zone	Continent	Above-ground biomass (tonnes d.m. ha^{-1})	References
	Subtropical steppe	Africa broadleaf	20	IPCC, 2003
		Africa Pinus sp. > 20 y	20	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	15	IPCC, 2003
		Americas Eucalyptus sp.	60	IPCC, 2003
		Americas Pinus sp.	60	IPCC, 2003
		Americas Tectona grandis	50	IPCC, 2003
		Americas other broadleaf	30	IPCC, 2003
		Asia broadleaf > 20 y	80	IPCC, 2003
		Asia broadleaf ≤ 20 y	10	IPCC, 2003
		Asia coniferous > 20 y	20	IPCC, 2003
		Asia coniferous ≤ 20 y	100-120	IPCC, 2003
	Subtropical mountain systems	Africa broadleaf > 20 y	60-150	IPCC, 2003
		Africa broadleaf ≤ 20 y	40-100	IPCC, 2003
		Africa Pinus sp. > 20 y	30-100	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	10-40	IPCC, 2003
		Americas Eucalyptus sp.	30-120	IPCC, 2003
		Americas Pinus sp.	60-170	IPCC, 2003
		Americas Tectona grandis	30-130	IPCC, 2003
		Americas other broadleaf	30-80	IPCC, 2003
		Asia broadleaf	40-150	IPCC, 2003
		Asia other	25-80	IPCC, 2003
Temperate	Temperate oceanic forest	Asia, Europe, broadleaf > 20 y	200	IPCC, 2003
		Asia, Europe, broadleaf ≤ 20 y	30	IPCC, 2003
		Asia, Europe, coniferous > 20 y	150-250	IPCC, 2003
		Asia, Europe, coniferous ≤ 20 y	40	IPCC, 2003
		North America	50-300	IPCC, 2003
		New Zealand	150-350	Hinds and Reid, 1957; Hall and Hollinger, 1997; Hall, 2001
		South America	90-120	IPCC, 2003
	Temperate continental forest and mountain systems	Asia, Europe, broadleaf > 20 y	200	IPCC, 2003
		Asia, Europe, broadleaf ≤ 20 y	15	IPCC, 2003
		Asia, Europe, coniferous > 20 y	150-200	IPCC, 2003
		Asia, Europe, coniferous ≤ 20 y	25-30	IPCC, 2003
		North America	50-300	IPCC, 2003
		South America	90-120	IPCC, 2003
Boreal	Boreal coniferous forest and mountain systems	Asia, Europe > 20 y	40	IPCC, 2003
		Asia, Europe ≤ 20 y	5	IPCC, 2003
		North America	40-50	IPCC, 2003
	Boreal tundra woodland	Asia, Europe > 20 y	25	IPCC, 2003
		Asia, Europe ≤ 20 y	5	IPCC, 2003
		North America	25	IPCC, 2003

TABLE 4.9
ABOVE-GROUND NET BIOMASS GROWTH IN NATURAL FORESTS

Domain	Ecological zone	Continent	Above-ground biomass growth (tonnes d.m. ha^{-1} yr^{-1})	Reference
Tropical	Tropical rain forest	Africa (≤20 y)	10	IPCC, 2003
		Africa (>20 y)	3.1 (2.3-3.8)	IPCC, 2003
		North America	0.9-18	Clark *et al*., 2003 ; Hughes *et al*., 1999
		South America (≤20 y)	11	Feldpausch *et al*., 2004
		South America (>20 y)	3.1 (1.5-5.5)	Malhi *et al*., 2004
		Asia (continental ≤20 y)	7.0 (3.0-11.0)	IPCC, 2003
		Asia (continental >20 y)	2.2 (1.3-3.0)	IPCC, 2003
		Asia (insular ≤20 y)	13	IPCC, 2003
		Asia (insular >20 y)	3.4	IPCC, 2003
	Tropical moist deciduous forest	Africa (≤20 y)	5	Harmand *et al*., 2004
		Africa (>20 y)	1.3	IPCC, 2003
		North and South America (≤20 y)	7.0	IPCC, 2003
		North and South America (>20 y)	2.0	IPCC, 2003
		Asia (continental ≤20 y)	9.0	IPCC, 2003
		Asia (continental >20 y)	2.0	IPCC, 2003
		Asia (insular ≤20 y)	11	IPCC, 2003
		Asia (insular >20 y)	3.0	IPCC, 2003
	Tropical dry forest	Africa (≤20 y)	2.4 (2.3-2.5)	IPCC, 2003
		Africa (>20 y)	1.8 (0.6-3.0)	IPCC, 2003
		North and South America (≤20 y)	4.0	IPCC, 2003
		North and South America (>20 y)	1.0	IPCC, 2003
		Asia (continental ≤20 y)	6.0	IPCC, 2003
		Asia (continental >20 y)	1.5	IPCC, 2003
		Asia (insular ≤20 y)	7.0	IPCC, 2003
		Asia (insular >20 y)	2.0	IPCC, 2003
	Tropical shrubland	Africa (≤20 y)	0.2-0.7	Nygård *et al*., 2004
		Africa (>20 y)	0.9 (0.2-1.6)	IPCC, 2003
		North and South America (≤20 y)	4.0	IPCC, 2003
		North and South America (>20 y)	1.0	IPCC, 2003
		Asia (continental ≤20 y)	5.0	IPCC, 2003
		Asia (continental >20 y)	1.3 (1.0-2.2)	IPCC, 2003
		Asia (insular ≤20 y)	2.0	IPCC, 2003
		Asia (insular >20 y)	1.0	IPCC, 2003
	Tropical mountain systems	Africa (≤20 y)	2.0-5.0	IPCC, 2003
		Africa (>20 y)	1.0-1.5	IPCC, 2003
		North and South America (≤20 y)	1.8-5.0	IPCC, 2003
		North and South America (>20 y)	0.4-1.4	IPCC, 2003
		Asia (continental ≤20 y)	1.0-5.0	IPCC, 2003
		Asia (continental >20 y)	0.5-1.0	IPCC, 2003
		Asia (insular ≤20 y)	3.0-12	IPCC, 2003
		Asia (insular >20 y)	1.0-3.0	IPCC, 2003
Subtropical	Subtropical humid forest	North and South America (≤20 y)	7.0	IPCC, 2003
		North and South America (>20 y)	2.0	IPCC, 2003
		Asia (continental ≤20 y)	9.0	IPCC, 2003
		Asia (continental >20 y)	2.0	IPCC, 2003
		Asia (insular ≤20 y)	11	IPCC, 2003
		Asia (insular >20 y)	3.0	IPCC, 2003
	Subtropical dry forest	Africa (≤20 y)	2.4 (2.3-2.5)	IPCC, 2003
		Africa (>20 y)	1.8 (0.6-3.0)	IPCC, 2003
		North and South America (≤20 y)	4.0	IPCC, 2003

TABLE 4.9 (CONTINUED)
ABOVE-GROUND NET BIOMASS GROWTH IN NATURAL FORESTS

Domain	Ecological zone	Continent	Above-ground biomass growth (tonnes d.m. ha^{-1} yr^{-1})	Reference
		North and South America (>20 y)	1.0	IPCC, 2003
		Asia (continental ≤20 y)	6.0	IPCC, 2003
		Asia (continental >20 y)	1.5	IPCC, 2003
		Asia (insular ≤20 y)	7.0	IPCC, 2003
		Asia (insular >20 y)	2.0	IPCC, 2003
	Subtropical steppe	Africa (≤20 y)	1.2 (0.8-1.5)	IPCC, 2003
		Africa (>20 y)	0.9 (0.2-1.6)	IPCC, 2003
		North and South America (≤20 y)	4.0	IPCC, 2003
		North and South America (>20 y)	1.0	IPCC, 2003
		Asia (continental ≤20 y)	5.0	IPCC, 2003
		Asia (continental >20 y)	1.3 (1.0-2.2)	IPCC, 2003
		Asia (insular ≤20 y)	2.0	IPCC, 2003
		Asia (insular >20 y)	1.0	IPCC, 2003
	Subtropical mountain systems	Africa (≤20 y)	2.0-5.0	IPCC, 2003
		Africa (>20 y)	1.0-1.5	IPCC, 2003
		North and South America (≤20 y)	1.8-5.0	IPCC, 2003
		North and South America (>20 y)	0.4-1.4	IPCC, 2003
		Asia (continental ≤20 y)	1.0-5.0	IPCC, 2003
		Asia (continental >20 y)	0.5-1.0	IPCC, 2003
		Asia (insular ≤20 y)	3.0-12	IPCC, 2003
		Asia (insular >20 y)	1.0-3.0	IPCC, 2003
Temperate	Temperate oceanic forest	Europe	2.3	
		North America	15 (1.2-105)	Hessl *et al*., 2004
		New Zealand	3.5 (3.2-3.8)	Coomes *et al*., 2002
		South America	2.4-8.9	Echevarria and Lara, 2004
	Temperate continental forest	Asia, Europe, North America (≤20 y)	4.0 (0.5-8.0)	IPCC, 2003
		Asia, Europe, North America (>20 y)	4.0 (0.5-7.5)	IPCC, 2003
	Temperate mountain systems	Asia, Europe, North America	3.0 (0.5-6.0)	IPCC, 2003
Boreal	Boreal coniferous forest	Asia, Europe, North America	0.1-2.1	Gower *et al*., 2001
	Boreal tundra woodland	Asia, Europe, North America	0.4 (0.2-0.5)	IPCC, 2003
	Boreal mountain systems	Asia, Europe, North America (≤20 y)	1.0-1.1	IPCC, 2003
		Asia, Europe, North America (>20 y)	1.1-1.5	IPCC, 2003

TABLE 4.10
ABOVE-GROUND NET BIOMASS GROWTH IN TROPICAL AND SUB-TROPICAL FOREST PLANTATIONS

Domain	Ecological zone	Continent	Above-ground biomass growth (tonnes d.m. ha^{-1} yr^{-1})	References
Tropical	Tropical rain forest	Africa Pinus sp. ≤ 20 y	20	IPCC, 2003
		Africa other ≤ 20 y	6 (5-8)	IPCC, 2003
		Americas Eucalyptus sp.	20 (6-40)	IPCC, 2003
		Americas Pinus sp.	20	IPCC, 2003
		Americas Tectona grandis	15	IPCC, 2003
		Americas other broadleaf	20 (5-35)	IPCC, 2003
		Asia Eucalyptus sp.	5 (4-8)	IPCC, 2003
		Asia other	5 (2-8)	IPCC, 2003
	Tropical moist deciduous forest	Africa Eucalyptus sp. >20 y	25	IPCC, 2003
		Africa Eucalyptus sp. ≤20 y	20	IPCC, 2003
		Africa Pinus sp. > 20 y	15	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	10	IPCC, 2003
		Africa other ≤ 20 y	9 (3-15)	IPCC, 2003
		Americas Eucalyptus sp.	16	Stape *et al*., 2004
		Americas Pinus sp.	7 (4-10)	IPCC, 2003
		Americas Tectona grandis	8 (4-12)	IPCC, 2003
		Americas other broadleaf	6-20	Lugo *et al*., 1990
		Asia	8	IPCC, 2003
	Tropical dry forest	Africa Eucalyptus sp. ≤20 y	13	IPCC, 2003
		Africa Pinus sp. > 20 y	10	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	8	IPCC, 2003
		Africa other ≤ 20 y	10 (4-20)	IPCC, 2003
		Americas Eucalyptus sp.	20 (6-30)	IPCC, 2003
		Americas Pinus sp.	7 (4-10)	IPCC, 2003
		Americas Tectona grandis	8 (4-12)	IPCC, 2003
		Americas other broadleaf	10 (3-12)	IPCC, 2003
		Asia Eucalyptus sp.	15 (5-25)	IPCC, 2003
		Asia other	7 (2-13)	IPCC, 2003
	Tropical shrubland	Africa Eucalyptus sp. >20 y	8 (5-14)	IPCC, 2003
		Africa Eucalyptus sp. ≤20 y	5 (3-7)	IPCC, 2003
		Africa Pinus sp. > 20 y	2.5	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	3 (0.5-6)	IPCC, 2003
		Africa other > 20 y	10	IPCC, 2003
		Africa other ≤ 20 y	15	IPCC, 2003
		Americas Eucalyptus sp.	20	IPCC, 2003
		Americas Pinus sp.	5	IPCC, 2003
		Asia	6 (1-12)	IPCC, 2003
	Tropical mountain systems	Africa	10	IPCC, 2003
		Americas Eucalyptus sp.	10 (8-18)	IPCC, 2003
		Americas Pinus sp.	10	IPCC, 2003
		Americas Tectona grandis	2	IPCC, 2003
		Americas other broadleaf	4	IPCC, 2003
		Asia Eucalyptus sp.	3	IPCC, 2003
		Asia other	5 (1-10)	IPCC, 2003
Subtropical	Subtropical humid forest	Americas Eucalyptus sp.	20 (6-32)	IPCC, 2003
		Americas Pinus sp.	7 (4-10)	IPCC, 2003
		Americas Tectona grandis	8 (4-12)	IPCC, 2003
		Americas other broadleaf	10 (3-12)	IPCC, 2003
		Asia	8	IPCC, 2003
	Subtropical dry forest	Africa Eucalyptus sp. ≤20 y	13	IPCC, 2003
		Africa Pinus sp. > 20 y	10	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	8	IPCC, 2003
		Africa other ≤ 20 y	10 (4-20)	IPCC, 2003
		Americas Eucalyptus sp.	20 (6-30)	IPCC, 2003
		Americas Pinus sp.	7 (4-10)	IPCC, 2003
		Americas Tectona grandis	8 (4-12)	IPCC, 2003
		Americas other broadleaf	10 (3-12)	IPCC, 2003
		Asia Eucalyptus sp.	15 (5-25)	IPCC, 2003
		Asia other	7 (2-13)	IPCC, 2003

