CHAPTER 4

FOREST LANDS

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This section has further elaboration on methods, and also provides new guidance.

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

Refining Application of Default Equations

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.

Three-Pool Steady-State C Model

The three-pool steady-state soil C model is based on estimating C inputs to soils and applying soil carbon pool specific decomposition rates that are modified by given environmental conditions and management practices. This model embraces more of the heterogeneity in soils, by subdividing soil C pool into different rates of turnover, i.e., fast (Active Pool), intermediate (Slow Pool), and long turnover times (Passive Pool).

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

No Refinement. See 2013 Wetlands Supplement.

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

Refining Application of Default Equations

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 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. The depth for evaluating soil C stock changes can be extended with the Tier 2 method. However, this will require extending the depth of the reference C stocks (SOC_{REF}) and stock change factors for all land uses (i.e., F_{LU}, F_I, and F_{MG}) to ensure consistency. Variable depths between reference stocks and stock change factors are likely to introduce biases into the inventory estimates computed using Equation 2.25.

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 different forest types, management practices and disturbance regimes, in which case stock change factors should 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, Batjes 2011). Additional guidance for deriving stock change factors and reference C stocks is provided in Section 2.3.3.1 (Chapter 2).

BOX X.X
GUIDANCE FOR DEVELOPING TIER 2 STOCK CHANGE FACTORS FOR FOREST LANDS

Several meta-analyses and reviews provide analyses and references to support incorporation of country-specific data into a Tier 2 method with estimation of management effects and corresponding stock change factors (F_{MG}) for *Forest Land Remaining Forest Land*. Quantification of management effects becomes increasingly important in cases in which forests represent a significant sink or source or in which changes in management intensity or regime are expected to result in gains or losses compared to earlier practices. Increased use of harvest residues or stumps for bioenergy is one example of changes in management intensity and regime. Past analyses have focused on the effects following harvests of different intensities (e.g., Johnson and Curtis 2001; Achat et al. 2015a; James and Harrison 2016; Zhou et al. 2013). Response ratios or effect sizes based on measurements of soil carbon stocks reflect all changes associated with a management action; thus separate carbon stock factors for input of organic matter (F_I) cannot be derived from the existing data.

Most field experiments have been carried out in cool temperate regions, and meta-analyses or reviews on harvest effects can be found to support adaptation of Tier 2 methods for these regions (Nave et al. 2010; Thiffault et al. 2011; Clarke et al. 2015; Hume et al. 2017). When selecting harvesting experiments on which to base the calculation of stock change factors, several factors need to be considered: intensity of harvest, treatment of harvest residues and other site preparation practices, such as burning, time since the management action, and soil layers and sampling depths (Liao et al. 2010; Strömgren et al. 2013; Achat et al. 2015b; James and Harrison 2016; Dean et al. 2017; Hume et al. 2017). Tree species composition, i.e., conifers versus broad-leaved or mixed species, could also influence the management effect although the influence can be confounded by other factors (e.g. Hume et al. 2017). The question of control conditions for evaluating the management action is of great importance because the control is often not a native reference condition, but rather another managed forest (Dean et al. 2017). This should be taken into account when estimating a stock change factor based on several field studies as well as the relationship to country-specific reference soil C stock.

Conclusions on the harvesting effects differ between meta-analyses. Confounding factors between field experiments and the different data selection criteria and weighting procedures could have contributed to the lack of consistency among these analyses. As an example, whole-tree harvests resulted in average 7.5% smaller carbon stocks in mineral soil than the stocks measured 10–30 years after stem-only harvests (Achat et al. 2015a). However, no effect was found in some other meta-analyses (Clarke et al. 2015; Hume et al. 2017) or a positive effect was reported (James and Harrison 2016). A tendency for smaller carbon stocks in forest floor has been reported after the whole-tree harvest compared to the stem-only or pre-treatment conditions (Johnson and Curtis 2001; Thiffault et al. 2011; Clarke et al. 2015).

Considerable spatial variability increases the challenge to detect relatively small management effects in soil C stocks (Jandl et al. 2007). Most studies have focused on the first one or two decades after the harvest, which can be considered too short to reveal the impacts of forest management actions on soil carbon stock changes, especially in the cool climate regions with long rotation periods (Clarke et al. 2015, Dean et al. 2017). Non-linearity in the responses has also been observed. For example an increase in soil C stocks after an initial decrease has been observed for a group of studies on Spodosols from a cool and humid climate with longer monitoring periods, up to eight decades or more (James and Harrison 2016).

In addition to guidance in this Chapter 4.2.3.2 above, detailed guidance on estimation of country-specific stock change factors and reference C stocks in general is given in Chapter 2, in Section 2.3.3.1., including guidance on using models to derive carbon stock change factors.

Three-Pool Steady-State C Model

Default parameters are provided for the three-pool steady-state C pool equations (Chapter 2, Section 2.3.3.1, Table 2), but parameters may be revised if experimental data are available to test the model.

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

No Refinement. See 2013 Wetlands Supplement.

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

Refining Application of Default Equations

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 forest type (native forest into a new forest type, and vice versa); intensification of forest management activities, such as site preparation, tree planting, interval and intensity of thinning and rotation length changes; changes in harvesting practices (bole vs. whole-tree harvesting; amount of residues left on-site); and the frequency of disturbances (e.g., pest and disease outbreaks, flooding, fires, typhoon/cyclone/hurricane, snow damage). 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 methods 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.

