4

SUPPLEMENTARY METHODS AND GOOD PRACTICE GUIDANCE ARISING FROM THE KYOTO PROTOCOL

AUTHORS AND REVIEW EDITORS

Sections 4.1 – 4.2

Coordinating Lead Authors

Bernhard Schlamadinger (Austria)
Kansri Boonpragob (Thailand), Henry Janzen (Canada), Werner Kurz (Canada), Rodel Lasco (Philippines), and Pete Smith (UK)

Lead Authors

Pascale Collas (Canada), El Nur Abdalla El Siddig (Sudan), Andreas Fischlin (Switzerland), Mitsuo Matsumoto (Japan), Alexander Nakhutin (Russia), Ian Noble (Australia), Gérôme Pignard (France), Zoltán Somogyi (Hungary), and Xiao-Quan Zhang (China)

Contributing Authors

Mark Easter (USA), Wojciech Galinski (Poland), Geneviève Patenaude (Canada), Keith Paustian (USA), and Yoshiki Yamagata (Japan)

Review Editors

Masahiro Amano (Japan) and Eveline Trines (Netherlands)

Section 4.3

Coordinating Lead Authors

Sandra Brown (USA) and Omar Masera (Mexico)

Lead Authors

Vitus Ambia (New Papua Guinea), Barbara Braatz (USA), Markku Kanninen (Finland), Thelma Krug (Brazil), Daniel Martino (Uruguay), Phanuel Oballa (Kenya), Richard Tipper (UK), and Jenny L. P. Wong (Malaysia)

Contributing Authors

Ben de Jong (Mexico) and David Shoch (USA)

Review Editor

Soobaraj N. Sok Appadu (Mauritius)

Contents

Equations

Figures

Tables

Boxes

4.1 INTRODUCTION

This chapter describes the supplementary methods and *good practice* guidance specifically linked to the land use, land-use change and forestry (LULUCF) activities in the Kyoto Protocol and gives full consideration to the requirements and methodologies for measuring, estimating and reporting of activities under Article 3.3, and under Article 3.4 (if elected by a Party). The supplementary methods and *good practice* guidance of this chapter apply generally to those Parties listed in Annex B of the Kyoto Protocol that have ratified the Protocol. This chapter also provides *good practice* guidance for LULUCF projects hosted by Parties listed in Annex B (Article 6 projects) and afforestation / reforestation projects hosted by Parties not listed in Annex B of the Kyoto Protocol (Article 12, Clean Development Mechanism or CDM projects), see Section 4.3.[1]

Under the Kyoto Protocol, Parties are to report emissions by sources and removals by sinks of CO_2 and other greenhouse gases resulting from LULUCF activities under Article 3.3, namely afforestation (A), reforestation (R) and deforestation (D) that occurred since 1990. They are also to report any elected human-induced activities under Article 3.4, which can be: forest management, revegetation, cropland management and grazing land management.[2] In the commitment period Parties have to report annually, along with their annual reports of greenhouse gas emissions by sources and removals by sinks, supplementary information related to LULUCF under the provisions of the Kyoto Protocol and the Marrakesh Accords to ensure compliance with their emission-limitation and reduction commitments.[3] The annual reporting requirement does not imply a need for annual measurements; however, Parties are expected to develop systems that combine measurements, models and other tools that enable them to report on an annual basis.

---

[1] It is assumed that the reader is familiar with Articles 3.3, 3.4, 3.7, 6 and 12 of the Kyoto Protocol (http://unfccc.int/resource/docs/convkp/kpeng.pdf).

[2] LULUCF related requirements are outlined in paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58:

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

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

"Deforestation" is the direct human-induced conversion of forested land to non-forested land.

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

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

"Cropland management" is the system of practices on land on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production.

"Grazing land management" is the system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced.

[3] Paragraph 5 of the Annex to draft decision -/CMP.1 (Article 7) contained in document FCCC/CP/2001/13/Add.3, p.22: *Each Party included in Annex I shall include in its annual greenhouse gas inventory information on anthropogenic greenhouse gas emissions by sources and removals by sinks from land use, land-use change and forestry activities under Article 3, paragraph 3 and, if any, elected activities under Article 3, paragraph 4, in accordance with Article 5, paragraph 2, as elaborated by any good practice guidance in accordance with relevant decisions of the COP/MOP on land use, land-use change and forestry. Estimates for Article 3, paragraphs 3 and 4, shall be clearly distinguished from anthropogenic emissions from the sources listed in Annex A to the Kyoto Protocol. In reporting the information requested above, each Party included in Annex I shall include the reporting requirements specified in the paragraphs 6 to 9 below, taking into consideration the selected values in accordance with paragraph 16 of the annex to decision -/CMP.1 (Land use, land-use change and forestry).* The footnote to the word "annual" in the first sentence says: *It is recognised in the IPCC 1996 Revised Guidelines that the current practice on land use, land-use change and forestry does not in every situation request annual data collection for the purpose of preparing annual inventories based on sound scientific basis.*

Article 7, paragraph 3 of the Kyoto Protocol: *Each Party included in Annex I shall submit the information required under paragraph 1 above annually, beginning with the first inventory due under the Convention for the first year of the commitment period after this Protocol has entered into force for that Party*[…].

Relationship between UNFCCC and Kyoto reporting:

The information to be reported under the Kyoto Protocol is supplementary to the information reported under the Convention. Countries do not have to submit two separate inventories but should provide information under the Kyoto Protocol as supplementary, within the inventory report.[4]

In practice, national circumstances, and specifically the technical details of the carbon accounting systems put into place by each country, will determine the sequence in which the reporting information is compiled. For example, it is possible to start with the UNFCCC inventory (with the additional spatial information required for Kyoto Protocol reporting) and expand it to the Kyoto Protocol inventory, or it is possible to use a system that generates the information for both UNFCCC and Kyoto Protocol reporting.

Example: when a Party that has elected cropland management under Article 3.4 prepares its UNFCCC inventory for croplands according to Section 3.3 of this report, it is efficient to use the stratification into geographical boundaries (Section 4.2.2) in doing so. Then, in preparing the supplementary information to be reported under the Kyoto Protocol, the Party would delineate those UNFCCC cropland areas that were forests before (Section 3.3.2, Land converted to cropland), report these under deforestation according to Article 3.3, and report the remaining croplands under Article 3.4.

This chapter covers supplementary estimation and inventory reporting requirements needed for accounting under the Kyoto Protocol. However, it does not address the implementation of accounting rules as agreed in the Kyoto Protocol and Marrakesh Accords (such as caps, net-net accounting[5] and other specific provisions related to accounting). This is because accounting is a policy matter and is not covered in the request to the IPCC. Estimation refers to the way in which inventory estimates are calculated, reporting in the tables or other standard formats used to transmit inventory information. Accounting refers to the way the information is used to assess compliance with commitments under the Protocol.

The Marrakesh Accords refer to land in two ways, and these terms are adopted here:

- *Units of land* refers to those areas subject to the activities defined under Article 3.3, namely afforestation, reforestation and deforestation, and
- *Land* refers to those areas subject to the activities defined under Article 3.4, namely forest management, cropland management, grazing land management, and revegetation.

4.1.1 Overview of steps to estimating and reporting supplementary information for activities under Articles 3.3, 3.4, 6 and 12

This section gives an overview of the steps required to estimate, measure, monitor and report changes in carbon stocks and emissions and removals of non-CO_2 greenhouse gases for Articles 3.3, 3.4, 6 and 12 under the Kyoto Protocol. Detailed methods and *good practice* guidance for each individual activity are provided in Sections 4.2 and 4.3.

STEP 1: Define "forest", apply definitions to national circumstances, establishing precedence conditions and/or a hierarchy among selected Article 3.4 activities.

STEP 1.1: Select the numerical values in the definition of "forest".[6]

---

[4] Article 7, paragraph 1 of the Kyoto Protocol: *Each Party included in Annex I shall incorporate in its annual inventory [...] the necessary supplementary information for the purposes of ensuring compliance with Article 3* […].

Article 7, paragraph 2 of the Kyoto Protocol: *Each Party included in Annex I shall incorporate in its national communication, submitted under Article 12 of the Convention, the supplementary information necessary to demonstrate compliance with its commitments under this Protocol*.

[5] Net-net accounting refers to the provisions of paragraph 9 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.59-60.

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

Parties must, by the end of 2006, decide on their choice of parameters to define forest, i.e., they must choose a minimum area (0.05 – 1 ha), the minimum crown closure at maturity (10 – 30%), and the minimum tree height at maturity (2 – 5 m). Areas that meet these minimum criteria are considered forest, as are recently disturbed forests or young forests that are expected to reach these parameter thresholds. The numerical values of those parameters cannot be changed for the commitment period. Each Party has to justify in its reporting that such values are consistent with the information that has historically been reported to the Food and Agriculture Organization of the United Nations or other international bodies, and if they differ, explain why and how differing values were chosen.

In addition to the minimum area of forest, it is *good practice* that countries specify the minimum width that they will apply to define forest and units of land subject to ARD activities, as explained in Section 4.2.2.5.1.

STEP 1.2: Apply definitions to national circumstances.

Parties must, by the end of 2006, decide and report which, if any, activities under Article 3.4 they elect (forest management, cropland management, grazing land management and/or revegetation). It is *good practice* that Parties document, for each elected activity, how the definitions will be applied to national circumstances and that they list the criteria that determine under which activity a land would be assigned. These criteria should be chosen in such a way as to minimize or avoid overlap and should be consistent with the guidance provided in the decision tree in Figure 4.1.1 in Section 4.1.2.

STEP 1.3: Establish precedence conditions and/or a hierarchy among selected Article 3.4 activities.

For cases where overlaps may occur, it is *good practice* that the country specifies its precedence conditions and/or a hierarchy among Article 3.4 activities prior to the commitment period, rather than on a case-by-case basis. For example, if land could fall into both cropland management and forest management (such as in agroforestry systems), then it is *good practice* to consistently apply the specified scheme of precedence conditions and/or hierarchy[7] in determining under which activity the land is to be reported.

STEP 2: Identify lands subject to activities under Article 3.3 and any elected activities under Article 3.4.

The second step of the inventory assessment is to determine the areas on which the activities have taken place since 1990 (and for which emissions and removals must be calculated). This step builds on the approaches described in Chapter 2.

STEP 2.1: Compile land-use and land-cover information in 1990 for the relevant activities.

Using the selected definition of forest, develop means for determining forest and non-forest areas in 1990. This can be accomplished with a map that identifies all areas considered forest on 1 January 1990. All forest-related land-use change activities since 1990 can then be determined with reference to this base map (see Section 4.2.2.2 Reporting methods for lands subject to Article 3.3 and Article 3.4 activities).

STEP 2.2: Stratify the country into areas of land for which the geographic boundaries will be reported, as well as the area of the units of land subject to Article 3.3 and/or the areas of lands subject to Article 3.4 within these geographic boundaries (see Section 4.2.2.4). This step can be omitted if Reporting Method 2 (see Section 4.2.2.2) is used.

STEP 2.3: Identify units of land that, since 1990, are subject to activities defined in Article 3.3, and estimate the total area of these units of land within each geographic boundary. Under Reporting Method 2 (Section 4.2.2.2) the estimation of the area of the units of land will be carried out individually for each unit of land.

Article 3.3 of the Kyoto Protocol requires that net carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period on land areas subject to afforestation (see Footnote 1 above), reforestation (R) and deforestation (D) since 1990 are used to meet the commitments under Article 3. The Marrakesh Accords require Parties to estimate the area of the units of lands that have been subject to afforestation, reforestation and/or deforestation within the boundaries mentioned in STEP 2.2 above (for details see Sections 4.2.2.2, 4.2.5 and 4.2.6).

STEP 2.4: Identify land areas subject to elected activities under Article 3.4, and estimate the total size of these land areas within each geographic boundary. Under Reporting Method 2 (Section 4.2.2.2) the estimation of land will be carried out individually for each land area subject to elected Article 3.4 activities.