TABLE 4.10 (CONTINUED)
ABOVE-GROUND NET BIOMASS GROWTH IN TROPICAL AND SUB-TROPICAL FOREST PLANTATIONS

Domain	Ecological zone	Continent	Above-ground biomass growth (tonnes d.m. ha^{-1} yr^{-1})	References
	Subtropical steppe	Africa Eucalyptus sp. >20 y	8 (5-14)	IPCC, 2003
		Africa Eucalyptus sp. ≤20 y	5 (3-7)	IPCC, 2003
		Africa Pinus sp. > 20 y	2.5	IPCC, 2003
		Africa Pinus sp. ≤ 20 y	3 (0.5-6)	IPCC, 2003
		Africa other > 20 y	10	IPCC, 2003
		Africa other ≤ 20 y	15	IPCC, 2003
		Americas Eucalyptus sp.	20	IPCC, 2003
		Americas Pinus sp.	5	IPCC, 2003
		Asia	6 (1-12)	IPCC, 2003
	Subtropical mountain systems	Africa	10	IPCC, 2003
		Americas Eucalyptus sp.	10 (8-18)	IPCC, 2003
		Americas Pinus sp.	10	IPCC, 2003
		Americas Tectona grandis	2	IPCC, 2003
		Americas other broadleaf	4	IPCC, 2003
		Asia Eucalyptus sp.	3	IPCC, 2003
		Asia other	5 (1-10)	IPCC, 2003
Temperate	Temperate oceanic forest	Asia, Europe, broadleaf > 20 y	-	-
		Asia, Europe, broadleaf ≤ 20 y	-	-
		Asia, Europe, coniferous > 20 y	-	-
		Asia, Europe, coniferous ≤ 20 y	-	-
		North America	-	-
		New Zealand	-	-
		South America	-	-
	Temperate continental forest and mountain systems	Asia, Europe, broadleaf > 20 y	-	-
		Asia, Europe, broadleaf ≤ 20 y	-	-
		Asia, Europe, coniferous > 20 y	-	-
		Asia, Europe, coniferous ≤ 20 y	-	-
		North America	-	-
		South America	-	-
Boreal	Boreal coniferous forest and mountain systems	Asia, Europe > 20 y	-	-
		Asia, Europe ≤ 20 y	-	-
		North America	-	-
	Boreal tundra woodland	Asia, Europe > 20 y	-	-
		Asia, Europe ≤ 20 y	-	-
		North America	-	-

TABLE 4.11A **ABOVE-GROUND NET VOLUME GROWTH OF SELECTED FOREST PLANTATION SPECIES**	
Tree species	**Above-ground net volume growth (m^3 ha^{-1} y^{-1})**
Acacia auriculiformis	6 - 20
Acacia mearnsii	14 - 25
Araucaria angustifolia	8 - 24
Araucaria cunninghamii	10 - 18
Casuarina equisetifolia	6 - 20
Casuarina junghuhniana	7 - 11
Cordia alliadora	10 - 20
Cupressus lusitanica	8 - 40
Dalbergia sissoo	5 - 8
Eucalyptus camaldulensis	15 - 30
Eucalyptus deglupta	14 - 50
Eucalyptus globulus	10 - 40
Eucalyptus grandis	15 - 50
Eucalyptus robusta	10 - 40
Eucalyptus saligna	10 - 55
Eucalyptus urophylla	20 - 60
Gmelina arborea	12 - 50
Leucaena leucocephala	30 - 55
Pinus caribaea v. caribaea	10 - 28
Pinus caribaea v. hondurensis	20 - 50
Pinus oocarpa	10 - 40
Pinus patula	8 - 40
Pinus radiata	10 - 50
Swietenia macrophylla	7 - 30
Tectona grandis	6 - 18
Terminalia ivorensis	8 - 17
Terminalia superba	10 - 14
Source: Ugalde and Perez, 2001	

TABLE 4.11B
MEAN ANNUAL INCREMENT (GROWTH OF MERCHANTABLE VOLUME) FOR SOME FOREST PLANTATION SPECIES

Planted forest type/ region	Tree species	Mean annual increment (MAI) over rotation ($m^3\ ha^{-1}\ yr^{-1}$)	
		MAI min	MAI max
Productive plantations			
Africa	Acacia mellifera	2.2	4.0
	Acacia nilotica	15.0	20.0
	Acacia senegal	1.4	2.6
	Acacia seyal	2.0	6.0
	Ailanthus excelsa	6.6	9.4
	Bamboo bamboo	5.0	7.5
	Cupressus spp.	15.0	24.0
	Eucalyptus spp.	12.0	14.0
	Khaya spp.	8.5	12.0
	Tectona grandis	2.5	3.5
Asia	Eucalyptus camaldulensis	21.0	43.0
	Pinus spp.	4.0	15.0
South America	Tectona grandis	7.3	17.3
	Xylia xylocapa	3.0	8.8
	Acacia spp.	15.0	30.0
	Araucaria angustifolia	15.0	30.0
	Eucalyptus spp.	20.0	70.0
	Hevea brasiliensis	10.0	20.0
	Mimosa scabrella	10.0	25.0
	Pinus spp.	25.0	40.0
	Populus spp.	10.0	30.0
	Tectona grandis	15.0	35.0
Productive, semi-natural forests			
Africa	Acacia albida	4.0	6.1
	Acacia mellifera	1.9	3.5
	Acacia nilotica	12.5	20.0
	Acacia senegal	1.1	2.4
	Acacia seyal	1.8	3.2
	Acacia tortilis	1.2	3.7
	Acacia tortilis var siprocarpa	1.5	2.4
	Balanites aegyptiaca	1.2	1.5
	Sclerocarya birrea	1.5	1.7
	Ziziphus mauritiana	0.9	1.0
Protective plantations			
Africa	Acacia mellifera	2.0	6.0
	Acacia nilotica	13.0	21.0
	Acacia senegal	1.4	2.8
	Acacia seyal	1.9	4.3
	Ailanthus spp.	6.0	12.0
	Bamboo bamboo	4.0	8.0
	Cupressus spp.	14.0	20.0
	Eucalyptus spp.	10.0	14.0
	Khaya spp.	7.0	16.0
	Tectona grandis	5.0	8.0

TABLE 4.11B (CONTINUED) MEAN ANNUAL INCREMENT (GROWTH OF MERCHANTABLE VOLUME) FOR SOME FOREST PLANTATION SPECIES			
Planted forest type/ region	**Tree species**	**Mean annual increment (MAI) over rotation (m^3 ha^{-1} yr^{-1})**	
		MAI min	**MAI max**
Protective Semi-natural plantations			
Africa	Acacia albida	4.0	6.2
	Acacia mellifera	1.7	3.2
	Acacia nilotica	12.0	15.0
	Acacia senegal	1.1	2.4
	Acacia seyal	1.8	3.3
	Acacia tortilis	1.3	3.5
	Acacia tortilis var siprocarpa	1.6	2.4
	Balanites aegyptiaca	1.2	1.5
	Sclerocarya birrea	1.5	1.7
	Ziziphus mauritiana	0.9	1.0
Source: FAO at http://www.fao.org/forestry/			

TABLE 4.12 TIER 1 ESTIMATED BIOMASS VALUES FROM TABLES 4.7–4.11 (EXCEPT TABLE 4.11B) (VALUES ARE APPROXIMATE; USE ONLY FOR TIER 1)					
Climate domain	**Ecological zone**	**Above-ground biomass in natural forests (tonnes d.m. ha^{-1})**	**Above-ground biomass in forest plantations (tonnes d.m. ha^{-1})**	**Above-ground net biomass growth in natural forests (tonnes d.m. ha^{-1} yr^{-1})**	**Above-ground net biomass growth in forest plantations (tonnes d.m. ha^{-1} yr^{-1})**
Tropical	Tropical rain forest	300	150	7.0	15.0
	Tropical moist deciduous forest	180	120	5.0	10.0
	Tropical dry forest	130	60	2.4	8.0
	Tropical shrubland	70	30	1.0	5.0
	Tropical mountain systems	140	90	1.0	5.0
Sub-tropical	Subtropical humid forest	220	140	5.0	10.0
	Subtropical dry forest	130	60	2.4	8.0
	Subtropical steppe	70	30	1.0	5.0
	Subtropical mountain systems	140	90	1.0	5.0
Temperate	Temperate oceanic forest	180	160	4.4	4.4
	Temperate continental forest	120	100	4.0	4.0
	Temperate mountain systems	100	100	3.0	3.0
Boreal	Boreal coniferous forest	50	40	1.0	1.0
	Boreal tundra woodland	15	15	0.4	0.4
	Boreal mountain systems	30	30	1.0	1.0

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3})) 1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992			
Species	**Density**	**Continent**	**Reference**
Adina cordifolia	0.58-0.59	Asia	5
Aegle marmelo	0.75	Asia	5
Afzelia bipidensis	0.67-0.79	Africa	3
Agathis sp.	0.44	Asia	5
Aglaia llanosiana	0.89	Asia	5
Agonandra brasiliensis	0.74	Americas	4
Aidia ochroleuca	0.78	Africa	5
Alangium longiflorum	0.65	Asia	5
Albizia sp.	0.52	Americas	5
Albizzia amara	0.70	Asia	5
Albizzia falcataria	0.25	Asia	5
Alcornea sp.	0.34	Americas	5
Aldina heterophylla	0.73	Americas	4
Aleurites trisperma	0.43	Asia	5
Alexa grandiflora	0.59	Americas	4
Alexa imperatricis	0.52	Americas	4
Allophyllus africanus	0.45	Africa	5
Alnus ferruginea	0.38	Americas	5
Alnus japonica	0.43	Asia	5
Alphitonia zizyphoides	0.50	Asia	5
Alphonsea arborea	0.69	Asia	5
Alseodaphne longipes	0.49	Asia	5
Alstonia congensis	0.33	Africa	5
Amburana cearensis	0.43	Americas	1
Amoora sp.	0.60	Asia	5
Amphimas pterocarpoides	0.63	Africa	5
Anacardium excelsum	0.41	Americas	4
Anacardium giganteum	0.44	Americas	4
Anadenanthera macrocarpa	0.86	Americas	4
Andira inermis	0.64	Americas	4
Andira parviflora	0.69	Americas	4
Andira retusa	0.67	Americas	5
Aniba amazonica	0.52-0.56	Americas	1
Aniba canelilla	0.92	Americas	4
Aningeria robusta	0.44-0.53	Africa	3
Anisophyllea obtusifolia	0.63	Africa	5
Anisophyllea zeylanica	0.46	Asia	5
Anisoptera sp.	0.54	Asia	5
Annonidium mannii	0.29	Africa	5
Anogeissus latifolia	0.78-0.79	Asia	5
Anopyxis klaineana	0.74	Africa	5
Anthocephalus chinensis	0.33-0.36	Asia	5
Anthocleista keniensis	0.50	Africa	5
Anthonotha macrophylla	0.78	Africa	5
Anthostemma aubryanum	0.32	Africa	5
Antiaris africana	0.38	Americas	5
Antiaris sp.	0.38	Africa	5
Antidesma pleuricum	0.59	Asia	5
Antrocaryon klaineanum	0.50	Africa	5
Apeiba aspera	0.28	Americas	1
Apeiba echinata	0.36	Americas	5
Apeiba peiouma	0.20	Americas	4
Aphanamiris perrottetiana	0.52	Asia	5
Apuleia leiocarpa	0.70	Americas	1
Apuleia molaris	0.76	Americas	4
Araucaria bidwillii	0.43	Asia	5
Ardisia cubana	0.62	Americas	1
Artocarpus comunis	0.70	Americas	5
Artocarpus sp.	0.58	Asia	5
Aspidosperma album	0.76	Americas	4