Three-Pool Steady-State C Model

This method requires soil C input data based on the amount of biomass that is converted to dead organic matter annually (i.e., annual litter fall). This rate will vary depending on the forest type, management activity, natural disturbance, and other environmental variables. Removals or reductions in dead organic matter are subtracted from the C input amount, which could occur with of wood from salvage logging operations and other removals of coarse woody debris, in addition to fires. Disturbance events, such as pest outbreaks, may increase the dead organic matter, and therefore C input to soils. Beyond the amount of C input, the average lignin and nitrogen contents of the new dead organic matter are also required to estimate the size of the three soil C pools.

Annual C input to soil can be estimated based on forest inventory data, ecosystem models and as a fraction from estimated net primary production (NPP)[1]. Estimation of the amount of annual C input based on forest inventory data requires models for biomass and models for annual turnover rates of litter (e.g., Liski et al. 2006, Kim et al. 2016). Moreover, the amount of understory vegetation litter is essential for soil C stock estimation, especially on high latitudes, where average litter input from understorey litter is similar to litter input from trees (Lehtonen et al. 2016). The litter input from senescence of fine tree roots is another important source of C input, which can be estimated based on the fine root production and turnover rate in boreal, temperate and tropical forests (Finér et al. 2011)

Additional ancillary data for this method include monthly weather data and soil texture (i.e., sand content), which are available from global weather and soils datasets if country-specific data are not available, such as the CRU

[1] A default method for estimating C inputs is under development and will be provided in the Second Order Draft for reviewer comments.

climate dataset (https://crudata.uea.ac.uk/cru/data/hrg/), and the Harmonized World Soil Database (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/), respectively.

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

No Refinement. See 2013 Wetlands Supplement.

4.2.3.4 CALCULATION STEPS FOR TIER 1

No Refinement

4.2.3.5 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 (see e.g. Peltoniemi et al. 2006, Metsäranta et al. 2017). However, if soil model parameters have been estimated with a Bayesian approach, the resultant joint probability distribution for the parameters can be sampled in a Monte Carlo Analysis to capture parameter uncertainty, along with sampling of probability distribution functions for model inputs and other associated data, see Lehtonen and Heikkinen (2016). 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, Ogle et al. 2007). 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-CO2 greenhouse gas emissions from biomass burning

No refinement

4.3 LAND CONVERTED TO FOREST LAND

4.3.1 Biomass

No refinement

4.3.2 Dead organic matter

No refinement

4.3.3 Soil carbon

This section has further elaboration on methods, and also provides new guidance.

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

Refining Application of Default Equations

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.

Three-Pool Steady-State C Model

The three-pool steady-state soil C model is based on estimating C inputs to soils and applying soil carbon pool specific decomposition rates that are modified by given environmental conditions and management practices. This model embraces more of the heterogeneity in soils, by subdividing soil C pool into different rates of turnover, i.e., fast (Active Pool), intermediate (Slow Pool), and long turnover times (Passive Pool).

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

No Refinement. See 2013 Wetlands Supplement

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

Refining Application of Default Equations

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.

The depth for evaluating soil C stock changes can also be extended with the Tier 2 method. This will require extending the depth of the reference C stocks (SOC_{REF}) and stock change factors for all land uses (i.e., F_{LU}, F_I, and F_{MG}) to ensure consistency. Variable depths between reference stocks and stock change factors are likely to introduce biases into the inventory estimates that are computed using Equation 2.25.

For the case of land use change to a system that is increasing in C, such as Croplands converted to Forest Land, a Tier 2 method may be a more accurate way to estimate the increase of soil C stocks to native levels given that this generally can take more than 20 years. In this case, the Tier 1 method may overestimate soil C stock increases on an annual basis (e.g., Villarino et al., 2014).

Furthermore, inventories may be improved by estimating carbon stocks on a mass equivalency basis if developing country-specific factors for F_{LU},. This is because the soil weight in a certain soil depth changes with the various activities associated with land use change, for example uprooting, land leveling, and rain compaction due to the disappearance of the cover of tree canopy. In addition, cropland soils usually tend to have relatively higher density than the soils in forest land and possibly grasslands or wetlands. Settlement management may also impact the soil bulk density. In such case, the comparison of the soil carbon stocks between the cropland, settlement, grassland, wetland, or forest land within the same depth is not appropriate. It is more robust to compare the carbon stock on an equivalent mass basis, with the stock change calculated on the same weight soil. However, it is important to realize that all measurements and associated stock change factors across all land uses must be on an equivalent mass basis if this method is applied. This will be challenging and possibly not even practical when compiling a national inventory.

Three-Pool Steady-State C Model

Default parameters are provided for the three-pool steady-state C pool equations (Chapter 2, Section 2.3.3.1, Table 2), but parameters may be revised if experimental data are available to test the model.

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

No Refinement. See 2013 Wetlands Supplement

4.3.3.3 CHOICE OF ACTIVITY DATA

Mineral soils

Tier 1 and Tier 2 - Application of Default Equations

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, Wetlands in 7.2.3.2, 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 2 - Three-Pool Steady-State C Model

This method requires soil C input data based on the amount of biomass that is converted to dead organic matter annually. This rate will vary depending on plant production, management activity, natural disturbances, and other environmental variables. Removals or reductions in dead organic matter are subtracted from the soil C input amount, which could occur with practices such as salvage logging, energy use of harvested residues, and other removals of coarse woody debris burning of grasslands, field burning of agricultural residues, livestock grazing, and other practices. Disturbance events, such as pest outbreaks, may increase the dead organic matter, and therefore the C input to soils. It is good practice to use country-specific methods for estimating C input to soils, but defaults approaches are provided for cropland (Section 5.2.3.3) and grassland (Section 6.2.3.3). See Section 4.2.3.3 for additional information about estimating C input to soils for forest lands.

