Appendix 3a.4 Settlements: Basis for Future Methodological Development

Appendix 3a.4 presents a basic method for estimating emissions and removals of carbon by trees in settlements. This land-use category was addressed in the Reference Manual of the *IPCC Guidelines* in Section 5.2 (Changes in Forest and Other Woody Biomass Stocks. The methodology covers the subcategory of changes in carbon stocks in living biomass. At this point, sufficient information is not available to develop a basic methodology with default data to estimate the contribution of dead organic matter and soils to CO_2 emissions and removals in settlements.

3a.4.1 Settlements Remaining Settlements

The category of settlements remaining settlements refers to all classes of urban tree formations, focusing primarily on urban trees grown along streets, in gardens, and parks, in lands that have been in use as settlements (e.g., areas that are functionally or administratively associated with cities, villages, etc.) since the last data collection period. Emissions and removals of CO_2 in this category are estimated by a single subcategory of changes in carbon stocks in biomass, as summarised in Equation 3a.4.1.

EQUATION 3a.4.1
SUMMARY EQUATION FOR CHANGES IN CARBON STOCKS IN SETTLEMENTS REMAINING SETTLEMENTS

$$\Delta C_{SS} = \Delta C_{SS_{LB}}$$

Where:

ΔC_{SS} = changes in carbon stocks in settlements remaining settlements, tonnes C yr^{-1}

$\Delta C_{SS_{LB}}$ = changes in carbon stocks in living biomass in settlements remaining settlements, tonnes C yr^{-1}

3a.4.1.1 CHANGES IN CARBON STOCKS IN LIVING BIOMASS

3A.4.1.1.1 METHODOLOGICAL ISSUES

When estimating emissions for settlements, it is assumed that changes in carbon stocks occur only in tree biomass. Changes in carbon stocks in bush biomass are not considered because data on bush growth are scarce. However, if there are activity data and parameter values for bush species, their effect on CO_2 emissions and removals can be estimated with either a Tier 2 or Tier 3 method. Also meadow and ornamental plants in parks and gardens are not addressed because sufficient information is not available.

Few data are available to estimate carbon removal by trees in settlements. Novak and Crane (2002) estimated the carbon removal by trees in settlements in the conterminous USA as 23 million tonnes C yr^{-1}. Besides an evaluation of the sink capacity of urban trees in Sydney (Brack, 2002), there are no similar studies from other regions of the world. The methods described in this section are based on research carried out mainly in US cities. They are useful as a first approximation to assess the net CO_2 emissions and removals by urban trees. However, it should be recognised that additional data are needed for other regions to develop a fully generalised method.

The general method estimates changes in biomass carbon stocks as a result of tree growth, subtracting out losses in biomass carbon stocks as a result of pruning and mortality. Depending on the magnitude of growth and losses, the resulting average annual changes in living biomass carbon stocks may be positive or negative.

This method is shown in Equation 3a.4.2.

EQUATION 3a.4.2
CHANGES IN CARBON STOCKS IN BIOMASS IN SETTLEMENTS REMAINING SETTLEMENTS

$$\Delta C_{SS_{LB}} = \Delta C_{SS_G} - \Delta C_{SS_L}$$

Where:

$\Delta C_{SS_{LB}}$ = changes in carbon stocks in living biomass in settlements remaining settlements, tonnes C yr-1

ΔC_{SS_G} = changes in carbon stocks due to growth in living biomass in settlements remaining settlements, tonnes C yr-1

ΔC_{SS_L} = changes in carbon stocks due to losses in living biomass in settlements remaining settlements, tonnes C yr-1

3a.4.1.1.1.1 Choice of Method

Depending on the availability of relevant data, either of the methodological tiers described in what follows can be used. Both are based on the same methodology (growth minus losses) as in Section 3.2.1.1 and shown in Equation 3a.4.2.

Tier 1: There are two options for a Tier 1 estimation of changes in living biomass in settlements remaining settlements. Tier 1a uses changes in carbon stocks per tree crown cover area as a removal factor, and Tier 1b uses changes in carbon stocks per number of trees as a removal factor. The choice of method will depend on availability of activity data.