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3})) 1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992			
Species	**Density**	**Continent**	**Reference**
Aspidosperma macrocarpon	0.67	Americas	1
Aspidosperma obscurinervium	0.86	Americas	4
Astronium gracile	0.73	Americas	4
Astronium graveolens	0.75	Americas	4
Astronium lecointei	0.73	Americas	5
Astronium ulei	0.71	Americas	4
Astronium urundeuva	1.21	Americas	4
Aucoumea klaineana	0.31-0.48	Africa	3
Autranella congolensis	0.78	Africa	5
Azadirachta sp.	0.52	Asia	5
Bagassa guianensis	0.69	Americas	4
Baillonella toxisperma	0.70	Africa	3
Balanites aegyptiaca	0.63	Africa	5
Balanocarpus sp.	0.76	Asia	5
Banara guianensis	0.61	Americas	5
Baphia kirkii	0.93	Africa	5
Barringtonia edulis	0.48	Asia	5
Basiloxylon exelsum	0.58	Americas	5
Bauhinia sp.	0.67	Asia	5
Beilschmiedia louisii	0.70	Africa	5
Beilschmiedia nitida	0.50	Africa	5
Beilschmiedia sp.	0.61	Americas	5
Beilschmiedia tawa	0.58	Asia	5
Berlinia sp.	0.58	Africa	5
Berrya cordifolia	0.78	Asia	5
Bertholletia excelsa	0.62	Americas	4
Bischofia javanica	0.54-0.62	Asia	5
Bixa arborea	0.32	Americas	4
Bleasdalea vitiensis	0.43	Asia	5
Blighia welwitschii	0.74	Africa	5
Bocoa sp.	0.42	Americas	1
Bombacopsis quinata	0.39	Americas	1
Bombacopsis sepium	0.39	Americas	5
Bombax costatum	0.35	Africa	3
Bombax paraense	0.39	Americas	1
Borojoa patinoi	0.52	Americas	5
Boswellia serrata	0.50	Asia	5
Bowdichia coccolobifolia	0.39	Americas	2
Bowdichia crassifolia	0.39	Americas	2
Bowdichia nitida	0.79	Americas	4
Bowdichia virgilioides	0.52	Americas	2
Brachystegia sp.	0.52	Africa	5
Bridelia micrantha	0.47	Africa	5
Bridelia squamosa	0.50	Asia	5
Brosimum acutifolium	0.55	Americas	4
Brosimum alicastrum	0.69	Americas	4
Brosimum guianense	0.96	Americas	4
Brosimum lactescens	0.70	Americas	1
Brosimum parinarioides	0.58	Americas	4
Brosimum potabile	0.53	Americas	4
Brosimum rubescens	0.87	Americas	4
Brosimum utile	0.40-0.49	Americas	1
Brysenia adenophylla	0.54	Americas	5
Buchenavia capitata	0.63	Americas	4
Buchenavia huberi	0.79	Americas	4
Buchenavia latifolia	0.45	Asia	5
Buchenavia oxycarpa	0.72	Americas	4
Buchenavia viridiflora	0.88	Americas	1
Bucida buceras	0.93	Americas	5
Bursera serrata	0.59	Asia	5
Bursera simaruba	0.29-0.34	Americas	5
Butea monosperma	0.48	Asia	5
Byrsonima coriacea	0.64	Americas	5
Byrsonima spicata	0.61	Americas	4

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Byrsonima verbascifolia	0.33	Americas	2
Cabralea canjerana	0.55	Americas	4
Caesalpinia sp.	1.05	Americas	5
Calophyllum brasiliense	0.53	Americas	4
Calophyllum sp.	0.46	Americas	1
Calophyllum sp.	0.53	Asia	5
Calpocalyx klainei	0.63	Africa	5
Calycarpa arborea	0.53	Asia	5
Calycophyllum spruceanum	0.74	Americas	1
Campnosperma panamensis	0.37	Americas	1
Cananga odorata	0.29	Asia	5
Canarium sp.	0.44	Asia	5
Canthium monstrosum	0.42	Asia	5
Canthium rubrocostratum	0.63	Africa	5
Carallia calycina	0.66	Asia	5
Carapa guianensis	0.55	Americas	4
Carapa procera	0.59	Africa	5
Cariniana integrifolia	0.49	Americas	4
Cariniana micrantha	0.64	Americas	4
Caryocar glabrum	0.65	Americas	1
Caryocar villosum	0.72	Americas	4
Casearia battiscombei	0.50	Africa	5
Casearia sp.	0.62	Americas	5
Cassia javanica	0.69	Asia	5
Cassia moschata	0.71	Americas	5
Cassia scleroxylon	1.01	Americas	4
Cassipourea euryoides	0.70	Africa	5
Cassipourea malosana	0.59	Africa	5
Castanopsis philippensis	0.51	Asia	5
Casuarina equisetifolia	0.81	Americas	5
Casuarina equisetifolia	0.83	Asia	5
Casuarina nodiflora	0.85	Asia	5
Catostemma commune	0.50	Americas	1
Cecropia sp.	0.36	Americas	5
Cedrela odorata	0.42	Americas	1
Cedrela odorata	0.38	Asia	5
Cedrela sp.	0.40-0.46	Americas	5
Cedrela toona	0.43	Asia	5
Cedrelinga catenaeformis	0.45	Americas	1
Ceiba pentandra	0.18-0.39	Africa	3
Ceiba pentandra	0.28	Americas	4
Ceiba pentandra	0.23	Asia	5
Ceiba samauma	0.57	Americas	1
Celtis luzonica	0.49	Asia	5
Celtis schippii	0.59	Americas	1
Celtis sp.	0.59	Africa	5
Centrolobium sp.	0.65	Americas	5
Cespedesia macrophylla	0.63	Americas	5
Cespedesia spathulata	0.54	Americas	1
Chaetocarpus schomburgkianus	0.80	Americas	5
Chisocheton pentandrus	0.52	Asia	5
Chlorophora excelsa	0.48-0.66	Africa	3
Chlorophora tinctoria	0.73	Americas	4
Chloroxylon swietenia	0.76-0.80	Asia	5
Chorisia integrifolia	0.28	Americas	1
Chrysophyllum albidum	0.56	Africa	5
Chukrassia tabularis	0.57	Asia	5
Citrus grandis	0.59	Asia	5
Clarisia racemosa	0.59	Americas	4
Cleidion speciflorum	0.50	Asia	5
Cleistanthus eollinus	0.88	Asia	5
Cleistanthus mildbraedii	0.87	Africa	5
Cleistocalyx sp.	0.76	Asia	5
Cleistopholis patens	0.36	Africa	5
Clusia rosea	0.67	Americas	5
Cochlospermum gossypium	0.27	Asia	5
Cochlospermum orinocensis	0.26	Americas	5
Cocos nucifera	0.50	Asia	5
Coda edulis	0.78	Africa	5
Coelocaryon preussii	0.56	Africa	5
Cola sp.	0.70	Africa	5
Colona serratifolia	0.33	Asia	5
Combretodendron quadrialatum	0.57	Asia	5
Conopharyngia holstii	0.50	Africa	5
Copaifera officinalis	0.61	Americas	1
Copaifera pubifora	0.56	Americas	1
Copaifera religiosa	0.50	Africa	5
Copaifera reticulata	0.63	Americas	4
Cordia alliodora	0.48	Americas	5
Cordia bicolor	0.49	Americas	4
Cordia gerascanthus	0.74	Americas	5
Cordia goeldiana	0.48	Americas	4
Cordia millenii	0.34	Africa	5
Cordia platythyrsa	0.36	Africa	5
Cordia sagotii	0.50	Americas	4
Cordia sp.	0.53	Asia	5
Corynanthe pachyceras	0.63	Africa	5
Corythophora rimosa	0.84	Americas	4
Cotylelobium sp.	0.69	Asia	5
Couepia sp.	0.70	Americas	5
Couma macrocarpa	0.50	Americas	4
Couratari guianensis	0.54	Americas	4
Couratari multiflora	0.47	Americas	4
Couratari oblongifolia	0.49	Americas	4
Couratari stellata	0.63	Americas	4
Crataeva religiosa	0.53	Asia	5
Cratoxylon arborescens	0.40	Asia	5
Croton megalocarpus	0.57	Africa	5
Croton xanthochloros	0.48	Americas	5
Cryptocarya sp.	0.59	Asia	5
Cryptosepalum staudtii	0.70	Africa	5
Ctenolophon englerianus	0.78	Africa	5
Cubilia cubili	0.49	Asia	5
Cullenia excelsa	0.53	Asia	5
Cupressus lusitanica	0.43-0.44	Americas	5
Curatella americana	0.41	Americas	2
Cylicodiscus gabonensis	0.80	Africa	5
Cynometra alexandri	0.74	Africa	5
Cynometra sp.	0.80	Asia	5
Cyrilla racemiflora	0.53	Americas	5
Dacrycarpus imbricatus	0.45-0.47	Asia	5
Dacrydium sp.	0.46	Asia	5
Dacryodes buttneri	0.44-0.57	Africa	3
Dacryodes excelsa	0.52-0.53	Americas	5
Dacryodes sp.	0.61	Asia	5
Dactyodes colombiana	0.51	Americas	5
Dalbergia paniculata	0.64	Asia	5
Dalbergia retusa.	0.89	Americas	5
Dalbergia stevensonii	0.82	Americas	5
Daniellia oliveri	0.53	Africa	3
Declinanona calycina	0.47	Americas	5
Decussocarpus vitiensis	0.37	Asia	5

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Degeneria vitiensis	0.35	Asia	5
Dehaasia triandra	0.64	Asia	5
Dendropanax arboreum	0.40	Americas	4
Desbordesia pierreana	0.87	Africa	5
Detarium senegalensis	0.63	Africa	5
Dialium excelsum	0.78	Africa	5
Dialium guianense	0.88	Americas	4
Dialium sp.	0.80	Asia	5
Dialyanthera sp.	0.36-0.48	Americas	5
Diclinanona calycina	0.47	Americas	4
Dicorynia ghuianensis	0.65	Americas	4
Dicorynia paraensis	0.60	Americas	5
Didelotia africana	0.78	Africa	5
Didelotia letouzeyi	0.50	Africa	5
Didymopanax sp.	0.74	Americas	5
Dillenia sp.	0.59	Asia	5
Dimorphandra mora	0.99	Americas	5
Dinizia excelsa	0.86	Americas	4
Diospyros sp.	0.82	Africa	5
Diospyros sp.	0.47	Americas	1
Diospyros sp.	0.70	Asia	5
Diplodiscus paniculatus	0.63	Asia	5
Diploon cuspidatum	0.85	Americas	4
Diplotropis martiusii	0.74	Americas	1
Diplotropis purpurea	0.78	Americas	4
Dipterocarpus caudatus	0.61	Asia	5
Dipterocarpus eurynchus	0.56	Asia	5
Dipterocarpus gracilis	0.61	Asia	5
Dipterocarpus grandiflorus	0.62	Asia	5
Dipterocarpus kerrii	0.56	Asia	5
Dipterocarpus kunstlerii	0.57	Asia	5
Dipterocarpus sp.	0.61	Asia	5
Dipterocarpus warburgii	0.52	Asia	5
Dipteryx odorata	0.93	Americas	4
Dipteryx polyphylla	0.87	Americas	4
Discoglypremna caloneura	0.32	Africa	5
Distemonanthus benthamianus	0.58	Africa	5
Dracontomelon sp.	0.50	Asia	5
Dryobalanops sp.	0.61	Asia	5
Drypetes sp.	0.63	Africa	5
Drypetes variabilis	0.71	Americas	4
Dtypetes bordenii	0.75	Asia	5
Durio sp.	0.53	Asia	5
Dussia lehmannii	0.59	Americas	5
Dyera costulata	0.36	Asia	5
Dysoxylum quercifolium	0.49	Asia	5
Ecclinusa bacuri	0.59	Americas	4
Ecclinusa guianensis	0.63	Americas	5
Ehretia acuminata	0.51	Africa	5
Elaeocarpus serratus	0.40	Asia	5
Emblica officinalis	0.80	Asia	5
Enantia chlorantha	0.42	Africa	5
Endiandra laxiflora	0.54	Asia	5
Endlicheria sp.	0.50	Americas	1
Endodesmia calophylloides	0.66	Africa	5
Endopleura uchi	0.78	Americas	4
Endospermum sp.	0.38	Asia	5
Entandrophragma utile	0.53-0.62	Africa	3
Enterolobium cyclocarpum	0.34	Americas	4
Enterolobium cyclocarpum	0.35	Asia	5
Enterolobium maximum	0.40	Americas	4
Enterolobium schomburgkii	0.78	Americas	4
Eperua falcata	0.78	Americas	4
Epicharis cumingiana	0.73	Asia	5
Eribroma oblongum	0.60	Africa	5
Eriocoelum microspermum	0.50	Africa	5
Eriotheca longipedicellata	0.45	Americas	4
Erisma uncinatum	0.47	Americas	1
Erismadelphus ensul	0.56	Africa	5
Erythrina sp.	0.23	Americas	5
Erythrina subumbrans	0.24	Asia	5
Erythrina vogelii	0.25	Africa	5
Erythrophleum ivorense	0.70-0.88	Africa	3
Erythrophloeum densiflorum	0.65	Asia	5
Eschweilera amazonica	0.90	Americas	4
Eschweilera coriacea	0.78	Americas	4
Eschweilera ovata	0.81	Americas	4
Eschweilera sagotiana	0.79	Americas	4
Eucalyptus citriodora	0.64	Asia	5
Eucalyptus deglupta	0.34	Asia	5
Eucalyptus robusta	0.51	Americas	5
Eugenia sp.	0.65	Asia	5
Eugenia stahlii	0.73	Americas	5
Euxylophora paraensis	0.70	Americas	4
Fagara macrophylla	0.69	Africa	5
Fagara sp.	0.69	Americas	5
Fagraea sp.	0.73	Asia	5
Ficus benjamina	0.65	Asia	5
Ficus insipida	0.50	Americas	1
Ficus iteophylla	0.40	Africa	5
Fumtumia latifolia	0.45	Africa	5
Gallesia integrifolia	0.51	Americas	1
Gambeya sp.	0.56	Africa	5
Ganua obovatifolia	0.59	Asia	5
Garcinia myrtifolia	0.65	Asia	5
Garcinia punctata	0.78	Africa	5
Garcinia sp.	0.75	Asia	5
Gardenia turgida	0.64	Asia	5
Garuga pinnata	0.51	Asia	5
Genipa americana	0.51	Americas	4
Gilletiodendron mildbraedii	0.87	Africa	5
Gluta sp.	0.63	Asia	5
Glycydendron amazonicum	0.66	Americas	4
Gmelina arborea	0.41-0.45	Asia	5
Gmelina vitiensis	0.54	Asia	5
Gonocaryum calleryanum	0.64	Asia	5
Gonystylus punctatus	0.57	Asia	5
Gossweilerodendron balsamiferum	0.40	Africa	5
Goupia glabra	0.68	Americas	1
Grewia tiliaefolia	0.68	Asia	5
Guarea cedrata	0.48-0.57	Africa	3
Guarea chalde	0.52	Americas	5
Guarea guidonia	0.68	Americas	4
Guarea kunthiana	0.60	Americas	1
Guatteria decurrens	0.52	Americas	1
Guatteria olivacea	0.51	Americas	4
Guatteria procera	0.65	Americas	4