For forest management (FM), if elected, each Party must identify the land area subject to forest management in each inventory year of the commitment period. A Party could interpret the definition of forest management in terms of specified forest management practices, such as fire suppression, harvesting or thinning, undertaken since 1990. Alternatively, a country could interpret the definition of forest management in terms of a broad

natural causes but which are expected to revert to forest. See paragraph 1(a) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

[7] Such as, e.g., "precedence is given to the dominant activity", or "precedence is given to cropland management".

classification of land subject to a system of forest management practices, without the requirement that a specified forest management practice has occurred on each land. (For details see Sections 4.2.2.2 and 4.2.7).[8]

For cropland management (CM), grazing land management (GM), or revegetation (RV), the area subject to each of these activities in any inventory year during the commitment period needs to be determined. As is discussed in more depth in Sections 4.2.8 – 4.2.10, the area under the same activity in 1990 (or the applicable base year) will also have to be determined, because carbon stock changes and non-CO_2 greenhouse gas emissions on this area in 1990 have to be known in order to implement net-net accounting rules of the Marrakesh Accords (see Section 4.2.8.1.1).

STEP 2.5: Identify the areas subject to projects under Article 6.

Some units of land subject to Article 3.3 or lands subject to Article 3.4 can also be projects under Article 6 of the Kyoto Protocol. These have to be reported under Article 3.3 or Article 3.4 (if the relevant activity was elected). In addition, these units of land or lands need to be delineated and the carbon stock changes and non-CO_2 greenhouse gas emissions reported separately as part of the project reporting (see Section 4.3). The relationship between estimation and reporting of activities under Articles 3.3 and 3.4, and projects under Article 6, is discussed in Section 4.1.3.

STEP 3: Estimate carbon stock changes and non-CO_2 greenhouse gas emissions on the lands identified under Step 2 above.

This step builds on the methodologies provided by Chapter 3 of this report (LUCF sector *good practice* guidance) and shows supplementary methodologies relevant to reporting of carbon stock changes and non-CO_2 greenhouse gas emissions under the Kyoto Protocol.

STEP 3.1: Estimate carbon stock changes and non-CO_2 greenhouse gas emissions for each year of the commitment period, on all areas subject to afforestation, reforestation or deforestation (as identified in STEP 2.3) and all areas subject to elected activities covered under Article 3.4 (as identified in STEP 2.4), while ensuring that there are no gaps and no double counting.

The estimation of carbon stock changes and non-CO_2 greenhouse gas emissions for an activity begins with the onset of the activity or the beginning of the commitment period, whichever comes later. For further details regarding the beginning of an activity see Section 4.2.3.2 (Years for which to estimate stock changes and non-CO_2 greenhouse gas emissions).

STEP 3.2: Estimate carbon stock changes and non-CO_2 greenhouse gas emissions in projects under Article 6 (see Section 4.3.3 Measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gas emissions).

For Article 12 Projects:

STEP 1: Identify areas. (Details can be found in Section 4.3.2 Project boundaries)

STEP 2: Estimate carbon stock changes and non-CO_2 greenhouse gas emissions. (Details can be found in Section 4.3.3 Measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gas emissions).

Table 4.1.1 provides an overview of the LULUCF activities in the Kyoto Protocol, and the accounting rules that are prescribed by the Marrakesh Accords. This information is summarized here because it has implications for the supplementary estimation and inventory reporting requirements under the Kyoto Protocol.

[8] Possible issues related to unbalanced accounting resulting from selective inclusion of forest management and revegetation are addressed in the IPCC Report on *Definitions and Methodological Options to Inventory and Report Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types.*

TABLE 4.1.1 SUMMARY OF THE LULUCF ACTIVITIES UNDER THE KYOTO PROTOCOL AND THE ASSOCIATED ACCOUNTING RULES			
Activities	**Net-net accounting**[9]	**Baseline scenario**	**Cap on Credits**[10]
Article 3.3 (Afforestation, Reforestation, Deforestation)	No	No	No
Article 3.4 (Forest Management)	No	No	Yes
Article 3.4 (all other)	Yes	No	No
Article 6	No	Yes	Yes for Forest Management
Article 12 (Clean Development Mechanism)	No	Yes	Yes

4.1.2 General rules for categorisation of land areas under Articles 3.3 and 3.4

Chapter 2 (Basis for consistent representation of land areas) describes approaches to classifying and representing land areas associated with LULUCF activities. This is the basis for the *good practice* guidance in Chapter 4 for identifying all relevant lands, for Kyoto reporting and for avoiding double counting of lands. It is *good practice* to follow the decision tree in Figure 4.1.1 for each year of the commitment period in order to

- Distinguish between afforestation and reforestation, deforestation, forest management, cropland management, grazing land management and revegetation activities under Articles 3.3 and 3.4, as well as to remove potential overlaps and gaps between them; and to
- Assign lands to a single activity at any given point in time (i.e., for each year of the commitment period 2008-2012). This is required because of the possible land-use changes which can lead to double counting of units of lands / lands subject to Articles 3.3 and/or 3.4. Additional guidance on how to deal with shifts in land use over time is given in the examples of Box 4.1.1 at the end of this section.

The decision tree in Figure 4.1.1 is based on Marrakesh Accords (MA) definitions and it identifies a single activity for a given year X of the commitment period under which the land should be reported. The decision tree recognises that a given piece of land could be reported under different activities over time, subject to certain conditions explained below. The decision tree is to be applied annually during the commitment period in order to update the allocation of lands to activities, thus taking into account shifts in land use that may have occurred. This may be achieved by annual tracking of land or by interpolation.

There are two main branches in the decision tree in Figure 4.1.1. If a unit of land was subject to an afforestation, reforestation or deforestation activity since 1990, then in addition, if a Party has elected one or more Article 3.4 activities, then the questions in the right branch should be answered to determine whether the land was also subject to an elected Article 3.4 activity (secondary classification). This is needed to fulfil the reporting needs of the Marrakesh Accords[11] and to demonstrate that there is no double counting (which could occur if full enumeration was not applied). More detailed decision trees to determine whether or not land or a unit of land is subject to specific activities are presented in Sections 4.2.5 through 4.2.10.

---

[9] Net-net accounting refers to the provisions of paragraph 9 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.59-60.

[10] See paragraphs 10 to 12 and 14 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.60-61.

[11] Paragraph 6 (b), bullet (ii) in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.22:

6. General information to be reported for activities under Article 3, paragraph 3, and any elected activities under Article 3, paragraph 4, shall include:[…]

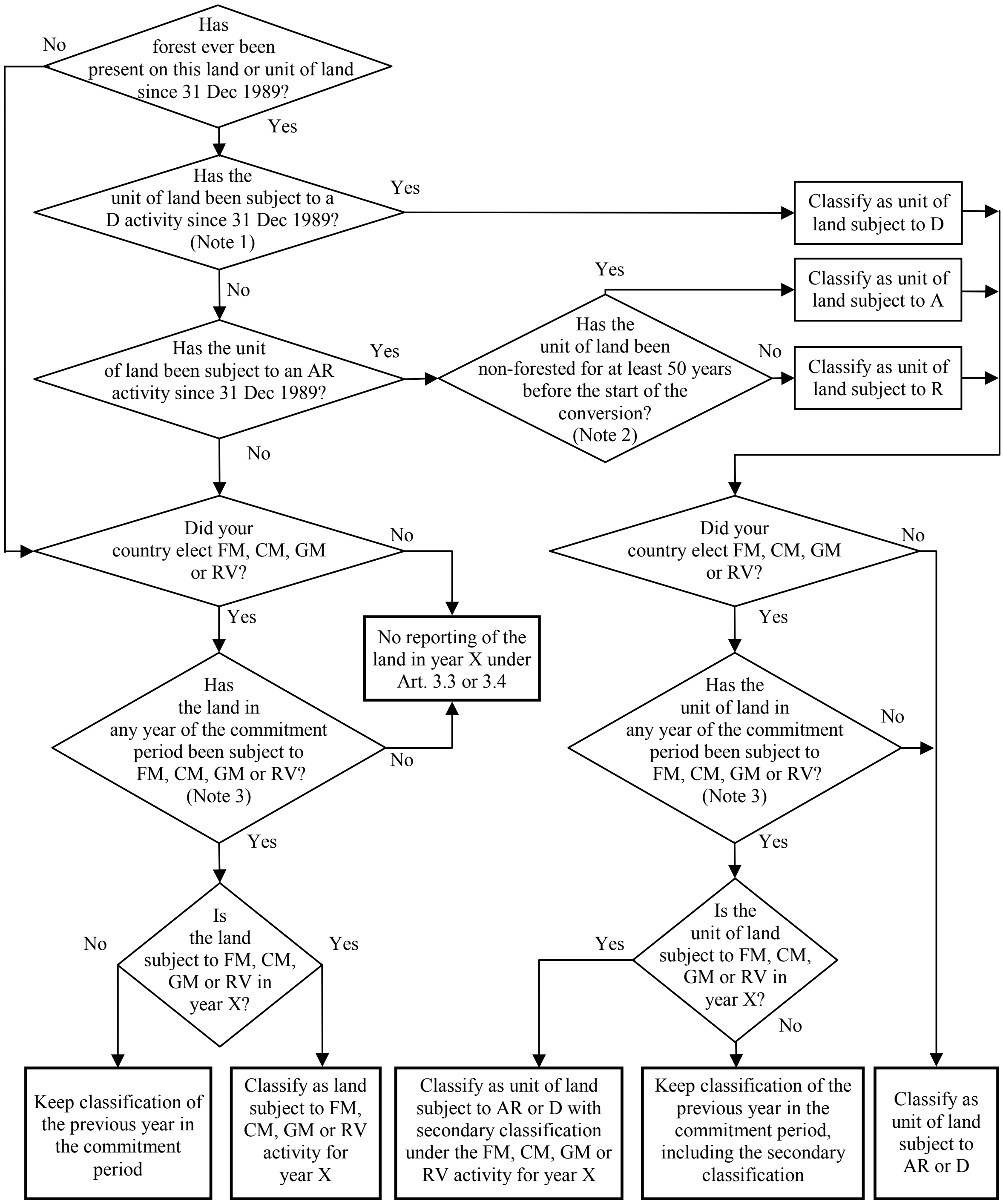
(b) The geographical boundaries of the areas that encompass:

(i) Units of land subject to activities under Article 3, paragraph 3;

(ii) Units of land subject to activities under Article 3, paragraph 3, which would otherwise be included in land subject to elected activities under Article 3, paragraph 4, under the provisions of paragraph 8 of the annex to decision -/CMP.1 (Land use, land-use change and forestry); and

(iii) Land subject to elected activities under Article 3, paragraph 4.

Figure 4.1.1 Decision tree for classifying a unit of land under Article 3.3 (ARD) or land under Article 3.4 (FM, CM, GM and RV) as of year X of the commitment period (2008, 2009, ..., 2012)



Note 1: No matter whether it had been subject to an AR activity before.
Note 2: The distinction between A and R is often irrelevant, in particular if the same methodologies apply. But sometimes they might differ in the rate and direction of soil and litter C stock change.
Note 3: Apply this test only to those activities that your country has elected.

Abbreviations used in the Figure:

AR	Afforestation / Reforestation	D	Deforestation	FM	Forest Management
CM	Cropland Management	GM	Grazing Land Management	RV	Revegetation

The left branch is for lands that are reported under Article 3.4, and needs to be checked by Parties that have elected one or more Article 3.4 activities. This is necessary to know whether a land was subject to an Article 3.4 activity, and also to determine which Article 3.4 activity (if elected) applied on the land most recently. If a land is subject to more than one Article 3.4 activity over the course of time, it is *good practice* to classify that land under only one Article 3.4 category. Therefore, it is *good practice* for countries to set up a hierarchy among the activities forest management, cropland management, grazing land management and revegetation, and – within the scope of the definitions in the Marrakesh Accords – to set up criteria by which lands will be assigned to a single category (see Section 4.1.1, Overview, STEP 1.3). For example, where agriculture and forestry are practiced on the same land, the land may qualify under forest management and under cropland management or grazing land management. It is *good practice* to assign land according to specific, pre-determined rules, rather than on a case-by-case basis. The definitions in the Marrakesh Accords imply that

- Forest management can only take place on lands that meet the definition of a forest;
- Revegetation can only take place when the land is forest neither before nor after the transition (otherwise it would be afforestation, reforestation or forest management); and
- Grazing land and cropland management can take place on either forest or non-forest lands, but will be predominantly on non-forest lands in practice. Any forest land under grazing land or cropland management can be subject to a deforestation activity.