Tier 1a: Crown cover area method

This method is represented by Equation 3a.4.3A and should be used when data are available on total area of tree crown cover in settlements remaining settlements.

EQUATION 3a.4.3A
ANNUAL BIOMASS GROWTH BASED ON TOTAL CROWN COVER AREA

$$\Delta B_{SS_G} = (A_{CROWN} \bullet CRW)$$

Where:

ΔB_{SS_G} = annual biomass growth in settlements remaining settlements, tonnes C yr-1

A_{CROWN} = total crown cover area, ha

CRW = crown cover area-based growth rate, tonnes C (ha crown cover)$^{-1}$ yr^{-1}

This method can be implemented in three steps:

Step 1: Estimate the total tree crown area of trees in all settlements remaining settlements.

Step 2: Multiply the total tree crown area by the appropriate default removal factor for CRW (see Sec. 3a.4.1.1.1.2) to obtain ΔB_{SS_G}.

Step 3: Use the estimate for ΔB_{SS_G} in Equation 3a.4.2. In addition, set $\Delta B_{SS_L} = 0$ if the average age of the tree population is less than or equal to 20 years; otherwise assume $\Delta B_{SS_G} = \Delta B_{SS_L}$ (see Section 3a.4.1.1.1.2).

Tier 1b: Tree growth rate method

The method is represented by Equation 3a.4.3B and should be used where data on the number of trees by broad species class in settlements remaining settlements are available.

EQUATION 3a.4.3B
ANNUAL AMOUNT OF BIOMASS GROWTH BASED ON NUMBER OF INDIVIDUAL TREES IN BROAD SPECIES CLASSES

$$\Delta B_{SS_G} = \sum_{i=1}^{n} (NT_i \bullet C_{Rate_i})$$

Where:

ΔB_{SS_G} = annual biomass growth in settlements remaining settlements, tonnes C yr^{-1}

NT_i = number of trees in broad species class *i*, tree #;

C_{Rate_i} = annual average carbon accumulation per tree of broad species class *i*, tonnes C yr^{-1} tree $\#^{-1}$

TABLE 3A.4.1
TIER 1B DEFAULT AVERAGE ANNUAL CARBON ACCUMULATION PER TREE (TONNES C YR^{-1}) IN URBAN TREES BY SPECIES CLASSES

Broad species class	Default annual carbon accumulation per tree(tonnes C yr^{-1})
Aspen	0.0096
Soft Maple	0.0118
Mixed Hardwood	0.0100
Hardwood Maple	0.0142
Juniper	0.0033
Cedar/larch	0.0072
Douglas fir	0.0122
True fir/Hemlock	0.0104
Pine	0.0087
Spruce	0.0092
Source: D. Nowak (2002; personal communication)	

This method can be implemented in four steps:

Step 1: Estimate the number of trees in settlements remaining settlements for each broad species class.

Step 2: Multiply each estimate by the appropriate rate of changes in carbon per tree to obtain the amount of carbon removed.

Step 3: Sum the amount of carbon removed by each broad species class over all classes present in settlements remaining settlements.

Step 4: Use the estimate for ΔB_{SS_G} in Equation 3a.4.2. In addition, set $\Delta B_{SS_L} = 0$ if the average age of the tree population is less than or equal to 20 years; otherwise assume $\Delta B_{SS_G} = \Delta B_{SS_L}$ (see Section 3a.4.1.1.1.2).

Tier 2: Under Tier 2, the basic equations laid out in Tiers 1a and 1b can be used with country-specific removal factors (CRW or C_{Rate_i}). In addition to relying on country-specific data, Tier 2 methods may disaggregate settlements by climate regions in order to apply more detailed removal factors to the data. Biomass loss (ΔB_{SS_L}) should be estimated explicitly rather than relying on default assumptions. Higher-level estimates of changes in carbon stocks in settlements may also include additional subcategories in the estimation, such as belowground biomass, dead organic matter, and soil organic matter.
Given the preliminary nature of this methodology, an explicit Tier 3 method is not provided. However, countries may choose to develop higher order estimation approaches, provided they yield more certain estimates of greenhouse gas emissions and removals in settlements.