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Guazuma ulmifolia	0.50-0.52	Americas	5
Guibourtia demeusii	0.70-0.84	Africa	3
Guillielma gasipae	0.95-1.25	Americas	5
Gustavia speciosa	0.34	Americas	1
Hannoa klaineana	0.28	Africa	5
Hardwickia binata	0.73	Asia	5
Harpullia arborea	0.62	Asia	5
Harungana madagascariensis	0.45	Africa	5
Helicostylis tomentosa	0.72	Americas	4
Heritiera sp.	0.56	Asia	5
Hernandia Sonora	0.29	Americas	5
Hevea brasiliensis	0.49	Americas	4
Hevea brasiliensis	0.53	Asia	5
Hexalobus crispiflorus	0.48	Africa	5
Hibiscus tiliaceus	0.57	Asia	5
Hieronyma chocoensis	0.59-0.62	Americas	1
Hieronyma laxiflora	0.55	Americas	1
Himatanthus articulatus	0.38	Americas	2
Hirtella davisii	0.74	Americas	5
Holoptelea grandis	0.59	Africa	5
Homalanthus populneus	0.38	Asia	5
Homalium sp.	0.70	Africa	5
Homalium sp.	0.76	Asia	5
Hopea acuminata	0.62	Asia	5
Hopea sp.	0.64	Asia	5
Huberodendron patinoi	0.50	Americas	1
Humiria balsamifera	0.66	Americas	4
Humiriastrum excelsum	0.75	Americas	4
Humiriastrum procera	0.70	Americas	5
Hura crepitans	0.36	Americas	4
Hyeronima alchorneoides	0.64	Americas	4
Hyeronima laxiflora	0.59	Americas	5
Hylodendron gabonense	0.78	Africa	5
Hymenaea courbaril	0.77	Americas	1
Hymenaea davisii	0.67	Americas	5
Hymenaea oblongifolia	0.62	Americas	1
Hymenaea parvifolia	0.95	Americas	4
Hymenolobium excelsum	0.64	Americas	4
Hymenolobium modestum	0.65	Americas	4
Hymenolobium pulcherrimum	0.67	Americas	4
Hymenostegia pellegrini	0.78	Africa	5
Inga alba	0.62	Americas	4
Inga edulis	0.51	Americas	1
Inga paraensis	0.82	Americas	4
Intsia palembanica	0.68	Asia	5
Irvingia grandifolia	0.78	Africa	5
Iryanthera grandis	0.55	Americas	4
Iryanthera sagotiana	0.57	Americas	4
Iryanthera trocornis	0.72	Americas	4
Jacaranda copaia	0.33	Americas	4
Joannesia heveoides	0.39	Americas	4
Julbernardia globiflora	0.78	Africa	5
Kayea garciae	0.53	Asia	5
Khaya ivorensis	0.40-0.48	Africa	3
Kingiodendron alternifolium	0.48	Asia	5
Klainedoxa gabonensis	0.87	Africa	5
Kleinhovia hospita	0.36	Asia	5
Knema sp.	0.53	Asia	5
Koompassia excelsa	0.63	Asia	5

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Koordersiodendron pinnatum	0.65-0.69	Asia	5
Kydia calycina	0.72	Asia	5
Lachmellea speciosa	0.73	Americas	5
Laetia procera	0.63	Americas	1
Lagerstroemia sp.	0.55	Asia	5
Lannea grandis	0.50	Asia	5
Lecomtedoxa klainenna	0.78	Africa	5
Lecythis idatimon	0.77	Americas	4
Lecythis lurida	0.83	Americas	4
Lecythis pisonis	0.84	Americas	4
Lecythis poltequi	0.81	Americas	4
Lecythis zabucaja	0.86	Americas	4
Letestua durissima	0.87	Africa	5
Leucaena leucocephala	0.64	Asia	5
Licania macrophylla	0.76	Americas	4
Licania oblongifolia	0.88	Americas	4
Licania octandra	0.77	Americas	4
Licania unguiculata	0.88	Americas	1
Licaria aritu	0.80	Americas	4
Licaria cannella	1.04	Americas	4
Licaria rigida	0.73	Americas	4
Lindackeria sp.	0.41	Americas	5
Linociera domingensis	0.81	Americas	5
Lithocarpus soleriana	0.63	Asia	5
Litsea sp.	0.40	Asia	5
Lonchocarpus sp.	0.69	Americas	5
Lophira alata	0.84-0.97	Africa	3
Lophopetalum sp.	0.46	Asia	5
Lovoa trichilioides	0.45	Africa	5
Loxopterygium sagotii	0.56	Americas	5
Lucuma sp.	0.79	Americas	5
Luehea sp.	0.50	Americas	5
Lueheopsis duckeana	0.62	Americas	4
Mabea piriri	0.59	Americas	5
Macaranga denticulata	0.53	Asia	5
Machaerium sp.	0.70	Americas	5
Maclura tinctoria	0.71	Americas	1
Macoubea guianensis	0.40	Americas	5
Madhuca oblongifolia	0.53	Asia	5
Maesopsis eminii	0.41	Africa	5
Magnolia sp.	0.52	Americas	5
Maguira sclerophylla	0.57	Americas	5
Malacantha sp.	0.45	Africa	5
Mallotus philippinensis	0.64	Asia	5
Malouetia duckei	0.57	Americas	4
Mammea africana	0.62	Africa	5
Mammea americana	0.62	Americas	5
Mangifera indica	0.55	Americas	5
Mangifera sp.	0.52	Asia	5
Manilkara amazonica	0.85	Americas	4
Manilkara bidentata	0.87	Americas	1
Manilkara huberi	0.93	Americas	4
Manilkara lacera	0.78	Africa	5
Maniltoa minor	0.76	Asia	5
Maquira sclerophylla	0.57	Americas	4
Marila sp.	0.63	Americas	5
Markhamia platycalyx	0.45	Africa	5
Marmaroxylon racemosum	0.81	Americas	4
Mastixia philippinensis	0.47	Asia	5
Matayba domingensis	0.70	Americas	5
Matisia hirta	0.61	Americas	5
Mauria sp.	0.31	Americas	1
Maytenus sp.	0.71	Americas	5
Melanorrhea sp.	0.63	Asia	5
Melia dubia	0.40	Asia	5
Melicope triphylla	0.37	Asia	5
Meliosma macrophylla	0.27	Asia	5

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Melochia umbellata	0.25	Asia	5
Memecylon capitellatum	0.77	Africa	5
Metrosideros collina	0.70-0.76	Asia	5
Mezilaurus itauba	0.70	Americas	4
Mezilaurus lindaviana	0.68	Americas	4
Michelia sp.	0.43	Asia	5
Michropholis sp.	0.61	Americas	5
Microberlinia brazzavillensis	0.70	Africa	5
Microcos coriaceus	0.42	Africa	5
Microcos stylocarpa	0.40	Asia	5
Micromelum compressum	0.64	Asia	5
Micropholi guyanensis	0.65	Americas	4
Micropholi venulosa	0.67	Americas	4
Milletia sp.	0.72	Africa	5
Milliusa velutina	0.63	Asia	5
Mimusops elengi	0.72	Asia	5
Minquartia guianensis	0.76	Americas	1
Mitragyna parviflora	0.56	Asia	5
Mitragyna stipulosa	0.47	Africa	5
Monopetalanthus heitzii	0.44-0.53	Africa	3
Mora excelsa	0.80	Americas	4
Mora gonggrijpii	0.78	Americas	1
Mora megistosperma	0.63	Americas	1
Mouriri barinensis	0.78	Americas	1
Mouriria sideroxylon	0.88	Americas	5
Musanga cecropioides	0.23	Africa	5
Myrciaria floribunda	0.73	Americas	5
Myristica platysperma	0.55	Americas	4
Myristica sp.	0.53	Asia	5
Myroxylon balsamum	0.78	Americas	1
Myroxylon peruiferum	0.78	Americas	1
Nauclea diderrichii	0.63	Africa	5
Nealchornea yapurensis	0.61	Americas	1
Nectandra rubra	0.57	Americas	5
Neesia sp.	0.53	Asia	5
Neonauclea bernardoi	0.62	Asia	5
Neopoutonia macrocalyx	0.32	Africa	5
Neotrewia cumingii	0.55	Asia	5
Nesogordonia papaverifera	0.65	Africa	5
Ochna foxworthyi	0.86	Asia	5
Ochroma pyramidale	0.30	Asia	5
Ochtocosmus africanus	0.78	Africa	5
Ocotea guianensis	0.63	Americas	4
Ocotea neesiana	0.63	Americas	4
Octomeles sumatrana	0.27-0.32	Asia	5
Odyendea sp.	0.32	Africa	5
Oldfieldia africana	0.78	Africa	5
Ongokea gore	0.72	Africa	5
Onychopetalum amazonicum	0.61	Americas	4
Ormosia coccinea	0.61	Americas	1
Ormosia paraensis	0.67	Americas	4
Ormosia schunkei	0.57	Americas	1
Oroxylon indicum	0.32	Asia	5
Otoba gracilipes	0.32	Americas	1
Ougenia dalbergiodes	0.70	Asia	5
Ouratea sp.	0.66	Americas	5
Oxystigma oxyphyllum	0.53	Africa	5
Pachira acuatica	0.43	Americas	5
Pachyelasma tessmannii	0.70	Africa	5
Pachypodanthium staudtii	0.58	Africa	5

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Palaquium sp.	0.55	Asia	5
Pangium edule	0.50	Asia	5
Paraberlinia bifoliolata	0.56	Africa	5
Parashorea stellata	0.59	Asia	5
Paratecoma peroba	0.60	Americas	5
Paratrophis glabra	0.77	Asia	5
Parinari excelsa	0.68	Americas	4
Parinari glabra	0.87	Africa	5
Parinari montana	0.71	Americas	4
Parinari rodolphii	0.71	Americas	4
Parinari sp.	0.68	Asia	5
Parkia multijuga	0.38	Americas	4
Parkia nitada	0.40	Americas	4
Parkia paraensis	0.44	Americas	4
Parkia pendula	0.55	Americas	4
Parkia roxburghii	0.34	Asia	5
Parkia ulei	0.40	Americas	4
Pausandra trianae	0.59	Americas	1
Pausinystalia brachythyrsa	0.56	Africa	5
Pausinystalia sp.	0.56	Africa	5
Payena sp.	0.55	Asia	5
Peltogyne paniculata	0.89	Americas	4
Peltogyne paradoxa	0.91	Americas	4
Peltogyne porphyrocardia	0.89	Americas	1
Peltophorum pterocarpum	0.62	Asia	5
Pentace sp.	0.56	Asia	5
Pentaclethra macroloba	0.43	Americas	1
Pentaclethra macrophylla	0.78	Africa	5
Pentadesma butyracea	0.78	Africa	5
Persea sp.	0.40-0.52	Americas	5
Peru glabrata	0.65	Americas	5
Peru schomburgkiana	0.59	Americas	5
Petitia domingensis	0.66	Americas	5
Phaeanthus ebracteolatus	0.56	Asia	5
Phyllanthus discoideus	0.76	Africa	5
Phyllocladus hypophyllus	0.53	Asia	5
Phyllostylon brasiliensis	0.77	Americas	4
Pierreodendron africanum	0.70	Africa	5
Pinus caribaea	0.51	Americas	5
Pinus caribaea	0.48	Asia	5
Pinus insularis	0.47-0.48	Asia	5
Pinus merkusii	0.54	Asia	5
Pinus oocarpa	0.55	Americas	5
Pinus patula	0.45	Americas	5
Piptadenia communis	0.68	Americas	4
Piptadenia grata	0.86	Americas	1
Piptadenia suaveolens	0.75	Americas	4
Piptadeniastrum africanum	0.56	Africa	5
Piratinera guianensis	0.96	Americas	5
Pisonia umbellifera	0.21	Asia	5
Pithecellobium guachapele	0.56	Americas	5
Pithecellobium latifolium	0.36	Americas	1
Pithecellobium saman	0.49	Americas	1
Pittosporum pentandrum	0.51	Asia	5
Plagiostyles africana	0.70	Africa	5
Planchonia sp.	0.59	Asia	5
Platonia insignis	0.70	Americas	5