Regarding the relationship between forest management on the one hand, and cropland/grazing land management on the other hand, countries have two options: 1) It is *good practice* to interpret the definition of forest management such that all managed forests are included, including those where also cropland and grazing land management takes place. With this, all lands subject to grazing or cropland management would necessarily have to be non-forest. 2) Alternatively, it is also *good practice* to use pre-defined criteria other than "forest / non-forest" to determine whether a land area is subject to forest management or grazing land management / cropland management. In that case it is possible that some forest lands are included under cropland or grazing land management.

Special attention should be given to avoid overlap or gaps between lands subject to revegetation (if elected) that could qualify under cropland management, grazing land management or potentially forest management (if elected).

In addition note that:

- The decision tree in Fig. 4.1.1 is not sufficient to identify all lands that fall under each activity. For the reporting of these lands, it is *good practice* to follow the methodological guidance provided under “Identification of lands” in the generic Section 4.2.2, and in the activity-specific sections on land identification (Sections 4.2.5.1 / 4.2.6.1 / 4.2.7.1 / 4.2.8.1 / 4.2.9.1 and 4.2.10.1).
- For the first commitment period, Article 3.3 applies to land that is subject to an afforestation, reforestation or deforestation activity at any time between 1 January 1990 and 31 December 2012.
- For reporting during the commitment period Article 3.4 applies to land that is subject to an elected forest management, cropland management, and grazing land management activity during the commitment period[12,13]. Article 3.4 also applies to land subject to revegetation resulting from direct human-induced activities since 1 January 1990.[14]
- Once a land is reported under Article 3.3 or Article 3.4, all anthropogenic greenhouse gas emissions by sources and removals by sinks on this land must be reported during the first and throughout subsequent and

[12] Conversely, for base year reporting, Article 3.4 applies to land that was subject to an elected cropland management, grazing land management or revegetation activity in the base year.

[13] The reason is that if a land was subject to an Article 3.4 activity between 1 January 1990 and 31 December 2007, but is no longer in the years 2008-2012, it could not be accounted for under the Kyoto Protocol. Carbon reporting of this land during the commitment period would be highly complicated because the land would be under a different land use. Land that left the FM category as a result of deforestation would, of course, be reported under Article 3.3.

[14] As stated in STEP 1.2 above, it is *good practice* to apply the definitions of Article 3.4 activities to national circumstances. In doing so, there may be Article 3.4 activities where an individual practice triggers the land to be reported (“narrowly defined activities”). This is likely to apply to revegetation, also possibly to forest management, and requires to report all lands that are subject to the activity since 1990 (as for AR and D). On the other hand, there will be Article 3.4 activities where the mere classification of the land, without a concrete practice, will suffice for the land to be reported (“broadly defined activities”). This is most likely for cropland and grazing land management – also because there the practices are most likely to occur on an annual basis anyway. Here it is sufficient to report the lands subject to the activity in the reporting year of the commitment period.

contiguous commitment periods[15], except the Party chooses not to report a pool that has been shown not to be a source as explained in Section 4.2.3.1. That is, the total land area included in the reporting of Article 3.3 and 3.4 activities can never decrease.

- If certain activities occur during the commitment period, it is possible that a unit of land or land can be reported under different activities in Article 3.3 and/or Article 3.4 over time during the commitment period. However, for each year it can only be reported under a single activity.
- In order to avoid the reporting of lands or units of land in more than one activity in any year during the commitment period, the following should be applied:
  - (i) Units of land subject to activities under Article 3.3 which would otherwise be included in land subject to an Article 3.4 activity (see item (ii) in footnote 11) must be reported separately as lands that are both subject to Article 3.3 and 3.4 activities (referred to as AR or D land with a secondary classification in the decision tree). The decision tree implies that afforestation, reforestation and deforestation have precedence over the other activities for land classification and reporting purposes not only in a given year, but for the entire period between 1990 and 2012.[16]
  - (ii) For lands that are subject to several activities under Article 3.4 it is *good practice* to apply the national criteria that establish the hierarchy among Article 3.4 activities (in the Marrakesh Accords no precedence is implied among Article 3.4 activities, see STEP 1.3 above).
- A land subject to land-use changes (LUCs) can move between categories in the following cases:
  - Afforestation/reforestation land that is subsequently deforested is reclassified as deforestation land (Section 4.2.4.3.2 describes specific provisions for units of land subject to afforestation and reforestation activities since 1990).
  - Land under one elected Article 3.4 activity is converted into land under another elected Article 3.4 activity and must be reclassified accordingly.
  - Land under an elected Article 3.4 activity becomes subject to an Article 3.3 activity and must subsequently be reported under the latter.
- On the other hand, the following transitions are not possible. Note that these restrictions apply to reporting under the Kyoto Protocol (but do of course not affect the actual management that a country applies to its lands):
  - Land cannot shift from an elected Article 3.4 activity to another Article 3.4 activity that was not elected.
  - Land cannot leave the Article 3.3 reporting.
  - Deforestation land cannot become afforestation/reforestation land in the first commitment period. That is, if a forest is established on land deforested since 1990, the carbon removals cannot be reported as a reforestation activity during the first commitment period because of the time limits in the definition for reforestation agreed in the Marrakesh Accords, designed not to credit reforestation on lands that were forest land in 1990.[17] However, because there is the need for continuous full reporting of lands subject to Article 3.3 and 3.4 activities, any carbon stock increases later in the commitment period on deforestation lands will be reported under the deforestation category.
- Boundaries between forest management and cropland or grazing land systems can be difficult to define where these activities are practiced on the same land area. The decision tree in Figure 4.1.1 suggests that planting of shelterbelt trees or orchards after 1990 that meet the criteria for a forest would be reported under the afforestation and reforestation category, even if they occur on lands whose use is mainly agricultural. For shelterbelts and orchards which already existed in 1990, however, the decision tree implies that the country can prioritise the Article 3.4 reporting category as either cropland management or grazing land management, or as forest management – provided that the land meets the definition of the category chosen, and the prioritisation is consistent with the hierarchy of Article 3.4 activities set up at the beginning. For example, if shelterbelts or farm woodlots do not appear to be part of forest management as such, and are

[15] Paragraph 19 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.61.

[16] This is implied in the text of the Marrakesh Accords cited in footnote 11 above, item b (ii).

[17] Paragraph 1(c) of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p 58.

clearly associated with cropping or grazing land systems, the hierarchical system set up by a country might determine this to be reported under cropland management or grazing land management.

In summary, this means that the area under Article 3.3 (afforestation, reforestation and deforestation lands) will grow from 0 hectares on 1 January 1990 up to a certain value in 2012. At any given point in time, the afforestation, reforestation and deforestation categories should contain all areas of land that have been afforested, reforested or deforested since 1990. The area under Article 3.3 (deforestation) will stay constant or increase in size during the commitment period. The land area in the afforestation and reforestation category will typically increase, but can also decrease if afforestation and reforestation lands are subject to deforestation activities.

The amount of lands in the forest management, cropland management, grazing land management, and revegetation categories can fluctuate because of various land-use changes. It is unlikely that those areas will stay constant over time for the purpose of reporting because, for example:

- Afforestation and reforestation, and deforestation land areas are allowed to grow;
- Grazing lands can become croplands and vice versa;
- Revegetated lands can become croplands or grazing lands or vice versa; and
- Forest management land areas can increase, for example, as countries expand the road infrastructure to areas previously unmanaged.

Box 4.1.1 provides several examples that summarise the Marrakesh Accords and the considerations that apply for lands subject to activities under Articles 3.3 and 3.4 of the Kyoto Protocol. The preceding sections of Chapter 4 have provided merely an overview of the Marrekech Accords. For more detailed explanations of the rationale behind the examples in Box 4.1.1, the reader is referred to the detailed explanations in the remaining sections of Chapter 4.

BOX 4.1.1
EXAMPLES FOR THE ASSIGNMENT OF UNITS OF LAND TO ARTICLE 3.3 ACTIVITIES AND LANDS TO ARTICLE 3.4 ACTIVITIES OVER TIME

The following examples are intended to show, conceptually, how different land-use transitions would be categorised in different inventory years under the Kyoto Protocol. This does not necessarily imply that the land-use transition can be directly measured on an annual basis. Note that for croplands and grazing lands only carbon stock changes are discussed in the examples below. Non-CO_2 greenhouse gas emissions for such lands are reported under the Agriculture Sector of the *IPCC Guidelines* (Section 4.5.2 in the Reference Manual), independently of which Article 3.4 activities were elected by the Party.

Example 1: A land under forest management is deforested in 1995 and turned into a cropland.

2008-2012: Carbon stock changes and non-CO_2 greenhouse gas emissions on this land are reported under deforestation. The methodology for croplands that were previously forest (Section 3.3.2) is to be used.

Carbon stock changes on this land will not be reported under cropland management, even if cropland management was elected, because deforestation takes precedence over cropland management. The decision tree in Figure 4.1.1 therefore assigns this land to deforestation, with cropland management as a secondary classification.

Should trees be re-established on this land again, for example in 2011, the land remains in the deforestation category, because reforestation is not admissible on lands that were forest in 1990. The methodology to be used to estimate for carbon stock changes, however, is the one for reforestation.

Example 2: A land under forest management is deforested on 1 January 2010 and turned into a cropland.

2008-2009: Carbon stock changes and non-CO_2 greenhouse gas emissions on this land for the years 2008 and 2009 are reported under forest management (if forest management is elected, otherwise they are not reported at all under the Kyoto Protocol, only as part of the regular annual LUCF inventory under the UNFCCC).

2010-2012: Carbon stock changes and non-CO_2 greenhouse gas emissions on this land in the years 2010-2012 are reported under deforestation. The methodology for croplands that were previously forest (Section 3.3.2) should be used. Non-CO_2 greenhouse gas emissions directly resulting from the deforestation should be reported under the Deforestation category. Non-CO_2 greenhouse gas emissions resulting from the agricultural practices should be reported in the Agriculture sector of the national inventory as per the *IPCC Guidelines*. Double counting should be avoided.

BOX 4.1.1 EXAMPLES (CONTINUED)

Carbon stock changes on this land will not be reported under cropland management, even if cropland management has been elected, because deforestation takes precedence over cropland management. The decision tree in Figure 4.1.1 therefore assigns this land to deforestation with cropland as a secondary classification.

Example 3: A cropland is turned into a grazing land in 2010.

2008-2009: Carbon stock changes and non-CO_2 GHG emissions on this land are reported under cropland management (if elected, otherwise not reported at all under the Kyoto Protocol, only as part of the annual LUCF inventory).

2010-2012: If grazing land management is elected, carbon stock changes and non-CO_2 greenhouse gas emissions from this land are reported under grazing land management (Sections 3.4.2 and 4.2.9). If grazing land management is not elected, carbon stock changes and non-CO_2 greenhouse gas emissions on this land will still have to be reported under cropland management for those years (if cropland management is elected), because of the requirement to continue to report on future stock changes once land has entered the Kyoto reporting system.

Example 4: A grazing land is turned into a settlement in 2005.

2008-2012: Carbon stock changes and non-CO_2 greenhouse gas emissions from this land are not reported under the Kyoto Protocol, since it was not subject to an elected activity during the commitment period.

Example 5: A grazing land is turned into a settlement land in 2010.

The land needs to be reported as being subject to grazing land management (if elected) in all five years of the commitment period (because it was under grazing land management at least in one year during the commitment period). Pre-2010, the grazing land methods need to be used whereas, starting in 2010, the methodologies for conversion to settlements need to be used.

Example 6: Forest management land is turned into a settlement in 2010.

2008-2009: Carbon stock changes and non-CO_2 greenhouse gas emissions from this land are reported under forest management (if elected, otherwise not reported at all under the Kyoto Protocol, only under the managed forest of the regular LUCF inventory).

2010-2012: Land reported as "deforested", using the methodologies of Chapter 3, Section 3.6, for lands converted to settlements.

Example 6 shows that land which is converted from an elected land use during the commitment period should continue to be reported. This does not apply to Example 4 because no removal units will have been generated.

Example 7: Forest management land is turned into a settlement[18] in 1995.

2008-2012 carbon stock changes are reported under Article 3.3, deforestation.

Example 8: Other land is turned into grazing land (and reported as revegetation) in 2005.

In each year of the commitment period the carbon stock changes and non-CO_2 greenhouse gas emissions from this land are reported under revegetation (if elected).