3a.4.1.1.1.2 Choice of Emission/Removal Factors

In Tier 1a, the removal factor is CRW in Equation 3a.4.3A. If using Tier 1a, use a default CRW of 2.9 tonnes C (ha crown cover)$^{-1}$ yr^{-1}. This estimate is based on a sample of eight US cities, with values that ranged from 1.8 to 3.4 tonnes C (ha crown cover)$^{-1}$ yr^{-1} (Nowak, 2002).

In Tier 1b, the removal factor is C_{Rate_i} in Equation 3a.4.3B. If using Tier 1b, use defaults in Table 3a.4.1 for carbon accumulation rates for each broad species class. These estimates are based on various allometric equations and limited field data from urban areas in the USA.

Under higher tiers, countries should develop removal factors that are appropriate for national circumstances. Either area- or individual-based rates may be used. Country-specific removal rates should be based on the dominant climate zones and tree species of settlements areas in a country. If country-specific removal rates are developed from estimates of biomass dry matter, they must be converted to units of carbon using either a default carbon fraction (CF) of 0.5 tonnes carbon per tonne dry matter, or a carbon fraction that is determined to be more appropriate for country-specific data.

The default that $\Delta B_{SS_L} = 0$ is based on the assumption that urban trees are net sinks for carbon when they are actively growing and that the active growing period is roughly 20 years, depending on tree species, planting density, and location (e.g., trees along thoroughfares or in parks, in shaded or sunny places, etc.). While growing conditions in parks and gardens may be good, the growth and health condition of older trees are assumed to progressively deteriorate with time because of the harshness of urban conditions (e.g., relatively low radiation levels, air pollution). Therefore, the method assumes that the accumulation of carbon in biomass slows with age, and thus for trees greater than 20 years of age, increases in biomass carbon are assumed offset by losses from pruning and mortality. This is conservatively accounted for by setting $\Delta B_{SS_G} = \Delta B_{SS_L}$.

Under higher tier levels, the assumptions for ΔB_{SS_L} should be evaluated and modified to better address national circumstances. For instance, countries may have information on age-dependent and or species-specific carbon losses in settlements trees. In this case, countries should develop a loss term and document the resources and rationale used in its development.

3a.4.1.1.1.3 Choice of Activity Data

The activity data needed to implement a Tier 1 method are either A_{CROWN}, areas of tree crown cover, or NT_i, number of individual trees in broad species classes. For Tier 1a, crown cover area data (A_{CROWN}) can be obtained from aerial photographs of urban areas with the help of personnel skilled in photo interpretation, image sampling and area measurement (Nowak *et al.*, 1996). Crown cover is typically defined as the percent of ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage of plants. It is important to note that Equation 3a.4.3A uses a term for area and not percent. Values in percent crown cover should be converted to total crown cover area for use in Equation 3a.4.3A by multiplying the percent crown cover by the total area of trees.

For Tier 1b, records of tree populations, disaggregated into species or broad species classes may be obtained from municipal agencies caring for urban vegetation or from sampling methods.

Under Tier 2, tree population numbers, disaggregated into species or broad species classes, can be obtained by an appropriate sampling design. The area sampling methods described in Chapter 5, Section 5.3 (Sampling) can be adapted to that purpose.