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Platymiscium sp.	0.71-0.84	Americas	5
Podocarpus oleifolius	0.44	Americas	1
Podocarpus rospigliosii	0.57	Americas	1
Podocarpus sp.	0.43	Asia	5
Poga oleosa	0.36	Africa	5
Polyalthia flava	0.51	Asia	5
Polyalthia suaveolens	0.66	Africa	5
Polyscias nodosa	0.38	Asia	5
Pometia sp.	0.54	Asia	5
Poulsenia armata	0.37-0.44	Americas	1
Pourouma sp.	0.32	Americas	5
Pouteria anibifolia	0.66	Americas	1
Pouteria anomala	0.81	Americas	4
Pouteria caimito	0.87	Americas	4
Pouteria guianensis	0.90	Americas	4
Pouteria manaosensis	0.64	Americas	4
Pouteria oppositifolia	0.65	Americas	4
Pouteria villamilii	0.47	Asia	5
Premna angolensis	0.63	Africa	5
Premna tomentosa	0.96	Asia	5
Prioria copaifera	0.40-0.41	Americas	5
Protium heptaphyllum	0.54	Americas	4
Protium tenuifolium	0.65	Americas	4
Pseudolmedia laevigata	0.62-0.63	Americas	1
Pseudolmedia laevis	0.71	Americas	1
Pteleopsis hylodendron	0.63	Africa	5
Pterocarpus marsupium	0.67	Asia	5
Pterocarpus soyauxii	0.62-0.79	Africa	3
Pterocarpus vernalis	0.57	Americas	1
Pterogyne nitens	0.66	Americas	4
Pterygota sp.	0.52	Africa	5
Pterygota sp.	0.62	Americas	1
Pycnanthus angolensis	0.40-0.53	Africa	3
Qualea albiflora	0.50	Americas	5
Qualea brevipedicellata	0.69	Americas	4
Qualea dinizii	0.58	Americas	5
Qualea lancifolia	0.58	Americas	4
Qualea paraensis	0.67	Americas	4
Quararibea asterolepis	0.45	Americas	1
Quararibea bicolor	0.52-0.53	Americas	1
Quararibea cordata	0.43	Americas	1
Quassia simarouba	0.37	Americas	4
Quercus alata	0.71	Americas	5
Quercus costaricensis	0.61	Americas	5
Quercus eugeniaefolia	0.67	Americas	5
Quercus sp.	0.70	Asia	5
Radermachera pinnata	0.51	Asia	5
Randia cladantha	0.78	Africa	5
Raputia sp.	0.55	Americas	5
Rauwolfia macrophylla	0.47	Africa	5
Rheedia sp.	0.60	Americas	1
Rhizophora mangle	0.89	Americas	4
Ricinodendron heudelotii	0.20	Africa	5
Rollinia exsucca	0.52	Americas	4
Roupala moniana	0.77	Americas	4
Ruizierania albiflora	0.57	Americas	4
Saccoglottis gabonensis	0.74	Africa	5
Saccoglottis guianensis	0.77	Americas	4
Salmalia malabarica	0.32-0.33	Asia	5
Samanea saman	0.45-0.46	Asia	5
Sandoricum vidalii	0.43	Asia	5
Santiria trimera	0.53	Africa	5
Sapindus saponaria	0.58	Asia	5
Sapium ellipticum	0.50	Africa	5
Sapium luzontcum	0.40	Asia	5
Sapium marmieri	0.40	Americas	1
Schefflera morototoni	0.36	Americas	1
Schizolobium parahyba	0.40	Americas	1

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Schleichera oleosa	0.96	Asia	5
Schrebera arborea	0.63	Africa	5
Schrebera swietenoides	0.82	Asia	5
Sclerolobium chrysopyllum	0.62	Americas	4
Sclerolobium paraense	0.64	Americas	4
Sclerolobium peoppigianum	0.65	Americas	4
Scleronema micranthum	0.61	Americas	4
Sclorodophloeus zenkeri	0.68	Africa	5
Scottellia coriacea	0.56	Africa	5
Scyphocephalium ochocoa	0.48	Africa	5
Scytopetalum tieghemii	0.56	Africa	5
Semicarpus anacardium	0.64	Asia	5
Serialbizia acle	0.57	Asia	5
Serianthes melanesica	0.48	Asia	5
Sesbania grandiflora	0.40	Asia	5
Shorea assamica forma philippinensis	0.41	Asia	5
Shorea astylosa	0.73	Asia	5
Shorea ciliata	0.75	Asia	5
Shorea contorta	0.44	Asia	5
Shorea palosapis	0.39	Asia	5
Shorea plagata	0.70	Asia	5
Shorea polita	0.47	Asia	5
Shorea robusta	0.72	Asia	5
Shorea sp. (balau)	0.70	Asia	5
Shorea sp. (dark red meranti)	0.55	Asia	5
Shorea sp. (light red meranti)	0.40	Asia	5
Sickingia sp.	0.52	Americas	5
Simaba multiflora	0.51	Americas	5
Simarouba amara	0.36	Americas	1
Simira sp.	0.65	Americas	1
Sindoropsis letestui	0.56	Africa	5
Sloanea guianensis	0.79	Americas	5
Sloanea javanica	0.53	Asia	5
Sloanea nitida	1.01	Americas	4
Soymida febrifuga	0.97	Asia	5
Spathodea campanulata	0.25	Asia	5
Spondias lutea	0.38	Americas	4
Spondias mombin	0.31-0.35	Americas	1
Spondias purpurea	0.40	Americas	4
Staudtia stipitata	0.75	Africa	5
Stemonurus luzoniensis	0.37	Asia	5
Sterculia apetala	0.33	Americas	4
Sterculia pruriens	0.46	Americas	4
Sterculia rhinopetala	0.64	Africa	5
Sterculia speciosa	0.51	Americas	4
Sterculia vitiensis	0.31	Asia	5
Stereospermum suaveolens	0.62	Asia	5
Strephonema pseudocola	0.56	Africa	5
Strombosia philippinensis	0.71	Asia	5
Strombosiopsis tetrandra	0.63	Africa	5
Strychnos potatorum	0.88	Asia	5
Stylogyne sp.	0.69	Americas	5
Swartzia fistuloides	0.82	Africa	5
Swartzia laevicarpa	0.61	Americas	1
Swartzia panacoco	0.97	Americas	4
Swietenia macrophylla	0.43	Americas	1
Swietenia macrophylla	0.49-0.53	Asia	5

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Swintonia foxworthyi	0.62	Asia	5
Swintonia sp.	0.61	Asia	5
Sycopsis dunni	0.63	Asia	5
Symphonia globulifera	0.58	Africa	5
Symphonia globulifera	0.58	Americas	1
Syzygium cordatum	0.59	Africa	5
Syzygium sp.	0.69-0.76	Asia	5
Tabebuia rosea	0.54	Americas	1
Tabebuia serratifolia	0.92	Americas	1
Tabebuia stenocalyx	0.55-0.57	Americas	5
Tachigalia myrmecophylla	0.53	Americas	4
Talisia sp.	0.84	Americas	5
Tamarindus indica	0.75	Asia	5
Tapirira guianensis	0.50	Americas	4
Taralea oppositifolia	0.80	Americas	1
Tectona grandis	0.50-0.55	Asia	5
Terminalia amazonica	0.65	Americas	1
Terminalia citrina	0.71	Asia	5
Terminalia copelandii	0.46	Asia	5
Terminalia ivorensis	0.40-0.59	Africa	3
Terminalia microcarpa	0.53	Asia	5
Terminalia nitens	0.58	Asia	5
Terminalia oblonga	0.73	Americas	1
Terminalia pterocarpa	0.48	Asia	5
Terminalia superba	0.40-0.66	Africa	3
Terminalia tomentosa	0.73-0.77	Asia	5
Ternstroemia megacarpa	0.53	Asia	5
Tessmania africana	0.85	Africa	5
Testulea gabonensis	0.60	Africa	5
Tetragastris altissima	0.74	Americas	4
Tetragastris panamensis	0.76	Americas	4
Tetrameles nudiflora	0.30	Asia	5
Tetramerista glabra	0.61	Asia	5
Tetrapleura tetraptera	0.50	Africa	5
Thespesia populnea	0.52	Asia	5
Thyrsodium guianensis	0.63	Americas	4
Tieghemella africana	0.53-0.66	Africa	3
Toluifera balsamum	0.74	Americas	5
Torrubia sp.	0.52	Americas	5
Toulicia pulvinata	0.63	Americas	5
Tovomita guianensis	0.60	Americas	5
Trattinickia sp.	0.38	Americas	5
Trema orientalis	0.31	Asia	5
Trema sp.	0.40	Africa	5
Trichilia lecointei	0.90	Americas	4
Trichilia prieureana	0.63	Africa	5
Trichilia propingua	0.58	Americas	5
Trichoscypha arborea	0.59	Africa	5
Trichosperma mexicanum	0.41	Americas	5
Trichospermum richii	0.32	Asia	5
Triplaris cumingiana	0.53	Americas	5
Triplochiton scleroxylon.	0.28-0.44	Africa	3
Tristania sp.	0.80	Asia	5
Trophis sp.	0.44	Americas	1
Turpinia ovalifolia	0.36	Asia	5
Vantanea parviflora	0.86	Americas	4
Vatairea guianensis	0.70	Americas	4
Vatairea paraensis	0.78	Americas	4
Vatairea sericea	0.64	Americas	4
Vateria indica	0.47	Asia	5
Vatica sp.	0.69	Asia	5
Vepris undulata	0.70	Africa	5
Virola michelii	0.50	Americas	4
Virola reidii	0.35	Americas	1
Virola sebifera	0.37	Americas	1

TABLE 4.13 BASIC WOOD DENSITY (D) OF TROPICAL TREE SPECIES (OVEN-DRY TONNES (MOIST M^{-3}))
1 = Baker *et al.*, 2004b; 2 = Barbosa and Fearnside, 2004; 3 = CTFT, 1989; 4 = Fearnside, 1997; 5 = Reyes *et al.*, 1992

Species	Density	Continent	Reference
Vismia sp.	0.41	Americas	5
Vitex doniana	0.40	Africa	5
Vitex sp.	0.52-0.57	Americas	5
Vitex sp.	0.65	Asia	5
Vitex stahelii	0.60	Americas	5
Vochysia densiflora	0.29	Americas	1
Vochysia ferruginea	0.37	Americas	1
Vochysia guianensis	0.53	Americas	4
Vochysia lanceolata	0.49	Americas	1
Vochysia macrophylla	0.36	Americas	1
Vochysia maxima	0.47	Americas	4
Vochysia melinonii	0.51	Americas	4
Vochysia obidensis	0.50	Americas	4
Vochysia surinamensis	0.66	Americas	4
Vouacapoua americana	0.79	Americas	4
Warszewicsia coccinea	0.56	Americas	5
Wrightia tinctorea	0.75	Asia	5
Xanthophyllum excelsum	0.63	Asia	5
Xanthoxylum martinicensis	0.46	Americas	5
Xanthoxylum sp.	0.44	Americas	5
Xylia xylocarpa	0.73-0.81	Asia	5
Xylopia frutescens	0.64	Americas	5
Xylopia nitida	0.57	Americas	4
Xylopia staudtii	0.36	Africa	5
Zanthoxylum rhetsa	0.33	Asia	5
Zizyphus sp.	0.76	Asia	5

TABLE 4.14
BASIC WOOD DENSITY (D) OF SELECTED TEMPERATE AND BOREAL TREE TAXA

Taxon	D [oven-dry tonnes (moist m^{-3})]	Source
Abies spp.	0.40	2
Acer spp.	0.52	2
Alnus spp.	0.45	2
Betula spp.	0.51	2
Fagus sylvatica	0.58	2
Fraxinus spp.	0.57	2
Larix decidua	0.46	2
Picea abies	0.40	2
Picea sitchensis	0.40	3
Pinus pinaster	0.44	4
Pinus radiata	0.38 (0.33 - 0.45)	1
Pinus strobus	0.32	2
Pinus sylvestris	0.42	2
Populus spp.	0.35	2
Prunus spp.	0.49	2
Pseudotsuga menziesii	0.45	2
Quercus spp.	0.58	2
Salix spp.	0.45	2
Tilia spp.	0.43	2

1 = Beets et al., 2001
2 = Dietz, 1975
3 = Knigge and Shulz, 1966
4 = Rijsdijk and Laming, 1994

Annex 4A.1 Glossary for Forest Land

Terminology for stocks and changes in forests as defined in this volume			
Component	**State**	**Increase**	**Decrease from harvest**
Merchantable volume	growing stock	net annual increment	removals
Biomass in the merchantable volume	growing stock biomass	increment biomass	removals biomass
Total above-ground biomass	above-ground biomass	above-ground biomass growth	above-ground biomass removals
Total below-ground biomass	below-ground biomass	below-ground biomass growth	below-ground biomass[1] removals
Total above-ground and below-ground biomass	total biomass	total biomass growth	biomass removals
Carbon	carbon in … (in any of the compartments above, e.g., carbon in growing stock or biomass removals), or in litter, dead wood and soil organic matter		

ABOVE-GROUND BIOMASS

All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage.