[18] which, by definition, is non-forest, see Chapter 2.

4.1.3 Relationship between Annex I Parties' national inventories and Article 6 LULUCF projects

Emissions or removals resulting from Article 6 projects will be part of the host country's annual inventory under the UNFCCC and Kyoto Protocol reporting. The methods for estimating, measuring, monitoring and reporting greenhouse gas emissions and removals resulting from LULUCF project activities are addressed in Section 4.3 (LULUCF Projects).

When estimating the greenhouse gas emissions and removals of Article 3.3 and 3.4 activities, it is possible to use the information that is reported for, or is meeting the standards of, Article 6 LULUCF projects on these lands (but not *vice versa*). Two options exist for Article 3.3 and Article 3.4 estimation, both of which are considered *good practice*:

Option 1: Carry out Article 3.3 and Article 3.4 assessment without consideration of information reported for Article 6 projects (which are reported separately according to Section 4.3). This assumes that a properly designed national system will also automatically include the effects of Article 6 projects. This approach is also taken in the other emission sectors. For example, an Article 6 project that reduces emissions from fossil fuels is not *individually* considered in the national emissions inventory, but will *implicitly* be included due to the project's impacts in the national statistics for fossil fuels.

Option 2: Consider all changes of carbon stocks as well as greenhouse gas emissions and removals at the project level as a primary data source for Article 3.3 and/or Article 3.4 estimation and reporting, for example by considering projects as a separate stratum. Any Article 3.3 and 3.4 activities that are not projects need to be monitored separately. In this case, the design of the monitoring must ensure that projects are explicitly excluded from the remaining lands under Articles 3.3 and 3.4, to avoid double counting.

One important difference between project and national (Articles 3.3 and 3.4) accounting is that projects have a baseline scenario (i.e., only **additional** carbon stock changes and non-CO_2 greenhouse gas emissions due to the project are accounted), while afforestation, reforestation, deforestation, forest management, cropland management, grazing land management and revegetation do not have a baseline scenario. Therefore, when using project-level information for reporting under Articles 3.3 and 3.4, one must take account of the overall carbon stock changes and non-CO_2 greenhouse gas emissions associated with the projects, and not just the change relative to the baseline scenario.

4.2 METHODS FOR ESTIMATION, MEASUREMENT, MONITORING AND REPORTING OF LULUCF ACTIVITIES UNDER ARTICLES 3.3 AND 3.4

Section 4.2 provides a discussion of generic methodological issues that concern all possible land use, land-use change and forestry (LULUCF) activities under Kyoto Protocol Articles 3.3 and 3.4 (Section 4.2.1 on the relationship between land-use categories in reporting under the UNFCCC and the Kyoto Protocol, 4.2.2 on land areas, Section 4.2.3 on estimating carbon stock changes and non-CO_2 greenhouse gas emissions, and Section 4.2.4 on other generic methodological issues). This is followed by specific methodologies for monitoring afforestation and reforestation (treated together), deforestation, forest management, cropland management, grazing land management and revegetation (Sections 4.2.5 – 4.2.10), and projects (Section 4.3). Readers should refer to both the generic and the specific issues for any one of the activities.

4.2.1 Relationship between UNFCCC land-use categories and Kyoto Protocol (Articles 3.3 and 3.4) land-use categories

This subsection provides an overview of how the activities under Articles 3.3 and 3.4 relate to the land-use categories introduced in Chapter 2 and elaborated/utilized for the purposes of reporting on national greenhouse gas emissions and removals under the UNFCCC in Chapter 3 (LUCF sector good practice guidance).

Land-use systems are classified in Chapters 2 and 3 into:

(i) Forest land (managed and unmanaged) (Section 3.2)

(ii) Cropland (Section 3.3)

(iii) Grassland (managed and unmanaged) (Section 3.4)

(iv) Wetlands (Section 3.5 and Appendix 3a.3)

(v) Settlements (Section 3.6 and Appendix 3a.4)

(vi) Other land (Section 3.7)

Relationships exist between the basic land-use categories (i) to (vi) described in Section 2.2 and the activities of the Kyoto Protocol and Marrakesh Accords (Table 4.2.1). Land subject to Kyoto Protocol activities should be identified as a subcategory of one of these six main types.

Using categories (i) to (vi) as a basis for estimating the effects of Articles 3.3 and 3.4 activities helps meet *good practice* requirements and will be consistent with the national land categorization used for preparing LUCF greenhouse gas inventories under the Convention. For example: Forest Land could be partitioned into: a) Forest Land under Article 3.3; b) Forest Land under Article 3.4, c) Other managed Forest Land (this would be the case if the definition of "managed forests" differs from the definition of "lands subject to forest management"); and d) Unmanaged Forest Land. More information on the relationship between "managed forests" and "forest management" can be found in Section 4.2.7, Figure 4.2.7.

Many of the methods described in subsequent sections of Chapter 4 build on methodologies that appear in Chapters 2 and 3 of this report or in the *IPCC Guidelines*. For continuity and clarity, cross-references back to these preceding descriptions appear periodically in Boxes, as they become pertinent. Direct references to the results in Chapter 3 reporting tables is not possible because for Kyoto Protocol reporting additional spatial stratification is required that cannot be inferred from Chapter 3 Reporting Tables.

TABLE 4.2.1
RELATIONSHIP BETWEEN ACTIVITIES UNDER ARTICLES 3.3 AND 3.4 OF THE KYOTO PROTOCOL AND THE BASIC LAND-USE CATEGORIES OF SECTION 2.2

Read this table as follows: For example, if a land is initially cropland and then managed forest, then this event **must** constitute either afforestation or reforestation. Such mandatory Article 3.3-related classifications are highlighted in **bold**. On the other hand, if a land is first cropland and then managed grassland, then this may constitute GM or RV. The latter choice depends on the election of Article 3.4 activities by a country and on how national circumstances are applied to the definitions related to Article 3.4. Such Article 3.4-related, election-dependent classifications are printed in normal font.

Final / Initial	Managed Forest land	Unmanaged Forest land	Cropland	Managed Grassland	Unmanaged Grassland	Wetland	Settlements	Other land
Managed Forest land	FM or GM or CM		**D***	**D***		**D***	**D***	**D***
Unmanaged Forest land	FM		**D***	**D***		**D***	**D***	**D***
Cropland	**A/R***		CM, RV	GM or RV		RV	RV	
Managed Grassland	**A/R***		CM	GM or RV		RV	RV	
Unmanaged Grassland	**A/R***		CM	GM			RV	
Wetland	**A/R***		CM	GM		RV	RV	
Settlements	**A/R***		CM	GM or RV		RV	RV	
Other land	**A/R***		CM, RV	GM or RV		RV	RV	

* Transitions involving Article 3.3 activities have to be the result of direct human-induced activities.

Notes

1. “Initial” and “Final” refer to the categories before and after a land-use change. A – Afforestation (land has not been forested for at least 50 years), R – Reforestation (land has not been forested at the end of the year 1989), D – Deforestation, FM – Forest management, CM – Cropland management, GM – Grazing land management, RV – Revegetation (activities other than A or R that increase carbon stocks by establishment of vegetation).
2. If the “initial” categorization was done for a year of the commitment period, then the land must be classified under the same activity for all subsequent years, even if the land use changes once more.
3. All units of land subject to direct human-induced A/R activities are considered to be managed forests, and therefore unmanaged forest land cannot result from an A/R event in the table. Similarly, it is assumed that all units of land subject to direct human-induced D activities are managed lands. This includes natural D followed by a change to a *managed* land use.

Figures 4.2.1 and 4.2.2 graphically show the relationship between these land-use categories reported in national inventories under the UNFCCC and those under Articles 3.3 and 3.4 of the Kyoto Protocol in any single reporting year. The outer rectangle represents the boundaries of a hypothetical country. The top diagram shows the reporting categories for the UNFCCC national inventory according to Chapter 3, and the bottom diagram includes an additional layer with the Article 3.3 and Article 3.4 categories under the Kyoto Protocol.

Figure 4.2.1 Land classification in the national inventories under the UNFCCC of a hypothetical country in year X of the commitment period[19]

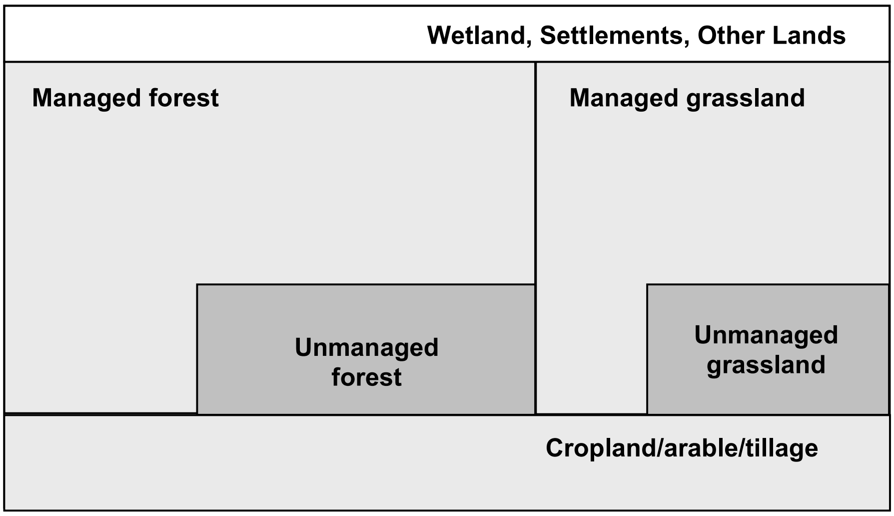
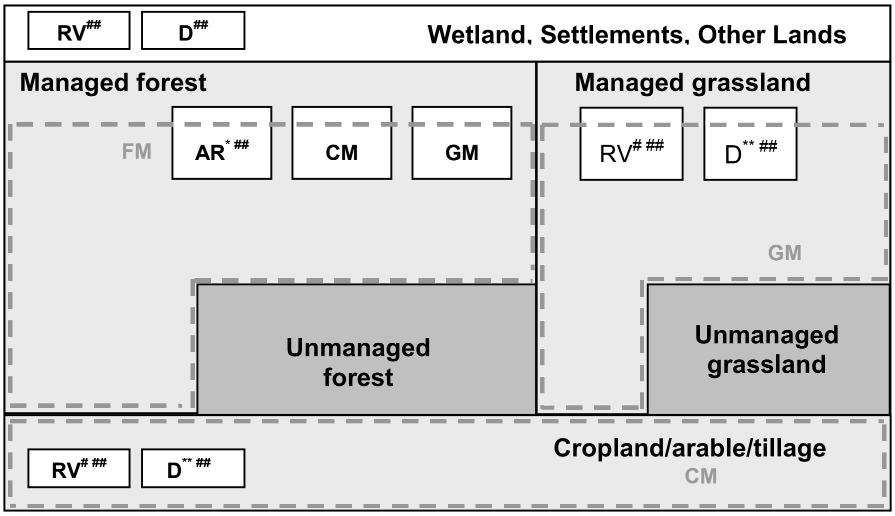


Figure 4.2.2 Land classification for Kyoto Protocol reporting for a hypothetical country in year X of the commitment period. This classification corresponds to the "final" status in Table 4.2.1.



Note * A/R takes precedence over FM, and therefore the land is subject to FM, but not reported in the FM category.

** D takes precedence over cropland/grassland categories.

Land can only count either in RV or in cropland/grassland management (choice according to hierarchy by country)

For A/R, D and RV the units of land are shown after the land-use transition has occurred. Therefore, A/R is in forest land, and RV and D are in non-forest lands in the Figure.

A/R : Afforestation / Reforestation, D : Deforestation, FM : Forest Management, CM : Cropland Management
GM : Grazing Land Management, RV : Revegetation

Some further observations relating to Figure 4.2.2:

- The areas surrounded by dashed lines are areas subject to the additional activities under Article 3.4, i.e., forest management, cropland management and grazing land management activities.

[19] Unmanaged forests and unmanaged grasslands are not reported in UNFCCC inventories.