Beyond the amount of C input, the average lignin and nitrogen contents of the new dead organic matter are also required to estimate the amount of C in the three soil pools. Tillage management data are also required for croplands (proportion of full tillage, reduced tillage and no-till), and irrigation data for any lands that are provided supplement water.

Additional ancillary data for this method include monthly weather data and soil texture (i.e., sand content), which are available from global weather and soils datasets if country-specific data are not available, such as the CRU climate dataset (https://crudata.uea.ac.uk/cru/data/hrg/), and the Harmonized World Soil Database (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/), respectively.

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

No Refinement. See 2013 Wetlands Supplements.

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

No Refinement

4.3.3.5 UNCERTAINTY ASSESSMENT

No Refinement

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

4.4.1 Completeness

No refinement

4.4.2 Developing a consistent time 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 forest-related activity data and emission factors may only be available every few years, achieving time series consistency may require interpolation or extrapolation from longer timeseries or trend.

In addition to the general guidance on linear interpolation or extrapolation in Volume 1, Chapter 5, further guidance is provided here on how to ensure methodological consistency when more sophisticated extrapolation is done in the forest land category, based on “functional relationships” among various interrelated variables. This more complex inter/extrapolation may allow reflecting the evolution of the main drivers of emissions and removals during the period to be gap filled, including forest increment and harvest, with a greater level of accuracy than a simple linear interpolation or extrapolation.

Typically, these functional relationships are expressed in models which are applied to simulate the dynamics of carbon stocks in different pools, taking into account a number of interrelated variables, or “methodological elements”. These methodological elements include: forest area; forest characteristics and management practices (including forest types, soil types, tree species composition, growing stock, age-class structure, increments, regeneration modality, rotation lengths, thinning frequency, etc.); carbon pools and gases; the estimation parameters for HWP; the treatment of natural disturbances; the possible inclusion of impact of “indirect human-induced effects" (see Section 2.5), such as human-induced climate and environmental changes (e.g., temperature, precipitation, CO_2 and nitrogen deposition feedbacks) that affect growth, mortality, decomposition rates and natural disturbances regimes.

It is good practice that the model used for inter/extrapolation utilizes information on the methodological element above that are consistent with those used in the rest of the time series.

With regard to harvest rate, i.e., a key driver of emissions and removals, if the actual harvest rate for the period to be gap-filled is known with confidence, then this rate may be directly applied by the models, in combination with the methodological elements above. However, sometimes no reliable statistics on harvest are available for the period to be gap-filled. In this case, it is good practice to assume the "continuation of management practices", as documented in the existing time series (e.g. for the "calibration period", see below). The functional relationships between age structure dynamics, the increment and the harvest under the continuation of management practices (which is the basis of yield tables for forest management) can be used to calculate, for each forest strata, a consistent time series of annual C stock gains (forest net increment) and annual C stock losses (e.g. harvest, etc.). For example, if a given tree species was typically harvested at 80 years, the extrapolation based on functional relationships will apply this harvesting age also in the period to be gap-filled, taking into account the age structure dynamics (e.g. if the forest is getting older, more area reaching 80 years may be available); the C gains will be calculated using the forest net increment associated with the simulated age structure and harvest rate.

A change in any of the methodological elements above used in the existing (i.e. non-extrapolated) time series triggers a methodological inconsistency, to be addressed through a re-run, for the entire time series, of the model used for the extrapolation. Such re-run should ensure consistency in the methodological elements described above.

As a general check for the consistency, it is good practice to demonstrate that the model used for the extrapolation reproduces the existing time series, for a selected "calibration period". The length of this calibration period may depend on various factors, but it is preferable to have at least 5 or 10 years of comparison between the model's results and the existing time series. If the model results for the calibration period fall within the estimated range of uncertainty of the existing time series (as documented in the GHG inventory), any remaining discontinuity between the existing time series and the portion extrapolated may be addressed through an "ex-post calibration" procedure, that shifts model results up or down to match the existing time series. This procedure represents an application of the "overlap" technique (Volume 1, Chapter 5.3.3.1) to extrapolated data. This procedure will affect the level of modelled GHG estimates, but not their trend. If, for the calibration period, the model's results do not fall within the reported range of uncertainty of the existing time series, it is *not* good practice to use these results for extrapolating the time series. An example of resolving forest data gaps through extrapolation based on functional relationships is provided in Box xxx.

BOX XX

EXAMPLE OF RESOLVING FOREST DATA GAPS THROUGH EXTRAPOLATION BASED ON FUNCTIONAL RELATIONSHIPS

Consider a case in which the stock difference method is applied to construct a consistent time series between 1990 and 2015. Suppose that the next complete forest inventory will be reported in 2025. Until this inventory becomes available, the years after 2015 may need to be extrapolated. A model may be used for that purpose, using either (a) the actual values of harvest, if available with confidence, or (b) the harvest associated with the continuity of management practices.

[Numerical examples will be elaborated for both case (a) and (b)]

If the 1990-2015 time series is subject to a methodological change or refinement, e.g. a new carbon pool is added or an error in datasets is corrected, this would introduce a methodological inconsistency. The model used for extrapolation needs to be re-run including the new added pool, and using adjusted datasets.