Note: In cases where forest understory is a relatively small component of the above-ground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series.

ABOVE-GROUND BIOMASS GROWTH

Oven-dry weight of net annual increment (s.b.) of a tree, stand or forest plus oven-dry weight of annual growth of branches, twigs, foliage, top and stump. The term “growth” is used here instead of “increment”, since the latter term tends to be understood in terms of merchantable volume.

AFFORESTATION[2]

The direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources.

AGROFORESTRY

A land-use system that involves deliberate retention, introduction, or mixture of trees or other woody perennials in crop and animal production systems to take advantage of economic or ecological interactions among the components (Dictionary of Forestry, helms, 1998, Society of American Foresters).

BASIC WOOD DENSITY

Ratio between oven dry mass and fresh stem-wood volume without bark.

BELOW-GROUND BIOMASS

All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.

BIOMASS CONVERSION AND EXPANSION FACTOR (BCEF)

A multiplication factor that coverts merchantable volume of growing stock, merchantable volume of net annual increment, or merchantable volume of wood-removal and fuelwood-removals to above-ground biomass, above-ground biomass growth, or biomass removals, repectively. Biomass conversion and expansion factors for growing stock ($BCEF_S$), for net annual increment ($BCEF_I$), and for wood-removal and fuelwood-removals

[1] Occurs in some cases, e.g., where root stocks (walnut) or entire root systems are removed (biomass harvesting).

[2] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land Use, Land-use Change and Forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

($BCEF_R$) usually differ. As used in these guidelines, they account for above-ground components only. For more detail see Box 4.2.

BIOMASS EXPANSION FACTOR (BEF)

A multiplication factor that expands the dry-weight of *growing stock biomass*, *increment biomass*, and biomass of *wood-removal or fuelwood-removals* to account for non-merchantable or non-commercial biomass components, such as stump, branches, twigs, foliage, and, sometimes, non-commercial trees. Biomass expansion factors usually differ for growing stock (BEF_S), net annual increment (BEF_I), and wood-removal and fuelwood-removals (BEF_R). As used in these guidelines, biomass expansion factors account for above-ground components only. For more detail see Box 4.2.

BIOMASS REMOVALS

Biomass of wood-removal and firewood-removals (s.b.) plus oven-dry weight of branches, twigs, foliage of the trees or stands removed.

CANOPY COVER

See crown cover

CARBON CONTENT

Absolute amount of carbon in a pool or parts of it.

CARBON FRACTION

Tonnes of carbon per tonne of biomass dry matter.

CARBON IN…

See table above; absolute amount in tonnes, obtained by multiplying amount of biomass in respective component by the applicable carbon fraction, usually 50%.

CARBON STOCK

The quantity of carbon in a pool.

CARBON STOCK CHANGE

The carbon stock in a pool changes due to gains and losses. When losses exceed gains, the stock decreases, and the pool acts as a source; when gains exceed losses, the pools accumulate carbon, and the pools act as a sink.

CLOSED FOREST

Formations where trees, in the various stories and the undergrowth, cover a high proportion of the ground (>40%).

CONVERSION

Change of one land use to another.

CONVERSION FACTOR

Multiplier that transforms the measurement units of an item without affecting its size or amount. For example, basic wood density is a conversion factor that transforms green volume of wood into dry weight.

CROWN COVER

The percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage (cannot exceed 100%).

DEAD WOOD

Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10cm in diameter (or the diameter specified by the country).

DEAD WOOD BIOMASS

All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots down to a diameter of 2mm, and stumps larger than or equal to 10cm in diameter or any other diameter used by the country.

DEFORESTATION[3]

The direct human-induced conversion of forested land to non-forested land.

DISTURBANCE

A disturbance is defined as an environmental fluctuation and destructive event that disturb forest health, structure, and/or change resources or physical environment at any given spatial or temporal scale. Disturbances that affect health and vitality which include biotic agents such as insects and diseases, and abiotic agents such as fire, pollution, and extreme weather conditions (see also below, mortality and other disturbance).

DISTURBANCE BY DISEASES

Disturbances caused by diseases attributable to pathogens such as bacteria, fungi, phytoplasma, or virus.

DISTURBANCE BY FIRE

Disturbance caused by wildfire regardless of whether it broke out inside or outside the Forest. A wildfire is any unplanned and uncontrolled wildland fire which, regardless of ignition source, may require suppression response.

DISTURBANCE BY INSECTS

Disturbance caused by insect pests that are detrimental to tree health.

DRY (FOREST)

Moisture regimes for boreal and temperate zones are defined by the ratio of mean annual precipitation (MAP) and potential evapotranspiration (PET): Dry (MAP/PET < 1) and Wet (MAP/PET > 1); and for tropical zones by precipitation alone: Dry (MAP < 1,000mm), Moist (MAP: 1,000-2,000mm) and Wet (MAP > 2,000mm).

DRY MATTER (D.M.)

Dry matter refers to biomass that has been dried to an oven-dry state, often at 70ºC.

FELLINGS

Volume (over bark) of all trees, living or dead, above a 10cm diameter at breast height, felled annually in forests or other wooded land. It includes volume of all felled trees whether or not they are removed. It includes silvicultural and pre-commercial thinning and cleanings of trees of more than 10cm diameter, left in the forest, and natural losses that are recovered.

Note: In these guidelines, only the terms "wood-removal" and "fuelwood-removals" are used, consistent with GFRA 2005. Removals are generally a subset of fellings.

FOREST[4]

Forest is a minimum area of land of 0.05 – 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 – 30 per cent with trees with the potential to reach a minimum height of 2 – 5 metres at maturity *in situ*. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high portion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10 – 30 per cent or tree height of 2 – 5 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest.

FOREST INVENTORY

System for measuring the extent, quantity, and condition of a forest, usually by sampling:

1. A set of objective sampling methods designed to quantify the spatial distribution, composition, and rates of change of forest parameters within specified levels of precision for the purpose of management;
2. The listing of data from such a survey. May be made of all forest resources including trees and other vegetation, fish, insects, and wildlife, as well as street trees and urban forest trees.

---

[3] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land Use, Land-use Change and Forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

[4] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land Use, Land-use Change and Forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

FOREST LAND

This category includes all land with woody vegetation consistent with thresholds used to define Forest Land in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but *in situ* could potentially reach the threshold values used by a country to define the Forest Land category.

FOREST MANAGEMENT[5]

A system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner.

FOREST PLANTATION

Forest stands established by planting or/and seeding in the process of afforestation or reforestation. They are either of introduced species (all planted stands), or intensively managed stands of indigenous species, which meet all the following criteria: one or two species at planting, even age class, and regular spacing.

FUELWOOD-REMOVAL

The wood removed for energy production purposes, regardless of whether for industrial, commercial, or domestic use. Fuel wood includes wood collected or removed directly from forest or other wooded land for energy purposes only. It excludes fuelwood which is produced as a by-product or residual matter from the industrial processing of round wood. It includes removal from fellings in an earlier period and from trees killed or damaged by natural causes. It also includes removal by local people or owners for their own use.

GROWING STOCK

Volume over bark of all living trees more than X cm in diameter at breast height. It includes the stem from ground level or stump height up to a top diameter of Y cm, and may also include branches to a minimum diameter of W cm. Countries indicate the three thresholds (X, Y, W in cm) and the parts of the tree that are not included in the volume. Countries also indicate whether the reported figures refer to volume above ground or above stump. The diameter is measured at 30cm above the end of the buttresses if these are higher than 1 meter. It includes windfallen living trees and excludes smaller branches, twigs, foliage, flowers, seeds, and roots.

GROWING STOCK BIOMASS

Oven-dry weight of the growing stock (s.a.).

HARVEST LOSS

Difference between the assessed merchantable volume of growing stock and the actual volume of the harvested timber. Due to different measurement rules for standing and felled timber, losses are from bucking, breakage, defect.

INCREMENT BIOMASS

Oven-dry weight of (merchantable) net annual increment of a tree, stand, or forest.

INTENSIVE FOREST MANAGEMENT

A regime of forest management, where silvicultural practices define the structure and composition of forest stands. A formal or informal forest management plan exists.

A forest is not under intensive management, if mainly natural ecological processes define the structure and composition of stands.

INTRODUCED SPECIES

A species introduced outside of its normal past and current distribution.

LITTER

Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2mm) and less than the minimum diameter chosen for dead wood (e.g., 10cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil

[5] Forest management has particular meaning under the Marrakesh Accords, which may require subdivision of the managed forest as described in Chapter 4.

typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.

LOW ACTIVITY CLAY (LAC) SOILS

Soils with low activity clay (LAC) minerals are highly weathered soils dominated by 1:1 clay mineral and amorphous iron and aluminium oxides (in FAO classification included: Acrisols, Nitosols, Ferrasols).

MANAGED FOREST

A managed forest is forest land subjected to conditions defined for managed land.

MANAGED LAND

Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions.

MERCHANTABLE VOLUME

Mechantable volume is the volume overbark of all trees defined using the conditions described for growing stocks. Further, this can be applied to growing stocks as well as net annual increment and wood removals.

MOIST (FOREST)

Moisture regimes for boreal and temperate zones are defined by the ratio of mean annual precipitation (MAP) and potential evapotranspiration (PET): Dry (MAP/PET < 1) and Wet (MAP/PET > 1); and for tropical zones by precipitation alone: Dry (MAP < 1,000mm), Moist (MAP: 1,000-2,000mm) and Wet (MAP > 2,000mm).

MORTALITY

Trees dying naturally from competition in the stem-exclusion stage of a stand or forest. As used here, mortality does not include losses due to disturbances (s.a.).

NATURAL FOREST

A forest composed of indigenous trees and not classified as a forest plantation.

NATURAL REGENERATION

Re-establishment of a forest stand by natural means i.e., by natural seeding or vegetative regeneration. It may be assisted by human intervention e.g., by scarification of the soil or fencing to protect against wildlife or domestic animal grazing.

NET ANNUAL INCREMENT

Average annual volume of gross increment over the given reference period minus mortality (s.a.), of all trees to a specified minimum diameter at breast height. As used here, it is not net of losses due to disturbances (s.a.).

ORGANIC SOILS

Soils are organic if they satisfy the requirements 1 and 2, or 1 and 3 below (FAO, 1998):

1) Thickness of organic horizon greater than or equal to 10cm. A horizon of less than 20cm must have 12 percent or more organic carbon when mixed to a depth of 20cm.
2) Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter).
3) Soils are subject to water saturation episodes and has either:
    a. At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or
    b. At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or
    c. An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

OTHER DISTURBANCE

Disturbance caused by factors other than fire, insects, or diseases. May include areas affected by drought, flooding, windfalls, acid rain, etc.

PEAT SOIL (ALSO HISTOSOL)

A typical wetland soil with a high water table and an organic layer of at least 40cm thickness (poorly drained organic soil).

POOL/CARBON POOL

A reservoir. A system which has the capacity to accumulate or release carbon. Examples of carbon pools are forest biomass, wood products, soils, and the atmosphere. The units are in mass.

REFORESTATION[6]

Direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land. For the first commitment period, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989.

REMOVAL BIOMASS

Oven dry weight of wood removals.

REVEGETATION[7]

A direct human-induced activity to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of afforestation and reforestation contained here.

ROOT-SHOOT RATIO

Ratio of below-ground biomass to above-ground biomass; applies to above-ground biomass, above-ground biomass growth, biomass removals and may differ for these components.

ROUNDWOOD

All round wood felled or otherwise harvested and removed; it comprises all wood obtained from removals e.g., quatities removed from forests and from trees outside forests, including wood recovered from natural felling and logging losses during a period. In the production statistics, it represents the sum of fuelwood, including wood for charcoal, saw-and veneer logs, pulpwood and other industrial roundwood. In the trade statistics, it represents the sum of industrial roundwood, and fuelwood, including wood for charcoal. It is reported in cubic meters *excluding bark.*

SANDY SOILS

Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay (based on standard textural measurements (in FAO classification include: Arenosols, sandy Regosols)).