- Forest, as defined by the Marrakesh Accords, relates to the physical characteristics of forests. An area subject to forest management is subsequently determined as an area upon which particular management practices are undertaken, consistent with Article 3.4 and the Marrakesh Accords. Forest management lands can include all managed forests according to the *IPCC Guidelines*. However, this situation may not always apply, because (i) countries could use different thresholds for defining forests for Kyoto Protocol as opposed to UNFCCC reporting, (ii) Article 3.4 as well as the Marrakesh Accords require that the activity took place since 1990, and (iii) the Marrakesh Accords' definition of forest management[20] contains additional criteria on stewardship. For further discussion of this possible definitional difference see Figure 4.2.8 and accompanying text in Section 4.2.7.2 (Choice of Methods for identifying lands subject to forest management). Unmanaged forests that remain unmanaged are included neither in the UNFCCC nor in the Kyoto Protocol reporting.
- For Kyoto reporting lands subject to cropland management as described in the Marrakesh Accords are identical to Cropland/arable/tillage lands in UNFCCC reporting.
- Grazing land management usually occurs on lands classified as grasslands in the UNFCCC inventory. However, grazing land management can also occur in managed forests, and not all grasslands are necessarily grazing lands. Unmanaged grasslands will be excluded from both the UNFCCC and the Kyoto Protocol reporting.
- Afforested and reforested (A/R) lands are always managed forests. Yet, carbon stock changes and non-CO_2 greenhouse gas emissions are to be reported under Article 3.3 only.
- Deforested lands are usually managed (thus, there is no "D" box in the unmanaged grasslands). An exception is a wetland created from alterations of a hydrological regime, e.g., through the construction of a road.

4.2.2 Generic methodologies for area identification, stratification and reporting

4.2.2.1 Reporting requirements

The Marrakesh Accords state that areas of land subject to Article 3.3 and Article 3.4 activities must be identifiable[21], adequately reported[22] and tracked in the future.[23] Section 4.2.2.2 discusses two land reporting

[20] Paragraph 1 (f) of the Annex to the draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p. 58: "*Forest management" is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological* (*including biological diversity*), *economic and social functions of the forest in a sustainable manner.*

[21] Paragraph 20 of the Annex to the draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.61: *National inventory systems under Article 5.1 shall ensure that areas of land subject to land use, land-use change and forestry activities under Article 3, paragraphs 3 and 4 are identifiable, and information about these areas should be provided by each Party included in Annex I in their national inventories in accordance with Article 7. Such information will be reviewed in accordance with Article 8.*

[22] Paragraph 6 of the Annex of the draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.22:

General information to be reported for activities under Article 3, paragraph 3, and any elected activities under Article 3, paragraph 4, shall include: [...]

(b)The geographical location of the boundaries of the areas that encompass:

(i) Units of land subject to activities under Article 3, paragraph 3;

(ii) Units of land subject to activities under Article 3, paragraph 3, which would otherwise be included in land subject to elected activities under Article 3, paragraph 4, under the provisions of paragraph 8 of the annex to decision -/CMP.1 (Land use, land-use change and forestry); and

(iii) Land subject to elected activities under Article 3, paragraph 4. [...]

(c)The spatial assessment unit used for determining the area of accounting for afforestation, reforestation and deforestation.

[23] Paragraph 19 of the Annex to the draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.61: *Once land is accounted for under Article 3, paragraphs 3 and 4, all anthropogenic greenhouse gas emissions by sources from and removals by sinks on this land must be accounted for throughout subsequent and contiguous commitment periods.*

methods that can be applied to all Article 3.3 and Article 3.4 activities. Section 4.2.2.3 discusses how these reporting methods can draw on the three approaches presented in Chapter 2. Section 4.2.2.4 provides a decision tree for selecting one of the two reporting methods, and Section 4.2.2.5 includes a more detailed discussion of how lands subject to Articles 3.3 and 3.4 can be identified, so that the requirements of either reporting method can be satisfied.

4.2.2.2 REPORTING METHODS FOR LANDS SUBJECT TO ARTICLE 3.3 AND ARTICLE 3.4 ACTIVITIES

To meet the reporting requirements of the Marrakesh Accords, general information to be reported on activities under Articles 3.3 and 3.4 must include the geographical boundaries of areas encompassing units of land subject to afforestation and reforestation, deforestation, and lands subject to elected activities among forest management, cropland management, grazing land management and revegetation activities. To achieve this, a Party may choose one of two methods (Figure 4.2.3):

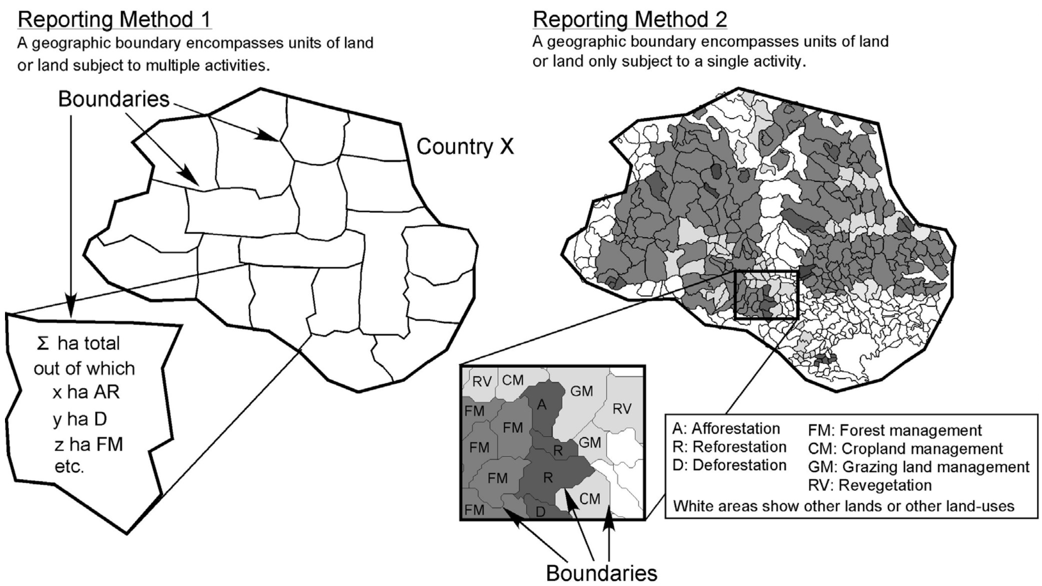
Reporting Method 1 entails delineating areas that include multiple land units subject to Article 3.3 and 3.4 activities by using legal, administrative, or ecosystem boundaries. This stratification is based on sampling techniques, administrative data, or grids on images produced by remote sensing techniques. The identified geographic boundaries must be georeferenced.

Reporting Method 2 is based on the spatially explicit and complete geographical identification of all units of land subject to Article 3.3 activities and all lands subject to Article 3.4 activities.

To implement Reporting Method 1, it is *good practice* to stratify the entire country and to define and report the geographic boundaries of these areas of land. Criteria for stratification of the country could include statistical considerations for the sampling intensity or sampling approaches, considerations of the type and amount of land-use change activities (Article 3.3) and elected activities (Articles 3.4), as well as ecological or administrative considerations. Within each resulting geographic boundary the units of land subject to Article 3.3 activities and the lands subject to any Article 3.4 activities (if elected) must then be quantified using the approaches described in Chapter 2 (Section 2.3 Representing land areas), in accordance with the guidance in Section 4.2.2.3, as well as the methods in Sections 4.2.2.5 (generic methods) and 4.2.5 to 4.2.10 (activity specific methods).

To implement Reporting Method 2, a Party should identify and report the spatial location of all lands and units of land based on a complete mapping of all areas within its national boundaries. This is described in Chapter 2 as the wall-to-wall mapping version of Approach 3 (Section 2.3.2.3). This reporting method uniquely identifies lands and units of land and enables activities to be reported without the risk of double counting. To put this reporting method fully into practice requires large-scale data collection and analysis, and the preparation of summary statistics to ensure that reporting is transparent yet concise.

Figure 4.2.3 Two reporting methods for land subject to Articles 3.3 and 3.4 activities



With either reporting method, once land is reported as being subject to activities specified under the Marrakesh Accords, it should be traceable for the first and subsequent commitment periods. Therefore, if a Party chooses Reporting Method 1, it is *good practice* to record the information needed to identify the sample locations and the units of land or lands identified in the samples, and to use the same sample locations for any future monitoring. This ensures that changes in the status of land covered by sample plots (Reporting Method 1) or in the entire country (Reporting Method 2) can be tracked and monitored from 1990 to the end of the commitment period.

The geographic boundaries resulting from the stratification of the country should be reported using printed maps or digital maps, as described in Section 4.2.4.3.1 (Reporting).

4.2.2.3 RELATIONSHIP BETWEEN APPROACHES IN CHAPTER 2 AND REPORTING METHODS IN CHAPTER 4

Chapter 2 (Basis for consistent representation of land areas) describes three approaches to representing land area. The detailed reporting requirements of Articles 3.3 and 3.4 of the Kyoto Protocol as elaborated in the Marrakesh Accords are met by the two reporting methods given in this chapter, and underpinned by the approaches described in Chapter 2. This section, summarised in Table 4.2.2, discusses which of the three Chapter 2 approaches are suitable for identifying units of land subject to Article 3.3 activities or lands subject to selected activities under Article 3.4. Note that even the most data-intensive Approach 3 outlined in Chapter 2 can only meet the requirements of the Marrakesh Accords without supplemental information if the spatial resolution at which land-use changes are tracked is consistent with the size parameter selected by a country to define forest, i.e., polygon sizes of 0.05 to 1 ha or grids of 20 to 100 m (see STEP 1.1 in Section 4.1.1). Land cover and land-use mapping using, for example, 1 km^2 (100 ha) pixel resolution does not meet the Protocol's requirements and supplemental information will be required.

4.2.2.3.1 APPROACH 1

Approach 1 in Chapter 2 provides information that is not spatially explicit and it only reports the net changes in the areas of different land-use categories. Hence, this approach does not meet the land identification requirements of the Marrakesh Accords. National inventory databases are often compiled from detailed spatial inventories that can be based, for example, on sampling approaches that involve a grid or sample plot system. In countries where this is the case, it may be possible to re-compile the detailed inventory information for the geographical boundaries, which have resulted from the stratification of the country, to meet the reporting requirements of the Marrakesh Accords. This means that Approach 1 can only be applied to Reporting Method 1 if additional spatial data at the required spatial resolution are available as a result of re-compiling the inventory information, and if the gross land-use transitions (rather than the net changes in land-use categories) are quantified.

4.2.2.3.2 APPROACH 2

Approach 2 focuses on land-use transitions. Although it provides useful information on land-use changes, especially regarding afforestation, reforestation and deforestation under Article 3.3, it is not spatially explicit. Hence, additional spatial information at the required spatial resolution is necessary to meet the reporting requirements of the Marrakesh Accords. This approach can therefore only be used to identify units of land or land subject to activities under Articles 3.3 and 3.4 if additional spatial data are available. As with Approach 1, it may be possible to apply Approach 2 to Reporting Method 1 if additional spatial data at the required spatial resolution become available from re-compiling the inventory information.

4.2.2.3.3 APPROACH 3

Approach 3 explicitly tracks land based on sample approaches, a grid system, or a polygon system within the geographic boundaries, which have resulted from the stratification of the country. This approach is applicable to Reporting Methods 1 and 2 above, as long as the spatial resolution is fine enough to represent the minimum forest area as defined by the Party under the Marrakesh Accords.