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 Quantity Assurance and Quality Control

No refinement

4.4.4 Reporting and Documentation

No refinement

4.5 TABLES

Table 4.4

Tables will be completed for the SOD (default data calculations in progress)
(To be determined – TBD)

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

Domain	Ecological zone	Continent	Origin	Above-ground biomass	R [tonne root d.m. (tonne shoot d.m.)-1]	References
Tropical	Tropical rainforest	Africa	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
		North and South America	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
		Asia	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
	Tropical moist deciduous forest	Africa	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
		North and South America	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
		Asia	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
	Tr op ica	Africa	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD

			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
		North and South America	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
		Asia	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
	Tropical shrubland	Africa	Natural		TBD	TBD
			Plantation		TBD	TBD
		North and South America	Natural		TBD	TBD
			Plantation		TBD	TBD
		Asia	Natural		TBD	TBD
			Plantation		TBD	TBD
	Tropical mountain systems	Africa	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
		North and South America	Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
		Asia	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
Subtropical	Subtropical humid forest	North and South America	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
		Asia	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
	Subtropical dry forest	North and South America	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
		Asia	Natural	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <125 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >125 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >125 tonnes ha-1	TBD	TBD
	Subtropical steppe	North and South America	Natural		TBD	TBD
			Plantation		TBD	TBD
		Asia	Natural		TBD	TBD
			Plantation		TBD	TBD
			Natural		TBD	TBD

	Subtropical mountain systems	North and South America	Plantation		TBD	TBD
		Asia	Natural		TBD	TBD
			Plantation		TBD	TBD
Temperate	Temperate oceanic forest, Temperate continental forest, Temperate mountain systems	Europe	Natural	conifers above-ground biomass < 50 tonnes ha-1	TBD	TBD
			Plantation	conifers above-ground biomass < 50 tonnes ha-1	TBD	TBD
			Natural	conifers above-ground biomass 50-150 tonnes ha-1	TBD	TBD
			Plantation	conifers above-ground biomass 50-150 tonnes ha-1	TBD	TBD
			Natural	conifers above-ground biomass > 150 tonnes ha-1	TBD	TBD
			Plantation	conifers above-ground biomass > 150 tonnes ha-1	TBD	TBD
			Natural	Quercus spp. above- ground biomass >70 tonnes ha-1	TBD	TBD
			Plantation	Quercus spp. above- ground biomass >70 tonnes ha-2	TBD	TBD
			Natural	Eucalyptus spp. above- ground biomass < 50 tonnes ha-1	TBD	TBD
			Plantation	Eucalyptus spp. above- ground biomass < 50 tonnes ha-2	TBD	TBD
			Natural	Eucalyptus spp. above- ground biomass 50-150 tonnes ha-1	TBD	TBD
			Plantation	Eucalyptus spp. above- ground biomass 50-150 tonnes ha-2	TBD	TBD
			Natural	Eucalyptus spp. above- ground biomass > 150 tonnes ha-1	TBD	TBD
			Plantation	Eucalyptus spp. above- ground biomass > 150 tonnes ha-2	TBD	TBD
			Natural	other broadleaf above- ground biomass < 75 tonnes ha-1	TBD	TBD
			Plantation	other broadleaf above- ground biomass < 75 tonnes ha-2	TBD	TBD
			Natural	other broadleaf above- ground biomass 75-150 tonnes ha-1	TBD	TBD
			Plantation	other broadleaf above- ground biomass 75-150 tonnes ha-2	TBD	TBD
			Natural	other broadleaf above- ground biomass >150 tonnes ha-0	TBD	TBD
			Plantation	other broadleaf above- ground biomass >150 tonnes ha-1	TBD	TBD
		North and South America	Natural	conifers above-ground biomass < 50 tonnes ha-1	TBD	TBD
			Plantation	conifers above-ground biomass < 50 tonnes ha-1	TBD	TBD
			Natural	conifers above-ground biomass 50-150 tonnes ha-1	TBD	TBD
			Plantation	conifers above-ground biomass 50-150 tonnes ha-1	TBD	TBD
			Natural	conifers above-ground biomass > 150 tonnes ha-1	TBD	TBD
			Plantation	conifers above-ground biomass > 150 tonnes ha-1	TBD	TBD