SAVANNA

Savannas are tropical and subtropical formations with continuous grass cover, occasionally interrupted by trees and shrubs. Savannas are found in Africa, Latin America, Asia and Australia.

SEASONAL (FOREST)

Semi-deciduous forests with a distinct wet and dry season and rainfall between 1,200 and 2,000 mm per year.

STAND–REPLACING DISTURBANCES

Major disturbances which kill or remove all the existing trees above the forest floor vegetation. Minor disturbances leave some of the pre-disturbance trees alive.

SHRUB

Woody perennial plants, generally more than 0.5 meters and less than 5 meters in height at maturity and without definite crown. Height limits for trees and shrubs should be interpreted with flexibility, particularly the minimum tree and maximum shrub height, which may vary between 5 and 7 meters.

---

[6] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land Use, Land-use Change and Forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

[7] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land Use, Land-use Change and Forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

SOIL CARBON

Organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots of less than 2mm (or other value chosen by the country as diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.

SOIL ORGANIC MATTER

Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series. Live and dead fine roots and DOM within the soil, that are less than the minimum diameter limit (suggested 2mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically. The default for soil depth is 30cm and guidance on determining country-specific depths is given in Chapter 2.3.3.1.

SPODIC SOILS

Soils exhibiting strong podzolization (in FAO classification includes many Podzolic groups).

TOTAL BIOMASS

Growing stock biomass of trees, stands or forests plus biomass of branches, twigs, foliage, seeds, stumps, and sometimes, non-commercial trees. Differentiated into above-ground biomass and below-ground biomass (s.a.). If there is no misunderstanding, possible also just to use "biomass" with the same meaning.

TOTAL BIOMASS GROWTH

Biomass of the net annual increment (s.a.) of trees, stands, or forests, plus the biomass of the growth of branches, twigs, foliage, seeds, stumps, and sometimes, non-commercial trees. Differentiated into above-ground biomass growth and below-ground biomass growth (s.a.). If there is no misunderstanding, possible also just to use "biomass growth" with the same meaning. The term "growth" is used here instead of "increment", since the latter term tends to be understood in terms of merchantable volume.

TREE

A woody perennial with a single main stem, or in the case of coppice with several stems, having a more or less definitive crown. Includes bamboos, palms, and other woody plants meeting the above criteria.

VOLUME OVERBARK

Growing stock or merchantable wood measured outside, that is including the bark. Bark adds 5-25% of total volume, depending on tree diameter and bark thickness of species. The weighted average bark percentage calculated from the data of TBFRA 2000 is 11% of the volume outside bark.

VOLUME UNDERBARK

Growing stock or merchantable wood without the bark. See above.

WET (FOREST)

Moisture regimes for boreal and temperate zones are defined by the ratio of mean annual precipitation (MAP) and potential evapotranspiration (PET): Dry (MAP/PET < 1) and Wet (MAP/PET > 1); and for tropical zones by precipitation alone: Dry (MAP < 1,000mm), Moist (MAP: 1,000-2,000mm) and Wet (MAP > 2,000mm).

WOODY BIOMASS

Biomass from trees, bushes and shrubs, for palms, bamboos not strictly correct in the botanical sense.

WOOD FUEL

Also wood-based fuels, wood-derived biofuels. All types of biofuels originating directly or indirectly from woody biomass.

WOOD-REMOVAL

The wood removed (volume of round wood over bark) for production of goods and services other than energy production (fuelwood). The term removal differs from fellings as it excludes felled trees left in the forest. It includes removal from fellings of an earlier period and from trees killed or damaged by natural causes. It also includes removal by local people or owners for their own use. As the term "removal" is used in the context of climate change to indicate sequestration of greenhouse gases from the atmosphere, removal in the context of forest harvesting should always be used as "wood-removal or fuelwood-removal" to avoid misunderstandings.

References

Australian Greenhouse Gas Office (AGO) (2002). Greenhouse Gas Emissions from Land Use Change in Australia: An Integrated Application of the National Carbon Accounting System (2002).

Andreae, M.O. and Merlet, P. (2001). Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles* **15**: 955-966.

Armentano, T.V. and Menges, E.S. (1986). Patterns of change in the carbon balance of organic soil-wetlands of the temperate zone. *Journal of Ecology* **74**: 755-774.

Baker, T.R., Phillips, O.L., Malhi, Y., Almeida, S., Arroyo, L., Di Fiore, A., Erwin, T., Higuchi, N., Killeen, T.J., Laurance, S.G., Laurance, W.F., Lewis, S.L., Monteagudo, A., Neill, D.A., Vargas, P.N., Pitman, N.C.A., Silva, J.N.M. and Martínez, R.V. (2004a). Increasing biomass in Amazonian forest plots. *Philosophical Transactions of the Royal Society of London* B **359**: 353-365.

Baker, T.R., Phillips, O.L., Malhi, Y., Almeida, S., Arroyo, L., Di Fiore, A., Erwin, T., Killeen, T.J., Laurance, S.G., Laurance, W.F., Lewis, S.L., Lloyd, J., Monteagudo, A., Neill, D.A., Patiño, S., Pitman, N.C.A., Silva, J.N.M. and Martínez, R.V. (2004b). Variation in wood density determines spatial patterns in Amazonian forest biomass. *Global Change Biology* **10**: 545-562.

Barbosa, R.I. and Fearnside, P.M. (2004). Wood density of trees in open savannas of the Brazilian Amazon. *Forest Ecology and Management* **199**: 115-123.

Battles, J.J., Armesto, J.J., Vann, D.R., Zarin, D.J., Aravena, J.C., Pérez, C. and Johnson, A.H. (2002). Vegetation composition, structure, and biomass of two unpolluted watersheds in the Cordillera de Piuchué, Chiloé Island, Chile. *Plant Ecology* **158**: 5-19.

Beets, P.N., Gilchrist, K. and Jeffreys, M.P. (2001). Wood density of radiata pine: Effect of nitrogen supply. *Forest Ecology and Management* 145: 173-180.

Bhatti, J.S., Apps, M.J., and Jiang, H. (2001). Examining the carbon stocks of boreal forest ecosystems at stand and regional scales. In: Lal R. et al. (eds.) Assessment Methods for Soil Carbon, Lewis Publishers, Boca Raton FL, pp. 513-532.

Cairns, M.A., Brown, S., Helmer, E.H. and Baumgardner, G.A. (1997). Root biomass allocation in the world's upland forests. *Oecologia* **111**: 1-11.

Cannell, M.G.R. (1982). World forest biomass and primary production data. Academic Press, New York, NY.

Centre Technique Forestier Tropical (CTFT) (1989). Memento du Forestier, 3e Édition. Ministère Français de la Coopération et du Développement, Paris, France.

Chambers, J.Q., Tribuzy, E.S., Toledo, L.C., Crispim, B.F., Higuchi, N., dos Santos, J., Araújo, A.C., Kruijt, B., Nobre, A.D. and Trumbore, S.E. (2004). Respiration from a tropical forest ecosystem: Partitioning of sources and low carbon use efficiency. *Ecological Applications* **14**: S72-S88.

Chambers, J.Q., dos Santos, J., Ribeiro, R.J., and Higuchi, N. (2001a). Tree damage, allometric relationships, and above-ground net primary production in a tropical forest. *Forest Ecology and Management* **152**: 73-84.

Chambers, J.Q., Schimel, J.P. and Nobre, A.D. (2001b). Respiration from coarse wood litter in Central Amazon Forests. *Biogeochemistry* **52**: 115-131.

Clark, D.A., Piper, S.C., Keeling, C.D. and Clark, D.B. (2003). Tropical rain forest tree growth and atmospheric carbon dynamics linked to interannual temperature variation during 1984-2000. *Proceedings of the National Academy of Sciences of the USA* **100**: 5852-5857.

de Groot, W.J., Bothwell, P.M., Carlsson, D.H. and Logan, K.A. (2003). Simulating the effects of future fire regimes on western Canadian boreal forests. *Journal of Vegetation Science* 14: 355-364

DeWalt, S.J. and Chave, J. (2004). Structure and biomass of four lowland Neotropical forests. *Biotropica* **36**: 7-19.

Dietz, P. (1975). Dichte und Rindengehalt von Industrieholz. Holz Roh- *Werkstoff* **33**: 135-141.

Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C. and Wisniewski, J. (1994). Carbon pools and flux of global forest ecosystems. *Science* **263**(1544): 185-190.

Dong, J., Kaufmann, R.K., Myneni, R.B., Tucker, C.J., Kauppi, P.E., Liski, J., Buermann, W., Alexeyev, V. and Hughes, M.K. (2003). Remote sensing estimates of boreal and temperate forest woody biomass: Carbon pools, sources, and sinks. *Remote Sensing of Environment* **84**: 393-410.

Dubé, S., Plamondon, A.P. and Rothwell, R.L. (1995). Watering up after clear-cutting on forested wetlands of the St. Lawrence lowland. *Water Resources Research* **31**:1741-1750.

Echeverria, C. and Lara, A. (2004). Growth patterns of secondary Nothofagus obliqua-N. alpina forests in southern Chile. *Forest Ecology and Management* **195**: 29-43.

Ellert, B.H., Janzen, H.H. and McConkey, B.G. (2001). Measuring and comparing soil carbon storage. In: R. Lal, J.M. Kimble, R.F. Follett and B.A. Stewart (eds.). Soil Management for Enhancing Carbon Sequestration. CRC Press, Boca Raton, FL., pp. 593-610.

Falloon, P. and Smith, P. (2003). Accounting for changes in soil carbon under the Kyoto Protocol: need for improved long-term data sets to reduce uncertainty in model projections. *Soil Use and Management*, **19**, 265-269.

Fearnside, P.M. (1997). Wood density for estimating forest biomass in Brazilian Amazonia. *Forest Ecology and Management* **90**: 59-87.

Feldpausch, T.R., Rondon, M.A., Fernandes, E.C.M. and Riha, S.J. (2004). Carbon and nutrient accumulation in secondary forests regenerating on pastures in central Amazonia. *Ecological Applications* **14**: S164-S176.

Filipchuk, A.N., Strakhov, V.V., Borisov, B.A. *et al*. (2000). A Brief National Overview on Forestry Sector and Wood Products: Russian Federation. UN ECE, FAO. New York, Geneva. ECE/TIM/SP/18, p. 94 (In Russian).

Fittkau, E.J. and Klinge, N.H. (1973). On biomass and trophic structure of the central Amazonian rainforest ecosystem. *Biotropica* **5**: 2-14.

Food and Agriculture Organization (FAO) 2001. Global forest resources assessment 2000. FAO, Rome, Italy.

Food and Agriculture Organization (FAO) 2006. Global forest resources assessment 2005. FAO, Rome, Italy.

Gayoso, J. and Schlegel, B. (2003). Estudio de línea de base de carbono: Carbono en bosques nativos, matorrales y praderas de la Décima Región de Chile. Universidad Austral de Chile, Valdivia, Chile.

Gayoso, J., Guerra, J. and Alarcón, D. (2002). Contenido de carbono y funciones de biomasa en especies natives y exóticas. Universidad Austral de Chile, Valdivia, Chile.

Gower, S.T., Krankina, O., Olson, R.J., Apps, M., Linder, S. and Wang, C. (2001). Net primary production and carbon allocation patterns of boreal forest ecosystems. *Ecological Applications* **11**: 1395-1411.

Hall, G.M.J. (2001). Mitigating an organization's future net carbon emissions by native forest restoration. *Ecological Applications* **11**: 1622-1633.

Hall, G.M.J. and Hollinger, D. Y. (1997). Do the indigenous forests affect the net CO_2 emission policy of New Zealand? *New Zealand Forestry* **41**: 24-31.

Hall, G.M.J., Wiser, S.K., Allen, R.B., Beets, P.N. and Goulding, C.J. (2001). Strategies to estimate national forest carbon stocks from inventory data: The 1990 New Zealand baseline. *Global Change Biology* **7**: 389-403.

Harmand, J.M., Njiti, C.F., Bernhard-Reversat, F. and Puig, H. (2004). Aboveground and belowground biomass, productivity and nutrient accumulation in tree improved fallows in the dry tropics of Cameroon. *Forest Ecology and Management* **188**: 249-265.

Harmon, M.E. and Marks, B. (2002). Effects of silvicultural practices on carbon stores in Douglas-fir-western hemlock forests in the Pacific Northwest, USA: results from a simulation model. *Canadian Journal of Forest Research* **32** (5): 863-877.

Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R., Lienkaemper, G.W., Cromack, J.R. and Cummins, K.W. (1986). Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research* **15**: 133–302.

Hessl, A.E., Milesi, C., White, M.A., Peterson, D.L. and Keane, R. (2004). Ecophysiological parameters for Pacific Northwest trees. U.S. Department of Agriculture, Forest Service, Portland, OR.

Hinds, H.V. and Reid, J.S. (1957). Forest trees and timbers of New Zealand. New Zealand Forest Service Bulletin 12: 1-221.

Hughes, R.F., Kauffman, J.B. and Jaramillo, V.J. (1999). Biomass, carbon, and nutrient dynamics of secondary forests in a humid tropical region of México. *Ecology* **80**: 1892-1907.