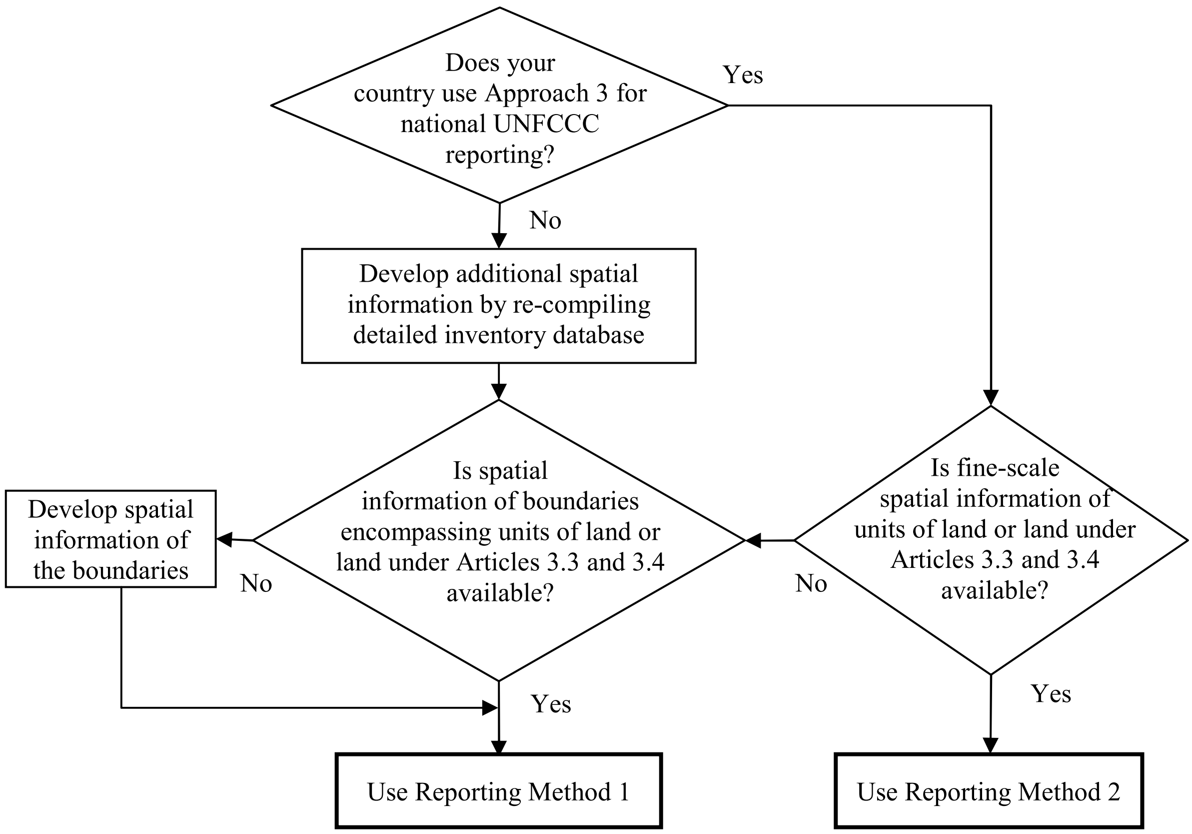
TABLE 4.2.2
RELATIONSHIP BETWEEN APPROACHES IN CHAPTER 2 AND REPORTING METHODS IN CHAPTER 4

Chapter 2 Approaches	Reporting Method 1 (Broad area identification)	Reporting Method 2 (Complete identification)
Approach 1	Can only be used if additional spatial information is available by re-compiling inventories.	Not applicable
Approach 2	Can only be used if additional spatial information is available by re-compiling inventories.	Not applicable
Approach 3	*Good practice* if resolution is fine enough to represent minimum forest area. Involves aggregating data within the reported geographic boundaries.	*Good practice* if resolution is fine enough to represent minimum forest area.

4.2.2.4 CHOICE OF REPORTING METHOD

It is *good practice* to choose an appropriate reporting method using the decision tree given in Figure 4.2.4. National circumstances may allow a Party to use a combination of both reporting methods. In such a case, it is *good practice* to first stratify the entire country and then to quantify and report the area of units of land and land using Reporting Method 1. Within those geographical boundaries where complete spatial identification of lands and units of land is possible, Reporting Method 2 can then be applied.

Figure 4.2.4 Decision tree for choosing a reporting method for land subject to activities under Articles 3.3 and 3.4



When using Method 1 it is usually *good practice* to use the same geographical boundaries for all activities. This will greatly facilitate the identification, quantification, and reporting of land-use changes. However, national circumstances may provide justification for different choices of geographic boundaries for different activities. For example, different geographic boundaries may be chosen so as to reduce the variance of estimates for one activity within a given boundary. When a Party uses more than one set of geographic boundaries (i.e., more than one stratification system is used), lands or units of land subject to Article 3.3 or 3.4 activities that moved from one category to another must be appropriately assigned to the correct geographical boundary. This might require proportional allocation of the units of land to each stratification system in use.

4.2.2.5 HOW TO IDENTIFY LANDS (UNITS OF LAND) IN GENERAL

4.2.2.5.1 SPATIAL CONFIGURATION OF FORESTS AND AFFORESTATION, REFORESTATION OR DEFORESTATION EVENTS

The Marrakesh Accords specify that each Annex I Party to the Kyoto Protocol must choose country-specific parameters within the definition of forest as an integral part of their Kyoto Protocol reporting. The latest possible date to do that is 31 December 2006, or one year after the entry into force of the Kyoto Protocol for that Party, whichever is later[24]. This requires selecting values for the following three parameters: the size of the minimum area of land that can constitute a forest, ranging between 0.05 and 1 ha, and parameters for crown cover (10 – 30%) and tree height at maturity (2 – 5 m). The parameter for the minimum area of land that constitutes a forest does also specify the minimum area on which afforestation/reforestation or deforestation events occur. Thus a country that selects, say 0.5 ha as the minimum area of forest land, must also identify all deforestation events that occur on lands that are 0.5 ha or larger. The identification of units of land on which land-use changes occur, such as deforestation, requires the detection of a reduction in forest cover from above to below the country-specific threshold of forest, accompanied by a change in land-use.

The Marrakesh Accords do not specify the shape of areas, neither for forest, nor for those areas on which afforestation, reforestation or deforestation events occur. Square areas that meet the size range of the Marrakesh Accords would be 22.36 m (0.05 ha) to 100 m (1 ha) on each side. But a rectangle that is 10 m wide and 1,000 m long is also 1 ha in area, as is a 5 m wide and 2,000 m long rectangle. Therefore, a treed shelterbelt or any other strip of trees that exceeds these sizes could be considered a forest. But if such “linear forests” are included in a Party’s definition of forest, it is *good practice* to also consider as non-forest any areas being cleared from trees by "linear deforestation events", such as roads, transmission right-of-ways, or pipeline corridors. When such corridors have resulted from cuts since 1990, they should be treated as deforestation events under Article 3.3.

For example, if a country selects 1 ha as the minimum area of forests and afforestation, reforestation or deforestation events, and further specifies that these areas are square, then a 20 m wide corridor cut through a forest with 100% canopy closure, will reduce canopy closure to 80%. This is higher than the range of canopy closures (10 – 30%) that could be selected by a Party. Therefore the residual area is defined as forest, and even when this corridor through the forest is cut since 1990, it would not constitute a deforestation event. If this "only" 20 m wide corridor is part of a long corridor, which streches for many kilometers, such as a transmission right-of-way or a pipeline corridor, the total corridor area is much greater than 1 ha. Therefore the definitional criteria applied to specify the shape of the forests and of the areas subject to afforestation, reforestation or deforestation events can have a large impact on the amount of land reported under Article 3.3.

It is therefore *good practice* for countries to include, with their report on the choice of forest definitions, a description of the definitional criteria which are used to identify forests and areas on which afforestation, reforestation or deforestation events occur. It is also *good practice* to apply these criteria consistently to the identification of both deforestation and afforestation or reforestation events that have occurred since 1990. For instance, these criteria can simply be defined as the minimum width that will be accepted for a forest and an area subject to an afforestation, reforestation or deforestation event. Then the minimum length of the area follows from the combination of width and the chosen parameter for minimum area which can constitute a forest. For example, if the size were defined as 1 ha, with a minimum width of 20 m, then a rectangle of minimum width has to be at least 500 m long to meet the 1 ha size requirement.

"Linear deforestation events" narrower than the selected minimum width criteria can contribute to reported carbon stock changes if they occur within lands subject to FM activities, given the Party has elected FM as Article 3.4 activity. Similarly, shelterbelts that are narrower than the selected minimum width criteria can also contribute to reported carbon stock changes, if these shelterbelts are within lands subject to cropland management, grazing land management, or revegetation activities, given the Party has elected the respective Article 3.4 activity.

[24] See paragraph 16 of the Annex of Draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p. 61, and paragraph 8 (b) of the Annex to Draft decision -/CMP.1 (Modalities for the accounting of assigned amounts), contained in document FCCC/CP/2001/13/Add.2, p. 59, and also Table 4.2.4a.

4.2.2.5.2 SOURCES OF DATA FOR IDENTIFYING LANDS

The needs for the reporting of lands subject to activities under Articles 3.3 and 3.4 have been outlined in the previous sections. The data and information available to a country to meet these needs will depend largely on national circumstances. These include the land and forest inventory systems already in place and the additional measures a country chooses to implement in order to meet the reporting requirements.

In very general terms there are three major options that can be taken to meet the information needs:

- To use information from existing land-use and forest inventory systems.
- To implement a monitoring and measurement system.
- To implement an activity reporting system that includes verification and auditing procedures.

It is likely that in most countries the existing land use and inventory systems are inadequate to meet all the land reporting requirements of the Kyoto Protocol, and that, with varying degrees of incremental efforts, additional information must be obtained through monitoring or in-country reporting systems. A country's choices of the appropriate systems will depend on national circumstances. For example, a country could determine that it would be most efficient to combine an activity reporting system to identify units of land subject to afforestation/reforestation, and a monitoring system to identify units of land subject to deforestation.

Use of existing inventories

Countries that maintain detailed forest and other land-use inventories or collect annual or periodic spatial land statistics may be able to identify lands affected by Article 3.3 and 3.4 activities since 1990 from their inventories. This, however, will only be possible if the national inventory and data collection systems meet stringent technical requirements. The systems must be able to define the land use and forest area in 1990, have an update cycle that is sufficiently short to capture land-use change events between 1990 and 2008, and between 2008 and 2012, and be of sufficient spatial resolution to identify events of the size of the minimum forest area chosen by the country, i.e., 1 ha or smaller. Also, the sample plots within a "boundary" need to be georeferenced and used repeatedly during future monitoring. If the latter is not possible, e.g., because monitoring procedures were changed, it is *good practice* to develop computational procedures, which allow to convert the data between the used sampling schemes or which, at least to have a method, allow to map the data from a previous to a successor sampling scheme (see also Sections 4.2.4.1. Developing a consistent time series and 4.2.4.1.1 Recalculation).

Forest inventories in large countries often do not record polygons less than, for example, 3 ha in size. The requirement to identify afforestation, reforestation or deforestation activities at a resolution of 0.05 to 1 hectares can be met, however, with additional statistical analyses to establish the area subject to afforestation, reforestation or deforestation events that occurred in units less than 3 ha in size. One possible approach could be to determine the size-class distributions of afforestation/reforestation and of deforestation events in the country, using a statistical sampling approach. The proportion of the area of afforestation/reforestation and of deforestation events that is between 0.05 – 1 ha and the minimum mapping unit in the inventory (in this example 3 ha) can then be applied to estimate the area of afforestation/reforestation and deforestation events from the 3-ha resolution inventory. For example, if the 3-ha resolution inventory shows that there have been 1,000 ha of afforestation/reforestation events in units of 3 ha or larger, and the sample-based size-class distribution of afforestation/reforestation events shows that on average 5% of the afforestation/reforestation events is in areas of size between 0.05 – 1 ha and 3 ha, then the 1,000 ha represent 95% of the total afforestation/reforestation area (and the total is estimated to be 1,000 • 100/95 = 1,052.6 ha). It is *good practice* to document the statistical validity of the sample-based size-class distribution, and its regional and temporal variation. Note that this approach to augmenting existing inventory information also has implications for the determination of carbon stock changes: since these 5% of the area are not geographically referenced, only statistical methods such as regional averages can be used to determine their carbon stock changes and trace their fate, once they are included under Article 3.3 or 3.4, over time.

Countries that choose an inventory-based approach for the identification of units of land subject to afforestation/reforestation activities can face the challenge that non-forest areas are not normally included in the forest inventory. In this case, countries must ensure that their inventory system detects land-use transitions from non-forest to forest and expands the forest inventory into the newly created forest area. Some countries monitor changes from non-forest to forest by means of remote sensing of lands not previously covered by the forest inventory or by maintaining inventory plots on non-forest land.

Monitoring and measurement of activities

In order to meet the reporting requirements of Articles 3.3 and 3.4, countries may have to develop and implement a monitoring system for the identification and recording of land use and land-use change. Such a monitoring system could combine a base map (or other sources of spatial information) on forest area and land use on 31 December 1989 with spatial data on land-use and forest area in subsequent years. Changes in land-use and forest area can then be inferred from a time series of spatial data. This may require interpolation, for example where a base map has been derived from composite satellite images obtained over several years, as is often the case where cloud cover, sensor failures, or other technical reasons make it impossible to obtain complete national coverage for a single point in time.