			Natural	Quercus spp. above- ground biomass >70 tonnes ha-1	TBD	TBD
			Plantation	Quercus spp. above- ground biomass >70 tonnes ha-2	TBD	TBD
			Natural	Eucalyptus spp. above- ground biomass < 50 tonnes ha-1	TBD	TBD
			Plantation	Eucalyptus spp. above- ground biomass < 50 tonnes ha-2	TBD	TBD
			Natural	Eucalyptus spp. above- ground biomass 50-150 tonnes ha-1	TBD	TBD
			Plantation	Eucalyptus spp. above- ground biomass 50-150 tonnes ha-2	TBD	TBD
			Natural	Eucalyptus spp. above- ground biomass > 150 tonnes ha-1	TBD	TBD
			Plantation	Eucalyptus spp. above- ground biomass > 150 tonnes ha-2	TBD	TBD
			Natural	other broadleaf above- ground biomass < 75 tonnes ha-1	TBD	TBD
			Plantation	other broadleaf above- ground biomass < 75 tonnes ha-2	TBD	TBD
			Natural	other broadleaf above- ground biomass 75-150 tonnes ha-1	TBD	TBD
			Plantation	other broadleaf above- ground biomass 75-150 tonnes ha-2	TBD	TBD
			Natural	other broadleaf above- ground biomass >150 tonnes ha-0	TBD	TBD
			Plantation	other broadleaf above- ground biomass >150 tonnes ha-1	TBD	TBD
		Australia and New Zealand	Natural	conifers above-ground biomass < 50 tonnes ha-1	TBD	TBD
			Plantation	conifers above-ground biomass < 50 tonnes ha-1	TBD	TBD
			Natural	conifers above-ground biomass 50-150 tonnes ha-1	TBD	TBD
			Plantation	conifers above-ground biomass 50-150 tonnes ha-1	TBD	TBD
			Natural	conifers above-ground biomass > 150 tonnes ha-1	TBD	TBD
			Plantation	conifers above-ground biomass > 150 tonnes ha-1	TBD	TBD
			Natural	Quercus spp. above- ground biomass >70 tonnes ha-1	TBD	TBD
			Plantation	Quercus spp. above- ground biomass >70 tonnes ha-2	TBD	TBD
			Natural	Eucalyptus spp. above- ground biomass < 50 tonnes ha-1	TBD	TBD
			Plantation	Eucalyptus spp. above- ground biomass < 50 tonnes ha-2	TBD	TBD
			Natural	Eucalyptus spp. above- ground biomass 50-150 tonnes ha-1	TBD	TBD
			Plantation	Eucalyptus spp. above- ground biomass 50-150 tonnes ha-2	TBD	TBD
			Natural	Eucalyptus spp. above- ground biomass > 150 tonnes ha-1	TBD	TBD
			Plantation	Eucalyptus spp. above- ground biomass > 150 tonnes ha-2	TBD	TBD

			Natural	other broadleaf above- ground biomass < 75 tonnes ha-1	TBD	TBD
			Plantation	other broadleaf above- ground biomass < 75 tonnes ha-2	TBD	TBD
			Natural	other broadleaf above- ground biomass 75-150 tonnes ha-1	TBD	TBD
			Plantation	other broadleaf above- ground biomass 75-150 tonnes ha-2	TBD	TBD
			Natural	other broadleaf above- ground biomass >150 tonnes ha-0	TBD	TBD
			Plantation	other broadleaf above- ground biomass >150 tonnes ha-1	TBD	TBD
Boreal	Boreal coniferous forest, Boreal tundra woodland, Boreal mountain systems	Asia	Natural	above-ground biomass <75 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <75 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >75 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >75 tonnes ha-1	TBD	TBD
		Europe	Natural	above-ground biomass <75 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <75 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >75 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >75 tonnes ha-1	TBD	TBD
		North America	Natural	above-ground biomass <75 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass <75 tonnes ha-1	TBD	TBD
			Natural	above-ground biomass >75 tonnes ha-1	TBD	TBD
			Plantation	above-ground biomass >75 tonnes ha-1	TBD	TBD

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Table 4.5

Table will be completed for the SOD (default data calculations in progress)

Table 4.7

Table will be completed for the SOD (default data calculations in progress)

TABLE 4.7
ABOVE-GROUND BIOMASS IN NATURAL FORESTS

Domain	Ecological zone	Continent	Status/condition*	Aboveground biomass [tonnes d.m. ha-1]	References
TTropical	Tropical rainforest	Africa	Primary		
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Tropical moist deciduous forest	Africa	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Tropical dry forest	Africa	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD

		North and South America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Tropical shrublands	Africa	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Tropical mountain systems	Africa	Primary	265,9	6
			Secondary >20 years	71,56	6
			Secondary <20 years	37,78	6
		North and South America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
Subtropical	Subtropical humid forests	Africa	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Subtropical dry forests	Africa	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD

	Subtropical steppe	Africa	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Subtropical mountain systems	Africa	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
Temperate	Temperate oceanic forest	Europe	Primary	81,46	See background data
			Secondary/disturbed >20 years	173,50	See background data
			Secondary/disturbed <20 years	66,50	See background data
		South America	Primary	TBD	TBD
			Secondary/disturbed >20 years	TBD	TBD
			Secondary/disturbed <20 years	TBD	TBD
		Australia and New Zealand	Primary	352,70	5
			Secondary/disturbed >20 years	120,50	5
			Secondary/disturbed <20 years	57,46	1
		Asia	Primary	TBD	TBD
			Secondary/disturbed >20 years	TBD	TBD
			Secondary/disturbed <20 years	TBD	TBD
		North America	Primary	TBD	TBD
			Secondary/disturbed >20 years	361,71	http://apps.fs.fed.us/fiadb-downloads/datamart.html
			Secondary/disturbed <20 years	57,83	http://apps.fs.fed.us/fiadb-downloads/datamart.html
	Temperate continental forest	Europe	Primary	332,45	See background data
			Secondary/disturbed >20 years	162,00	See background data