Hughes, R.F., Kauffman, J.B. and Jaramillo-Luque, V.J. (2000). Ecosystem-scale impacts of deforestation and land use in a humid tropical region of México. *Ecological Applications* **10**: 515-527.

IPCC (1997). Revised 1996 IPCC Guidelines for National Greenhouse Inventories. Houghton J.T., Meira Filho L.G., Lim B., Tréanton K., Mamaty I., Bonduki Y., Griggs D.J. Callander B.A. (Eds). Intergovernmental Panel on Climate Change (IPCC), IPCC/OECD/IEA, Paris, France.

IPCC (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. Penman J., Gytarsky M., Hiraishi T., Krug, T., Kruger D., Pipatti R., Buendia L., Miwa K., Ngara T., Tanabe K., Wagner F. (Eds).Intergovernmental Panel on Climate Change (IPCC), IPCC/IGES, Hayama, Japan.

Jenkins, J.C., Chojnacky, D.C., Heath, L.S. and Birdsey, R.A. (2004). Comprehensive database of diameter-based biomass regressions for North American tree species. U.S. Department of Agriculture, Forest Service, Newtown Square, PA.

Jobbagy, E.G. and Jackson, R.B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* **19**(2):423-436.

Johnson, D.W., and Curtis, P.S. (2001). Effects of forest management on soil C and N storage: meta analysis. *Forest Ecology and Management* **140**: 227-238.

Johnson, D.W., Knoepp, J.D. and Swank, W.T. (2002). Effects of forest management on soil carbon: results of some long-term resampling studies. *Environment Pollution* **116**: 201-208.

Knigge, W. and Schulz, H. (1966). Grundriss der Forstbenutzung. Verlag Paul Parey, Hamburg, Berlin.

Köppen, W. (1931). Grundriss der Klimakunde. Walter deGruyter Co., Berlin, Germany.

Kraenzel, M., Castillo, A., Moore, T. and Potvin, C. (2003). Carbon storage of harvest-age teak (Tectona grandis) plantations, Panama. *Forest Ecology and Management* **173**: 213-225.

Kurz, W.A., Apps, M.J., Banfield, E. and Stinson, G. (2002). Forest carbon accounting at the operational scale. *The Forestry Chronicle* **78**: 672-679.

Kurz, W.A. and Apps, M.J. (2006). Developing Canada's national forest carbon monitoring, accounting and reporting system to meet the reporting requirements of the Kyoto Protocol. *Mitigation and Adaptation Strategies for Global Change* **11**(1): 33-43.

Kurz, W.A., Apps, M.J., Webb, T.M. and McNamee, P.J. (1992). The carbon budget of the Canadian forest sector: phase I. Forestry Canada, Northwest Region. Information Report NOF-X-326, 93 pp.

Kurz, W.A., Beukema, S.J. and Apps, M.J. (1998). Carbon budget implications of the transition from natural to managed disturbance regimes in forest landscapes. *Mitigation and Adaptation Strategies for Global Change* **2**:405-421.

Kurz, W.A., Beukema, S.J. and Apps, M.J. (1996). Estimation of root biomass and dynamics for the carbon budget model of the Canadian forest sector. *Can. J. For. Res.* **26**:1973-1979.

Lamlom, S.H. and Savidge, R.A. (2003). A reassessment of carbon content in wood: variation within and between 41 North American species. *Biomass and Bioenergy* **25**: 381-388.

Lasco, R.D. and Pulhin, F.B. (2003). Philippine forest ecosystems and climate change: Carbon stocks, rate of sequestration and the Kyoto Protocol. *Annals of Tropical Research* **25**: 37-51.

Levy, P.E., Hale, S.E. and Nicoll, B.C. (2004). Biomass expansion factors and root:shoot ratios for coniferous tree species in Great Britain. Forestry 77: 421-430.

Li, C. and Apps, M.J. (2002). Fire Regimes and the Carbon Dynamics of Boreal Forest Ecosystems. In Shaw C. and Apps MJ (Eds). The role of Boreal Forests and Forestry in the Global Carbon Budget, Northern Forestry Centre Report Fo42-334/2000E, 107-118.

Li, C., Kurz, W.A., Apps, M.J. and Beukema, S.J. (2003). Belowground biomass dynamics in the Carbon Budget Model of the Canadian Forest Sector: recent improvements and implications for the estimation of NPP and NEP. *Canadian Journal of Forest Research* **33**: 126-136.

Liski, J., Pussinen, A., Pingoud, K., Makipaa, R. and Karjalainen, T. (2001). Which rotation length is favourable to carbon sequestration? *Canadian Journal of Forest Research* **31**: 2004-2013.

Loveland, T.R, Reed, B.C., Brown, J.F., Ohlen, D.O., Zhu, Z., Yang, L. and Merchant, J.W. (2000). Development of a global land cover characteristics database and IGBP DISCover from 1-km AVHRR data. *International Journal of Remote Sensing* **21**: 1303-1330.

Lugo, A.E., Wang, D. and Bormann, F.H. (1990). A comparative analysis of biomass production in five tropical tree species. *Forest Ecology and Management* **31**: 153-166.

Malhi, Y., Baker, T.R., Phillips, O.L., Almeida, S., Alvarez, E., Arroyo, L., Chave, J., Czimczik, C.I., Di Fiore, A., Higuchi, N., Killeen, T.J., Laurance, S.G., Laurance, W.F., Lewis, S.L., Montoya, L.M.M., Monteagudo, A., Neill, D.A., Vargas, P.N., Patiño, S., Pitman, N.C.A., Quesada, C.A., Salomãos, R., Silva, J.N.M., Lezama, A.T., Martínez, R.V., Terborgh, J., Vinceti, B. and Lloyd, J. (2004). The above-ground coarse wood productivity of 104 Neotropical forest plots. *Global Change Biology* **10**: 563-591.

Matthews, G.A.R. (1993). The carbon content of trees. UK Forestry Commission, Edinburgh, UK.

McGroddy, M.E., Daufresne, T. and Hedin, L.O. (2004). Scaling of C:N:P stoichiometry in forests worldwide: Implications of terrestrial Redfield-type ratios. *Ecology* **85**: 2390-2401.

McKenzie, N.J., Cresswell, H.P., Ryan, P.J. and Grundy, M. (2000). Opportunities for the 21st century: Expanding the horizons for soil, plant, and water analysis. *Communications in Soil Science and Plant Analysis* **31**: 1553-1569.

Mokany, K., Raison, J.R. and Prokushkin, A.S. (2006). Critical analysis of root:shoot ratios in terrestrial biomes. *Global Change Biology* **12**: 84-96.

Monte, L, Hakanson, L., Bergstrom, U., Brittain, J. and Heling, R. (1996). Uncertainty analysis and validation of environmental models: the empirically based uncertainty analysis. *Ecological Modelling* **91**:139-152.

Montès, N., Bertaudière-Montes, V., Badri, W., Zaoui, E.H. and Gauquelin, T. (2002). Biomass and nutrient content of a semi-arid mountain ecosystem: the Juniperus thurifera L. woodland of Azzaden Valley (Morocco). *Forest Ecology and Management* **166**: 35-43.

Nygård, R., Sawadogo, L. and Elfving, B. (2004). Wood-fuel yields in short-rotation coppice growth in the north Sudan savanna in Burkina Faso. *Forest Ecology and Management* **189**: 77-85.

Ogle, S.M., Breidt, F.J., Eve, M.D. and Paustian, K. (2003). Uncertainty in estimating land use and management impacts on soil organic carbon storage for U.S. agricultural lands between 1982 and 1997. *Global Change Biology* **9**:1521-1542.

Ogle, S.M., Breidt, F.J. and Paustian, K. (2006). Bias and variance in model results associated with spatial scaling of measurements for parameterization in regional assessments. *Global Change Biology* **12**:516-523.

Post, W.M. and Kwon, K.C. (2000). Soil carbon sequestration and land-use change: processes and potential. *Global Change Biology* **6**:317-327.

Poupon, H. (1980). Structure et dynamique de la strate ligneuse d'une steppe Sahélienne au nord du Sénégal. Office de la Recherche Scientifique et Technique Outre-Mer, Paris, France.

Powers, J.S., Read, J.M., Denslow, J.S. and Guzman, S.M. (2004). Estimating soil carbon fluxes following land-cover change: a test of some critical assumptions for a region in Costa Rica. *Global Change Biology* **10**:170-181.

Pregitzer, K.S. (2003). Woody plants, carbon allocation and fine roots. *New Phytologist* **158** (3): 421-424.

Reyes, G., Brown, S., Chapman, J. and Lugo, A.E. (1992). Wood densities of tropical tree species. U.S. Department of Agriculture, Forest Service, New Orleans, LA.

Rijsdijk, J.F. and Laming, P.B. (1994). Physical and related properties of 145 timbers. Kluwer Academic Publishers, Dordrecht, Netherlands.

Saldarriaga, J.G., West, D.C., Tharp, M.L. and Uhl, C. (1988). Long term chronosequence of forest succession in the upper Rio Negro of Colombia and Venezuela. *Journal of Ecology* **76**: 938-958.

Scott, N.A., Tate, K.R., Giltrap, D.J., *et al.* (2002). Monitoring land-use change effects on soil carbon in New Zealand: quantifying baseline soil carbon stocks. *Environmental Pollution* **116**: 167-186.

Sebei, H., Albouchi, A., Rapp, M. and El Aouni, M.H. (2001). Évaluation de la biomasse arborée et arbustive dans une séquence de dégradation de la suberaie à Cytise de Kroumirie (Tunisie). *Annals of Forest Science* **58**: 175-191.

Siltanen, et al. (1997). A soil profile and organic carbon data base for Canadian forest and tundra mineral soils. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta.

Singh, K. and Misra, R. (1979). Structure and Functioning of Natural, Modified and Silvicultural Ecosystems in Eastern Uttar Pradesh. Banras Hindu University, Varanasi, India.

Singh, S.S., Adhikari, B.S. and Zobel, D.B. (1994). Biomass, productivity, leaf longevity, and forest structure in the central Himalaya. *Ecological Monographs* **64**: 401-421.

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

Smithwick, E.A.H., Harmon, M.E., Remillard, S.M., Acker, S.A. and Franklin, J.F. (2002). Potential upper bounds of carbon stores in forests of the Pacific Northwest. *Ecological Applications* **12**: 1303-1317.

Somogyi, Z., Cienciala, E., Mäkipää, R., Muukkonen, P., Lehtonen, A. and Weiss, P. (2006). Indirect methods of large-scale forest biomass estimation. *European Journal of Forest Research*. DOI: 10.1007/s10342006-0125-7.

Stape, J.L., Binkley, D. and Ryan, M.G. (2004). Eucalyptus production and the supply, use and efficiency of use of water, light and nitrogen across a geographic gradient in Brazil. *Forest Ecology and Management* **193**: 17-31.

Stephens, P., Trotter, C., Barton, J., Beets, P., Goulding, C., Moore, J., Lane, P. and Payton, I. (2005). Key elements in the development of New Zealand's carbon monitoring, accounting and reporting system to meet Kyoto Protocol LULUCF good practice guidance, Poster paper presented at IUFRO World Congress, Brisbane Australia, August 2005.

Stocks, B.J., Mason, J.A., Todd, J.B., Bosch, E.M., Wotton, B.M., Amiro, B.D., Flannigan, M.D., Hirsch, K.G., Logan, K.A., Martell, D.L., and Skinner, W.R. (2002). "Large forest fires in Canada, 1959 – 1997", *Journal of Geophysical Research,* **107,** 8149 [printed 108(D1), 2003].

Trotter, C., Barton, J., Beets, P., Goulding, C., Lane, P., Moore, J., Payton, I., Rys, G., Stephens, P., Tate, K. and Wakelin, S. (2005). New Zealand's approach to forest inventory under the UNFCCC and Kyoto Protocol. Proceedings of the International Workshop of Forest Inventory for the Kyoto Protocol (Eds Matsumoto, M. and Kanomata, H.), pp. 33–43, published by: Division of Policy and Economics, Forestry and Forest Products Research Institute, 1 Matsunosato, Tsukuba, Ibaraki, 305-8687, Japan.

Trotter, C.M. (1991). Remotely sensed data as an information source for Geographical Information Systems in natural resource management. *International Journal of Geographical Information Systems* **5**, No. 2, 225-240.

Ugalde, L. and Perez, O. (2001). Mean annual volume increment of selected industrial forest planatation species. Food and Agriculture Organization, Rome, Italy.

VandenBygaart, A.J., Gregorich, E.G., Angers, D.A., *et al.* (2004). Uncertainty analysis of soil organic carbon stock change in Canadian cropland from 1991 to 2001. *Global Change Biology* **10**:983-994.

Wulder, M., Kurz, W.A. and Gillis, M. (2004). National level forest monitoring and modeling in Canada, Progress in Planning, Volume 61:365-381.

Zianis, D., Muukkonen, P., Mäkipää, R. and Mencuccini, M. (2005). Biomass and stem volume equations for tree species in Europe. *Silva Fennica*, Monographs 4. 63. p.