In many countries repeated complete (wall-to-wall) coverage of the entire country is not feasible on an annual basis. When implementing temporal and spatial sampling strategies, it is *good practice* to ensure that the sampling methods are statistically sound, well-documented and transparent, and that estimates of uncertainty are provided (see Sections 2.4.2 Sampling methods; 4.2.4.3 Uncertainty assessment; 5.2 Identifying and quantifying uncertainties; and 5.3 Sampling). Appropriate pre-stratification of the country (see Section 4.1.1, STEP 1.3) for which sample estimates will be developed may reduce the uncertainty.

Activity reporting

Identification of lands that are subject to activities under Articles 3.3 and 3.4 can be achieved through the implementation of an activity reporting system. For example, since afforestation events are often difficult to detect through remote sensing and often occur outside the area of existing forest inventories, a country may choose to identify these lands through an activity reporting system. Instead of trying to detect afforestation events from inventory or monitoring systems, countries can request that those individuals or agencies that afforest or reforest areas report on their activities. Activity reporting may also be most efficient where information about land use is required that may not be readily determined from remote sensing, such as cropland management, or grazing land management.

Reporting systems can usefully include spatial databases that facilitate the compilation of the pertinent activity information. It is *good practice* to include the location and the area of the activity, and information relevant to the estimation of carbon stock changes, such as site preparation methods, tree species planted, and the actual as well as the expected volume growth function for the land.

It is *good practice* for Parties that rely on activity reporting systems, which put into place methods for internal auditing and verification to ensure that activities are neither over- nor underreported. Administrative information on programmes or subsidies for afforestation activities alone may not include information on plantation establishment success. Spatially explicit information, i.e., either the delineation of the units of land, or references to a country's national map grid coordinates (e.g., UTM, Universal Transverse Mercator) or legal description of the units of land subject to an activity, are required for the domestic audit and verification procedures applied to a reporting system.

Further details on the identification of lands are provided in the activity-specific sections of this chapter (Sections 4.2.5 to 4.2.10).

4.2.3 Generic Methodological Issues for Estimating Carbon Stock Changes and Non-CO_2 Greenhouse Gas Emissions

Once the areas subject to activities under Articles 3.3 and 3.4 have been determined, the Marrekesh Accords specify that the carbon stock changes and non-CO_2 greenhouse gas emissions on these areas must be estimated. The generic methods of estimating the carbon stock changes, for all pools to be reported (see below), are described in Chapter 3 (LUCF sector good practice guidance). This section provides supplementary guidance applicable to all activities under Articles 3.3 and 3.4. Guidance for specific activities can be found in Sections 4.2.5 to 4.2.10.

Coverage of activities under Articles 3.3 and 3.4 requires an estimation of all carbon stock changes, and emissions and removals of non-CO_2 greenhouse gases (regardless of cause, such as growth, harvest, natural disturbance, decomposition etc.) from all lands subject to the included activities and for all pools with discretionary omission of those that are not a source of carbon, with higher-tier methods used for key categories.

The methodology used to estimate greenhouse gas emissions and removals for a particular year (1990, 2008, 2009,…, or 2012) depends on the land use in the current and in prior years, because shifts in categories or land uses can occur over time (see Section 4.1.2). Therefore the methodologies may vary between units of land or land within one Article 3.3 or Article 3.4 category.[25] The methodology used to calculate greenhouse gas emissions or removals associated with a unit of land or land at a given year should correspond to the actual land use on that land in that year, supplemented by additional methodologies to account for past land uses and changes in land use, where appropriate. If the land use in the current year does not correspond to an Article 3.3 activity or an elected Article 3.4 activity, and if a reporting requirement was not established through land use or land-use change in prior years, then the land is not reported at all under the Kyoto Protocol.

4.2.3.1 POOLS TO BE REPORTED

The *IPCC Guidelines* provide methodologies for the estimation of the carbon stock changes in two major carbon pools: biomass and soil organic carbon; they mention dead organic matter as an area that should be considered in future work on inventory methods. The Marrakesh Accords specify that carbon stock changes in five pools must be reported: aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon (Table 3.1.2). Decreases in one pool may be offset by increases in another pool, e.g., biomass pools decline after a disturbance but litter and dead wood pools can increase. Thus the change in a single pool can be greater than the net change in the sum of the pools.

Once the individual pools have been estimated and reported for a specific area, the sum of the carbon stock increases or decreases in the five pools is calculated. Any net decrease in carbon stocks is converted to the equivalent CO_2 emission in the reporting tables (see Section 4.2.4.3) and any net increase is reported as the equivalent CO_2 removal. Carbon stock changes are converted to CO_2 emissions and removals by multiplying the net carbon stock change by 44/12 (the stochiometric ratio of CO_2 and C) and by converting the sign: a decrease in carbon stocks (negative sign) leads to an emission to the atmosphere (positive sign) and vice versa. The storage of carbon in harvested wood products is not included in the reporting since it is not listed as a pool covered by the Marrakesh Accords. Chapter 3 provides clear definitions of carbon pools (Table 3.1.2). If national circumstances require modifications to those definitions, rationale and documentation should be provided for these modifications and on the criteria used to distinguish between carbon pools. It is *good practice* to provide such information on both the individual pools included in the reporting, and on the total carbon stock change of the five pools.

The Marrakesh Accords specify that a Party may choose not to account for a given pool in a commitment period, if transparent and verifiable information is provided that the pool is not a source.[26] *Good practice* in providing verifiable information, which demonstrates that excluded pools, if any, are not a net source of greenhouse gases, can be achieved by:

- Representative and verifiable sampling and analysis to show that the pool has not decreased. It is *good practice* under this approach to measure the pool at enough sites, within regions, to provide statistical confidence, and to document the sampling and research methods;
- Reasoning based on sound knowledge of likely system responses. For instance, if cropland is converted to forest land by afforestation or reforestation, the dead wood pool cannot decrease, because there is typically no deadwood in a cropland (if it does not contain trees, e.g., if it does not contain any shelterbelts, was no orchard, and was no other agroforestry system);
- Surveys of peer-reviewed literature for the activity, ecosystem type, region and pool in question (for example, showing that in the climatic situation and with the soil types of the region, afforestation or reforestation of cropland leads to increases in soil organic carbon stocks); or
- Combined methods.

It is *good practice* to report, wherever it is applicable, levels of confidence in estimates that led to the exclusion of a pool, and how this level of confidence was established (see also Section 4.2.4.2 Uncertainty Assessment).

---

[25] For example, two units of land may both be in the cropland management category. However, one of them may have resulted from grassland conversion into cropland, the other from continuing cropland management, so that the greenhouse gas assessment methods need to take account of differing values of soil carbon resulting from their different management histories.

[26] See paragraph 21 in the Annex to the draft decision -/CMP.1 (Land use, lan-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.62.

4.2.3.2 YEARS FOR WHICH TO ESTIMATE CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

The Marrakesh Accords specify that the carbon stock changes for each unit of land subject to an Article 3.3 activity, and for lands subject to elected activities under Article 3.4 be reported for each year of the commitment period[27], beginning with the start of the commitment period, or with the start of the activity, whichever is later.

To ensure that actual carbon stock changes are reported, and not artefacts resulting from changes in area over time, the calculations of carbon stock changes should be implemented in the following sequence: For each unit of land or land, the carbon stock change should first be calculated for the year of interest, and these stock changes should then be summed for all areas. The inverse sequence, i.e., first summing up the carbon stocks across all areas at times t_1 and t_2 and then calculating the difference in carbon stocks, can result in errors if the area at times t_1 and t_2 is not the same, and is therefore not recommended.[28]

It is therefore *good practice* to conduct all calculations of carbon stock changes and greenhouse gas emissions for the area at the end of the inventory year, and to use this approach consistently through time.

This means that if the activity started on 1 July 2009, then the carbon stock changes and greenhouse gas emissions should be reported for each of the last four years of the commitment period, 2009-2012. If the activity started after 1990 but before 1 January 2008, then reporting of the carbon stock changes and greenhouse gas emissions for the commitment period should cover each of the five years of the commitment period, 1 January 2008 to 31 December 2012. These reporting requirements as a function of time are summarized in Table 4.2.3. Where differences occur between the sum of the five annual reports and the report for the entire commitment period, these should be addressed and reconciled at the end of the commitment period (see Sections 4.2.3.3, 4.2.4.1.1 and Chapter 5).

TABLE 4.2.3
CALENDAR YEARS FOR WHICH CARBON STOCK CHANGES ARE TO BE REPORTED (FOR EACH ACTIVITY AND EACH OF THE FIVE POOLS DESCRIBED ABOVE), AS A FUNCTION OF THE TIME WHEN THE ACTIVITY STARTED. "R" DENOTES YEARS FOR WHICH REPORTING IS NECESSARY

Activity started	Calendar year for which reporting is necessary				
	2008	2009	2010	2011	2012
Before 2008	R	R	R	R	R
In 2008	R	R	R	R	R
In 2009		R	R	R	R
In 2010			R	R	R
In 2011				R	R
In 2012					R

Each activity (afforestation, reforestation, deforestation, forest management, cropland management, grazing land management and revegetation) may consist of a suite of practices and may begin with one or several of these. For instance, an afforestation programme may begin with planning, land purchase, producing propagation material etc. Operations like site preparation can also precede the planting or seeding (as a result of which the land actually becomes a "forest"). Some of these operations are carbon-neutral, while others like site preparation may result in significant carbon, nitrous oxide or methane emissions. It is *good practice* to interpret the beginning of an activity as the start of *in situ* carbon stock change and/or non-CO_2 emissions due to any of the suite of the operations. For example, if an afforestation activity includes site preparation, then it is *good practice* to include carbon stock changes caused by site preparation. In order to do that, one can either a) measure the

[27] See paragraph 5 in the Annex to the draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p. 22.

[28] For example, if the area of an Article 3.4 activity is 100 ha at the beginning of an inventory year and 200 ha at the end of the same inventory year, then the difference in carbon stocks on the 200 ha over the inventory year must be calculated – otherwise the carbon stock at the beginning of the year (X tonnes of C / ha • 100 ha) is almost always smaller than the carbon stock at the end of the year (Y tonnes of C / ha • 200 ha), and an apparent increase would merely result from the presence of carbon stocks as the area increases.

carbon stocks on the site prior to the start of any operations related to the activity (in case carbon stock changes are estimated using multiple stock measurements), or b) make sure that the estimate of the stock change includes an estimate of the emissions resulting from these initial operations.

4.2.3.3 REPORTING AND MEASUREMENT INTERVALS

The Marrakesh Accords specify that all emissions from sources and removal by sinks caused by Article 3.3 and elected Article 3.4 activities be reported annually.[29] A number of methods are available to obtain annual estimates and the annual reporting requirement does not imply that annual field measurements are necessary. This would be neither feasible nor cost-effective. In fact, although more frequent measurement will generally decrease uncertainties, the opposite can also happen because of short-term variability, as discussed in Section 4.2.3.7 (Interannual variability). Carbon stock changes for pools with high uncertainties, e.g., soil organic carbon, are usually not detectable on an annual or short-term basis. Broadly speaking, when countries are developing and selecting methods to meet their reporting requirements, they should seek a balance which is affordable, make best use of data that are already available, allow stock changes to be verified consistently with the approaches set out in Chapter 5 (Section 5.7 Verification), and not make inventories susceptible to the impacts of annual fluctuations in weather. Although Section 4.2.3.7 suggests that field data collection on a five-year cycle may represent a reasonable compromise, the re-measurement interval also depends on the pool and the magnitude of the expected changes relative to the spatial variability in the pool and the uncertainties involved in pool size assessments. For example, changes in soil carbon can often only be detected over longer time periods. Data already available annually, such as planting or harvest statistics, may be combined with measurements conducted over longer time periods – which are less affected by annual fluctuations – or with data based on a five-year running mean.