			Secondary/disturbed <20 years	51,65	See background data
		South America	Primary	TBD	TBD
			Secondary/disturbed >20 years	TBD	TBD
			Secondary/disturbed <20 years	TBD	TBD
		Australia and New Zealand	Primary	TBD	TBD
			Secondary/disturbed >20 years	TBD	TBD
			Secondary/disturbed <20 years	TBD	TBD
		Asia	Primary	241,22	See background data
			Secondary/disturbed >20 years	87,91	16
			Secondary/disturbed <20 years		
		North America	Primary		
			Secondary/disturbed >20 years	113,22	http://apps.fs.fed.us/fiadb-downloads/datamart.html
			Secondary/disturbed <20 years	23,75	http://apps.fs.fed.us/fiadb-downloads/datamart.html
	Temperate mountain systems	Europe	Primary	301,11	See background data
			Secondary/disturbed >20 years	243..56	See background data
			Secondary/disturbed <20 years	27,80	TY - JOUR AU - Avitabile, Valerio AU - Camia, Andrea TI - An assessment of forest biomass maps in Europe using harmonized national statistics and inventory plots JO - Forest Ecology and Management PY - in review ER -
		South America	Primary	TBD	TBD
			Secondary/disturbed >20 years	TBD	TBD
			Secondary/disturbed <20 years	TBD	TBD
		Australia and New Zealand	Primary	TBD	TBD
			Secondary/disturbed >20 years	TBD	TBD
			Secondary/disturbed <20 years	TBD	TBD
		Asia	Primary	170,39	16
			Secondary/disturbed >20 years	108,61	16
			Secondary/disturbed <20 years	25,27	16
			Primary		

		North America	Secondary/disturbed >20 years	152,52	http://apps.fs.fed.us/fiadb-downloads/datamart.html
			Secondary/disturbed <20 years	20,42	http://apps.fs.fed.us/fiadb-downloads/datamart.html
Boreal	Boreal coniferous forest	Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Europe	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Boreal tundra woodland	Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Europe	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North America	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Boreal mountain systems	Asia	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Europe	Primary	TBD	TBD
			Secondary >20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North America	Primary	TBD	TBD
			Secondary >20 years	104,25	http://apps.fs.fed.us/fiadb-downloads/datamart.html
			Secondary <20 years	1,93	http://apps.fs.fed.us/fiadb-downloads/datamart.html

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Table 4.8

Table will be completed for the SOD (default data calculations in progress)

Table 4.9

Table to will be completed for the SOD (default data calculations in progress)

TABLE 4.9
ABOVE-GROUND NET BIOMASS GROWTH IN NATURAL FOREST

Domain	Ecological Zone	Continent	Status/Condition	Aboveground biomass growth [tonnes d.m. ha-1 yr-1]	References
Tropical	Tropical rainforest	Africa	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Tropical moist deciduous forest	Africa	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Tropical dry forest	Africa	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Tropical shrublands	Africa	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD

			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Tropical mountain systems	Africa	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
Subtropical	Subtropical humid forests	Africa	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Subtropical dry forests	Africa	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Subtropical steppe	Africa	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		North and South America	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
	Subtropical mountain systems	Africa	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
			Primary	TBD	TBD

		North and South America	Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD
		Asia	Primary	TBD	TBD
			Secondary>20 years	TBD	TBD
			Secondary <20 years	TBD	TBD

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Table 4.10

Table will be completed for the SOD (default data calculations in progress)

655 **Table 4.11**

656 *Replaces Table 4.11A and Table 4.11B in the 2006 GL*

TABLE 4.11
REPORTED MEAN ANNUAL INCREMENT (GROWTH RATE OF MERCHANTABLE VOLUME) VALUES FOR SOME PLANTATION FOREST SPECIES [M^3 HA^{-1} YR^{-1}]

Continent	Region/Country	Tree species	Plantation Purpose	MAI min	MAI max	Reference*

World	General	*Acacia auriculiformis*	Productive	6	20	1
		Acacia mearnsii	Productive	14	25	1
		Araucaria angustifolia	Productive	8	24	1
		Araucaria cunninghamii	Productive	10	18	1
		Casuarina equisetifolia	Productive	6	20	1
		Casuarina junghuhniana	Productive	7	11	1
		Cordia alliodora	Productive	10	20	1
		Cupressus lusitanica	Productive	8	40	1
		Dalbergia sissoo	Productive	5	8	1
		Eucalyptus camaldulensis	Productive	15	30	1
		Eucalyptus deglupta	Productive	14	50	1
		Eucalyptus globulus	Productive	10	40	1
		Eucalyptus grandis	Productive	15	50	1
		Eucalyptus robusta	Productive	10	40	1
		Eucalyptus saligna	Productive	10	55	1
		Eucalyptus urophylla	Productive	20	60	1
		Gmelina arborea	Productive	12	50	1
		Leucaena leucocephala	Productive	30	55	1
		Pinus caribaea v. *caribaea*	Productive	10	28	1
		Pinus caribaea v. hondurensis	Productive	20	50	1
		Pinus oocarpa	Productive	10	40	1
		Pinus patula	Productive	8	40	1
		Pinus radiata	Productive	10	50	1
		Swietenia macrophylla	Productive	7	30	1
		Tectona grandis	Productive	6	18	1
		Terminalia ivorensis	Productive	8	17	1
		Terminalia superba	Productive	10	14	1
Africa	Africa	*Acacia mellifera*	Productive	2.2	4.0	2
		Acacia nilotica	Productive	15.0	20.0	2
		Acacia senegal	Productive	1.4	2.6	2
		Acacia seyal	Productive	2.0	6.0	2
		Ailanthus excelsa	Productive	6.6	9.4	2
		Bamboos	Productive	5.0	7.5	2
		Cupressus spp.	Productive	15.0	24.0	2
		Eucalyptus spp.	Productive	12.0	14.0	2
		Khaya spp.	Productive	8.5	12.0	2
		Tectona grandis	Productive	2.5	3.5	2
		Acacia albida	Productive semi-natural	4.0	6.1	2