3a.4.1.1.1.4 Uncertainty Assessment

There are two primary sources of uncertainty in the basic methods: uncertainty in removal factors and uncertainty in activity data. The default Tier 1a removal factor, CRW, has an uncertainty of ±50% of the mean. The default values provided for Tier 1b removal factors have a general uncertainty of ±30% of the mean, based on expert judgement. Countries will need to assess the uncertainty of area estimates or tree numbers used in either the Tier 1a or 1b approach. Common to the activity data of each of the tiers is the uncertainty in the delineation of settlements boundaries. These influence the relative sizes of urban land-use types (e.g., commercial, residential, parks, etc.) differing in tree population and extent of paved and built surfaces. Uncertainties in activity data depend on the method used to estimate tree crown cover area. Most methods are based on the interpretation of aerial photographs, but differ in the methods used for sampling those photographs. The relative uncertainty of crown cover area estimates may conservatively range from ±5% to ±20% of the mean estimate. Uncertainties in activity data (number of trees in each broad species class) are mainly derived from the sampling methods used for estimating the size of the tree population. Conservative uncertainty estimates range from ±15% to ±25% of the tree number value.

For general guidance to identifying, quantifying, and combining uncertainties refer to Chapter 5, Section 5.2 (Identifying and Quantifying Uncertainties) of this report.

3a.4.2 Completeness

Ensuring the completeness of emission and removal estimates from settlements requires the inclusion of all settlements in a country or at least those above some definite threshold size, and estimates of all greenhouse gases and sources and sinks relevant to settlements.

At present, developing a complete estimate of changes in carbon stocks for this land-use category is constrained by the lack of worldwide studies providing both quantification methods and default parameter data. With data available at most municipal agencies, however, the methods and methodological approaches presented above should allow for a fairly complete accounting of the changes in the carbon pools of settlements.

3a.4.3 Developing a consistent time series

Guidance for developing consistent time series is given in Chapter 5, Section 5.6 (Time Series Consistency and Recalculations). To develop a consistent time series for the category of settlements remaining settlements, efforts should be made to develop a regular inventory of settlements trees. The inventory may occur annually or over some other regular time period, and include the number of individual species, and a measure of tree size, such as diameter at breast height (dbh) such that growth can be estimated over multiple sampling periods. In addition, biomass losses through pruning and mortality should also be tracked, ideally through the regular settlements tree inventory.

3a.4.4 Reporting and Documentation

Countries should document estimates of emissions and removals in biomass of settlements remaining settlements in reporting tables. Changes in carbon stocks (tonnes C yr^{-1}) as well as emissions / removals of CO_2 (Gg CO_2 yr^{-1}) should be included in the reporting tables. It is critical to note that, by convention, changes in carbon stocks are positive when carbon stocks in terrestrial pools are increasing and negative when carbon stocks in terrestrial pools are decreasing. In contrast, CO_2 emissions / removals follow an opposing convention. More guidance on the sign convention is given in Section 3.1.7 Reporting and in Annex 3A.2 Reporting tables.

For the purposes of transparent reporting and to facilitate further refinement of inventory estimates, countries should carefully document decisions made and approaches used to estimate CO_2 emissions and removals from settlements. To meet this end, countries should consider the following items when developing documentation:

- Name and geographical location of each settlements;
- Name of the source (or sources) of activity data, or of data the latter were derived from;
- Methods used to obtain activity data;
- Criteria used for including tree species into the broad species classes indicated in Table 3a.4.1;
- Factors and/or ratios used to adjust average annual carbon accumulation per tree to growth in urban conditions, if applicable;
- Source (or sources) of growth equations and methods used for combining them, and for obtaining parameter values different from those presented in this appendix;
- Sampling methods and models used for developing country-specific carbon accumulation rates;
- Description of the methods used for settlements area delimitation; and
- The results of time-trend analysis of previous emission records, the justification of their recalculation, and the procedures used to that end. Large oscillations in the series values should be explained. For general guidance see Chapter 5 of this report.

The foregoing documentation should be properly archived for future reference.

3a.4.5 Inventory Quality Assurance/Quality Control

It is advisable to implement quality control checks as outlined in Chapter 5, Section 5.5 (Quality Assurance and Quality Control) of this report, and supplement the general QA/QC related to data processing, handling, and reporting as outlined in Chapter 5 of this report, with source-specific procedures, particularly the review of the parameters, equations, and calculations used to estimate emission values. External specialists (particularly experts on urban forestry) as well as concerned stakeholders should peer-review the inventory estimates and the values of all important parameters and emission factors.