		Acacia mellifera	Productive semi-natural	1.9	3.5	2
		Acacia nilotica	Productive semi-natural	12.5	20.0	2
		Acacia senegal	Productive semi-natural	1.1	2.4	2
		Acacia seyal	Productive semi-natural	1.8	3.2	2
		Acacia tortilis	Productive semi-natural	1.2	3.7	2
		Acacia tortilis var *siprocarpa*	Productive semi-natural	1.5	2.4	2
		Balanites aegyptiaca	Productive semi-natural	1.2	1.5	2
		Sclerocarya birrea	Productive semi-natural	1.5	1.7	2
		Ziziphus mauritiana	Productive semi-natural	0.9	1.0	2
		Acacia mellifera	Protective	2.0	6.0	2
		Acacia nilotica	Protective	13.0	21.0	2
		Acacia senegal	Protective	1.4	2.8	2
		Acacia seyal	Protective	1.9	4.3	2
		Ailanthus spp.	Protective	6.0	12.0	2
		Bamboos	Protective	4.0	8.0	2
		Cupressus spp.	Protective	14.0	20.0	2
		Eucalyptus spp.	Protective	10.0	14.0	2
		Khaya spp.	Protective	7.0	16.0	2
		Tectona grandis	Protective	5.0	8.0	2
	E and S	*Acacia* spp. (Australia)	Productive	10	12	3
	N	*Acacia nilotica*	Productive	15	20	3
	N	*Acacia nilotica*	Productive semi-natural	12.5	20	3
	N	*Acacia senegal*	Productive	1.4	2.6	3
	N	*Acacia senegal*	Productive semi-natural	1.1	2.4	3
	N	*Acacia seyal*	Productive	2	6	3
	N	*Acacia seyal*	Productive semi-natural	1.8	3.2	3
	E and S	*Eucalyptus grandis*	Productive	18	24	3
	E and S	*Eucalyptus nitens*	Productive	22	28	3
	N	*Eucalyptus* spp.	Productive	12	14	3
	E and S	*Pinus elliottii*	Productive	12	18	3
	N and C	*Pinus elliottii*	Productive	7	8	3
	N	*Pinus halapensis*	Productive semi-natural	1	2	3
		Pinus patula	Productive	12	18	3

		Pinus pinaster	Productive semi-natural	1	2	3
		Pinus radiata	Productive	12	16	3
	Congo	*Eucalyptus* spp.	Experimental	13.8	25	8
Asia	Asia	*Eucalyptus camaldulensis*	Productive	21.0	43.0	2
	Asia	*Pinus* spp.	Productive	4.0	15.0	2
	S and SE	*Acacia mangium*	Productive	19	40	3
	E and S	*Castanea molissima*	Productive	1	6	3
	E and S	*Cunninghamia lanceolata*	Productive	2.5	13.5	3
	E and S	*Cunninghamia lanceolata*	Productive semi-natural	2.5	13.5	3
	E	*Eucalyptus* spp.	Productive	1.6	8.7	3
	S and SE	*Eucalyptus* spp.	Productive	7	12	3
	S and SE	*Eucalyptus* spp.	Productive semi-natural	8	12	3
	W and C	*Eucalyptus* spp.	Productive	4	10	3
		Pinus massoniana	Productive semi-natural	2.8	16.3	3
		Populus spp. and cultivars	Productive	3.7	18.5	3
		Populus spp. and cultivars	Productive semi-natural	3.7	17.7	3
		Populus spp. and cultivars	Productive	5	12	3
		Tectona grandis	Productive	4	17.3	3
		Tectona grandis	Productive semi-natural	4	6	3
	China	*Dalbergia sissoo*	Productive	4	6	6
	China	*Eucalyptus* spp.	Productive	8	12	6
	China	*Gmelina arborea*	Productive	10	15	6
	China	*Acacia nilotica*	Productive	3	4	6
	China	*Populus* spp.	Productive	20	25	6
	China	*Tectona grandis*	Productive	0.6	7	6
	Vietnam	Acacia hybrid	Experimental	24.4	39.4	7
	Turkey	*Pinus pinaster*	Productive	9.8	22.4	9
	Turkey	*Eucalyptus camaldulensis*	Productive	18.3	24.1	9
	Turkey	*Populus* spp. and cultivars	Productive	23.5	55.1	9
	Turkey	*Pinus brutia*	Productive	1	15.4	9
	Vietnam	*Acacia mangium*	Productive	11	23	10
	Vietnam	*Melia azedarach*	Productive	15	17	10
Europe	Europe	*Fagus sylvatica*	Productive	4	14	3

	Europe	*Fagus sylvatica*	Productive semi-natural	2	14	3
	Europe	*Larix decidua*	Productive	7	13	3
	Europe	*Larix decidua*	Productive semi-natural	2	11	3
	Europe	*Picea abies*	Productive	3.5	6	3
	Europe	*Picea abies*	Productive semi-natural	1.5	15	3
		Pinus pinaster	Productive	4.7	13.8	3
		Pinus sylvestris	Productive	2.5	14	3
		Pinus sylvestris	Productive semi-natural	1	10	3
		Quercus suber	Productive	3	9	3
		Quercus suber	Productive semi-natural	1.5	10	3
	Sweden	*Pinus sylvestris*	Productive semi-natural	3.3	5.3	11
	Sweden	*Picea abies*	Productive semi-natural	3.4	10	11
	Sweden	*Larix sibirica*	Productive semi-natural	4	5.9	11
	Sweden	*Pinus contorta*	Productive semi-natural	4.6	6.9	11
	Sweden	*Betula pendula*	Productive semi-natural	3	8	11
	Sweden	*Populus* spp. and *cultivars*	Productive semi-natural	12	16	11
	Sweden	*Quercus robur*	Productive semi-natural	3.9	5.2	11
	Finland	*Pinus sylvestris*	Productive semi-natural	2	5	11
	Finland	*Picea abies*	Productive semi-natural	3	7	11
	Finland	*Betula pendula*	Productive semi-natural	3	7	11
	Norway	*Pinus sylvestris*	Productive semi-natural	1.5	3.5	11
	Norway	*Picea abies*	Productive semi-natural	4	8.5	11
	Norway	*Picea sitchensis*	Productive semi-natural	12	18	11
North and Central America		*Pinus taeda*	Productive	9	10	3
Oceania	Oceania	*Eucalyptus globulus*	Productive	15.6	25	3
		Pinus radiata	Productive	15.7	21	3
South America	South America	*Tectona grandis*	Productive	7.3	17.3	2
	South America	*Xylia xylocarpa*	Productive	3.0	8.8	2
	South America	*Acacia* spp.	Productive	15.0	30.0	2

	South America	Araucaria angustifolia	Productive	15.0	30.0	2
	South America	Eucalyptus spp.	Productive	20.0	70.0	2
	South America	*Hevea brasiliensis*	Productive	10.0	20.0	2
	South America	*Mimosa scabrella*	Productive	10.0	25.0	2
	South America	*Pinus* spp.	Productive	25.0	40.0	2
	South America	*Populus* spp.	Productive	10.0	30.0	2
	South America	*Tectona grandis*	Productive	15.0	35.0	2
	South America	*Eucalyptus* spp.	Productive	15	70	3
		Pinus radiata	Productive	14	34	3
	Brazil	*Khaya ivorensis*	Productive	18	25	4
	Brazil	*Schizolobium amazonicum*	Productive	10	33	5

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Table 4.12

Table 4.12 will be updated if information is available for the SOD

4.6 BASIS FOR FUTURE METHODOLOGICAL DEVELOPMENT

This section provides new guidance.

The Tier 1 method for soil C stocks associated with Forest Land Remaining Forest Land assumes that the C inputs and outputs are in balance with a net flux of zero. As the reference soil C stock is often unknown and there is a large variability in soil organic carbon (SOC) stocks on which soil C change factors are to be applied, the assumption of no change in forest SOC may be the best possible assumption at this time. However, because of the considerable size of the pool and associated changes, there is a need to show the importance of managed forests as either long-term C sinks or sources depending on management and other factors (Luyssaert *et al.*, 2014, Noormets *et al.*, 2015). Inputs of C to the soil in litter inputs and harvest residues are largely determined by the forest productivity and the management regimes (Luyssaert *et al.*, 2010), while outputs rely on the decomposition rate, and the difference between these represents the net flux (net uptake or net emission). For instance, increased forest productivity and a long rotation length have been shown to result in higher C input to soils, provided that the forest age is not beyond where the forest changes from being a net sink to a source of C (Jandl *et al.*, 2007). Loss of C due to management practices have been investigated but experimental results are still inconclusive on the general effect (Clarke *et al.*, 2015), but there is a significant potential for soil C gains and losses. Therefore, there is a need for future methodological development to estimate forest management influences on the carbon balance of forest soils (Luyssaert *et al.*, 2014, Pregitzer & Euskirchen, 2004).

The new approach could use fluxes (rate of emission or removal) instead of the current approach based on reference C stocks and stock change factors. These factors would be independent of the initial SOC stock, and instead related to climate, soil types, vegetation types, biomass and litter production, management and/or forest rotation length. Flux factors would be developed for all forest rotations and management type, possibly using a combination of modeling with field measurement data (Kurz *et al.*, 2009, Ortiz *et al.*, 2014). The combination is required because existing measurement data does not differentiate and show the influence of changes in C inputs and outputs on SOC stock changes. Several models need to be used for the flux factors generation, the resulting factors will need to be evaluated against measurement data.

Besides management other factors influencing fluxes could be included in an analysis to develop country-specific Tier 2 factors, depending on applicability and available activity data. These factors include climate/regional variation; soil types; tree species (e.g., coniferous, deciduous, N-fixing, monoculture or mixture ratio of tree species); forest ecosystem biomass productivity or biomass loss data (remote sensing may be used to inform models about productivity and losses); management regimes such as intensive (e.g., plantation forestry) or extensive (e.g., natural forest), or classifications based on recovery after slash and burn, harvest intensity, clear-cut rotations, and selective cutting; typical rotation length or forest age structure (examples of classes: 20-40, 40-80. 80-120, >120 years, even-aged or multilayered); and land use history previous natural or planted forests (e.g., continuous grassland for thousands of years before afforested, plantation after use of long-term cropland rotation). Production of country-specific Tier 2 flux factors is encouraged, where it is possible to combine different influences on SOC flux by forest management.

Reframing this method around fluxes will also require special attention for land use changes to forest land or from forest land to other uses. In addition, the method would need to consider length of time over which the fluxes are relevant because soils will eventually reach a new equilibrium and/or become saturated with C over time. (Stewart et al. 2007).).

Annex 4A-1 Glossary for Forest Land

No refinement

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