4.2.3.4 CHOICE OF METHOD

Estimation of carbon stock changes and non-CO_2 greenhouse gas emissions from Articles 3.3 and elected Article 3.4 activities should be consistent with the methods set out in Chapter 3. For each unit of land under Article 3.3 or land under Article 3.4, it is *good practice* to use the same tier or a higher tier for estimating stock changes and greenhouse gas emissions as the one that was used for the same land in the UNFCCC inventory, following Chapter 3 of this report. The only exception to this rule is revegetation: if the lands on which revegetation occurs are not a key category, then revegetation is also not a key category. If the lands on which the revegetation occurs are a key category in the UNFCCC inventory[30], then revegetation can either be treated as a key category, or a separate test to identify the "key category" can be applied (see Chapter 5, Section 5.4.4 Identifying key categories under Kyoto Protocol Articles 3.3 and 3.4).

Tier 1 as elaborated in Chapter 3 assumes that the net change in the carbon stock for litter (forest floor), dead wood and soil organic carbon (SOC) pools is zero, but the Marrakesh Accords specify that above- and belowground biomass, litter, dead wood and SOC should all be counted unless the country chooses not to count a pool that can be shown not to be a source. Therefore Tier 1 can only be applied if the litter, dead wood and SOC pools can be shown not to be a source using the methods outlined in the Section 4.2.3.1. Tier 1 can also only be applied if forest management is not considered a key category, which can only be the case if "forests remaining forests" in Chapter 3 are not a key category.

4.2.3.5 FACTORING OUT INDIRECT, NATURAL AND PRE-1990 EFFECTS

The Marrakesh Accords specify that information be provided whether or not anthropogenic greenhouse gas emissions by sources and removals by sinks from activities under Articles 3.3 and 3.4 factor out removals from elevated carbon dioxide concentrations above pre-industrial levels, indirect nitrogen deposition, and the dynamic

[29] Note that although annual reporting is required, countries have the option to account either annually or over the entire commitment period (cf. paragraph 8(d) in the Annex to draft decision -/CMP.1 (Modalities for the accounting of assigned amounts), contained in document FCCC/CP/2001/13/Add.2, p.59).

[30] This is possible where the croplands or grasslands on which the revegetation takes place are key categories with respect to the UNFCCC inventory, whereas the area on which the revegetation takes place may be very small compared to those under cropland or grassland management.

effects of age structure resulting from activities prior to 1 January 1990.[31] In addition to the requirement to report whether or not these effects are factored out, those Parties that choose factoring out should also report the methods they used. For the purpose of accounting under the Kyoto Protocol for the first commitment period, "factoring out" has been addressed through the cap for carbon credits for forest management under Articles 3.4 and 6. The "factoring out" issue is currently under consideration by the IPCC and will therefore not be addressed further here.

4.2.3.6 DISTURBANCES

Disturbances include processes that reduce or redistribute carbon pools in terrestrial ecosystems. Examples include fire, windthrow, insects, droughts, flooding, ice storms, etc. Although disturbances can be either natural or human-induced, or of unknown causes, they affect the carbon cycle of managed forests and other managed lands, and therefore, they are to be included in the carbon stock change and greenhouse gas assessments for those landsthat are subject to activities under Articles 3.3, 3.4 or 6. These disturbances are also considered in the inventories under the UNFCCC (see Chapter 3, e.g., the Introduction to Section 3.2 Forest land).

Since unmanaged forests and other unmanaged lands are included neither in the UNFCCC nor in the Kyoto Protocol reporting requirements disturbances in areas which remain unmanaged are not to be considered.

Four major impacts of disturbances on managed ecosystems can be identified. First, disturbances can cause direct releases of carbon and non-CO_2 greenhouse gases to the atmosphere (e.g., during fires) or transfers of carbon out of the ecosystem (e.g., during harvest). Second, they redistribute carbon between ecosystem carbon pools, e.g., live biomass is transferred to dead wood and litter. Third, they result in post-disturbance emissions, e.g., through the decay of residual biomass after a disturbance. Forth, they re-set stand dynamics to an earlier age class of the same or a new growth trajectory. Tier 3 models that estimate carbon stock changes in forested landscapes simulate each of these processes and integrate the impacts of disturbances on stand and landscape-level carbon stocks (e.g., Kurz *et al.*, 1992; Kurz and Apps 1999).

Taking this into account, the following can be said:

- Carbon stock changes and non-CO_2 greenhouse gas emissions resulting from disturbances on land subject to an Article 3.3 activity (afforestation, reforestation, and deforestation) or an elected Article 3.4 activity (e.g., forest management) have to be included in the reported numbers. See for example, Section 3.2.1.1 for guidance on how to estimate and report carbon stock changes and Section 3.2.1.4 for greenhouse gas emissions from fires. If the carbon stock changes resulting from disturbances were not included in the UNFCCC reporting, they have to be added for the Kyoto reporting.
- Carbon stock changes and non-CO_2 greenhouse gas emissions resulting from disturbances during the commitment period on land subject to projects (Article 6) have to be included in the reported numbers.
- If project-related management activities (e.g., Article 6) result in a reduction or avoidance of disturbances (e.g., fire or insect control), a change in carbon stocks relative to a baseline (with disturbances) can occur. It is *good practice* to estimate and include in the reporting the actual carbon stock changes occurring in the project area.

4.2.3.7 INTERANNUAL VARIABILITY

The annual rate of net carbon emissions or removals in an ecosystem is strongly influenced by local weather patterns, climate variability, management actions, natural disturbance variations and other factors that alter growth and decomposition rates (e.g., in Griffis *et al.,*2000 ; Tian *et al.,* 1998; Flanagan *et al.*, 2002). Consequently, the rate of net carbon emissions or removals in a given area may vary from year to year, and can shift between a net source and a net sink in successive years.

There are two aspects to interannual variability, and they need to be addressed independently. First, the national statistics on the between-years variation in harvest rates, land-use change, or natural disturbances such as the area burned, are usually available, and it is *good practice* to include these in the calculation of carbon stock changes. Second, the variations in growth and decomposition rates due to seasonal and annual variations in environmental conditions, such as moisture regimes, temperature, or growing season length are much more difficult to quantify.

[31] See paragraph 7 in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p. 23.

The impacts of interannual variability in environmental conditions on the estimates of annual rates of net emissions and removals of carbon may result in incorrect conclusions about long-term trends where estimates from a single year are extrapolated. Conversely, interpolation of long-term trends in, for example, forest growth rates may result in under- or overestimation of the actual growth in a single year. The forest growth functions and yield tables used in countries with forest management planning systems are based on measurements of periodic growth (e.g., over 5 or 10-year re-measurement intervals) and thus are incorporating and averaging the impacts of past interannual variability of environmental conditions. One approach that would meet *good practice* is to use such growth functions to estimate biomass growth rates, because they represent the average growth rates and are therefore influenced little by short-term fluctuations in environmental conditions.

Where empirical growth and yield functions are used to estimate stand growth, it is *good practice* to evaluate the potential influences of interannual variability in environmental conditions, for example through comparisons of predicted and actual growth on a set of regionally distributed permanent sample plots. Where the periodic (e.g., 5-year) increment is consistently under- or over-predicted, the growth estimates should be adjusted accordingly. Countries that use process-based models to simulate annual variability in stand growth and other stock changes need to also evaluate these predictions against measurements of periodic stock changes on permanent sample plots and adjust the predictions where necessary.

In addition to the carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period, the Kyoto Protocol also requires an estimate of carbon stock changes during the base year (1990 in most cases) for those elected activities for which net-net accounting applies (Table 4.1.1). The impact of this estimate for a single year could be large because it will be compared against the estimates for each year in the commitment period in which this activity occurred. The effects of interannual variability in the base year could therefore be large. The direction of the impact depends on how the year 1990 deviated from the long-term climatic averages. Moreover, it may be difficult to confirm the estimate for the base year using direct measurements, unless these were already taken in 1990. Where environmental conditions in the base year (e.g., 1990) caused major deviations in the carbon stock changes and non-CO_2 greenhouse gas emissions from their longer-term (e.g., 5-year) averages, it is *good practice* to consistently report emissions using longer-term averages of environmental conditions or actual annual estimates of emissions when estimating stock changes and non-CO_2 greenhouse gas emissions.

The effect of interannual variability may decrease as the geographical area considered increases. For example, the effects of local weather patterns may partially offset each other across a large country, but may be very pronounced in a small country or within a small region of a country. There are, however, climatic processes that can synchronize variations in weather over large regions, such as El Niño Southern Oscillation (ENSO) events which typically occur on time scales of 3 to 7 years, or global climate change. Within limits, the longer the measurement or estimation interval the more likely it is that the results will capture the true long-term average value. Where non-linear processes are involved, e.g., the sigmoidal accumulation of forest biomass over age, simple linear interpolation for intermediate years will become increasingly unreliable with longer time periods. In general, an averaging period of about five years is likely to reduce the impacts of interannual variation.

It is *good practice* to document whether the methods selected for the estimation of carbon stock changes and non-CO_2 greenhouse gas emissions are sensitive to interannual variability of environmental conditions during the commitment period, and to report how interannual variation was addressed in the inventory calculations.

4.2.4 Other generic methodological issues

4.2.4.1 DEVELOPING A CONSISTENT TIME SERIES

The lands subject to Article 3.3 or elected Article 3.4 activities and the management thereon need to be tracked continuously through time, to ensure that all emissions and removals are reported. Moreover, the continuity of management greatly influences carbon emissions and removals, and changes in management or land use are often the periods associated with the greatest changes in carbon stocks. For example, it is not sufficient merely to state that 10% of a cropland management area has been under no-till for a specified period. The rate of carbon stock change for the total area depends on whether the same 10% of land has remained under no-till or whether the 10% of no-till occurred on a different portion of the area in different years. It is therefore *good practice* to follow continuously the management of land subject to Article 3.3 and elected 3.4 activities. (See also Box 4.2.1)

Assessment of the continuity of management on land could be achieved either by continuously tracking lands subject to an Article 3.3 or elected Article 3.4 activity from 1990 until the end of the commitment period (cf. Section 4.2.7.2 Choice of methods for identification of forest management lands), or by developing statistical sampling techniques that allow the transition of different types of management on land subject to Article 3.3 or elected 3.4 activities to be determined (see Section 5.3 Sampling). An example of how such a scheme could operate is given in Box 4.2.1.

A supplementary condition for developing a consistent time series is to use the same methods for estimating carbon stock change and non-CO_2 greenhouse gas emissions during the whole period.

Time series consistency is discussed further in Section 5.6 (Time series consistency and recalculations) of this report.

BOX 4.2.1
AN EXAMPLE OF CONSISTENCY FOR MANAGEMENT PRACTICES

To estimate changes in soil carbon stocks, whether by Tier 1, 2 or 3 methods, management practices on applicable lands need to be followed continuously over time. Ideally, the management of each land would be tracked explicitly. But such data may not always be available. An alternative approach may be to estimate the *average* history of lands now under a given management. Consider the following example.

Example: Cropland management

Suppose there was a cropland region of 10,000 ha, of which 5,000 are in no-till (NT) in the year 2000, up from 2,000 ha in 1990. The remainder, in each year, is under conventional tillage (CT). In order to simplify this example, suppose also that the land management in the year 1990 was unchanged for a long period before (more than 20 years). The estimated soil carbon change is based on a matrix of coefficients; say 0.3 Mg C/ha/yr for land shifting from CT to NT, -0.3 Mg C/ha/yr for a shift from NT to CT. (The carbon stock change is calculated by the amount of soil carbon, the relative carbon stock change[32] factor, over 20 years, for the management activity, and the length of the period, one year. See Chapter 3.3.1.2, and Tables 3.3.3 and 3.3.4.) Unfortunately, there has been no tracking of management on individual land. However, based on a statistical analysis (e.g., a survey), it is possible to estimate, with reasonable confidence, the following shifts:

CT	→	NT	3,500 ha
CT	→	CT	4,500 ha
NT	→	CT	500 ha
NT	→	NT	1,500 ha

The total carbon gain is therefore:
(3,500 • 0.3 + 4,500 • 0 + 500 • (-0.3) + 1,500 • 0) Mg C/yr = 900 Mg C/yr.

4.2.4.1.1 RECALCULATION

As inventory capacity and data availability improve, the methods and data used to calculate estimates are updated and refined. Recalculation of historic emissions and removals is *good practice* when new methods are introduced or existing ones refined, when new sources and sinks categories are included, or when data are updated (for example through new measurements during the commitment period or the availability of new information on verification). Recalculations may also be needed if lands are reclassified at a later time (e.g., for lands that have lost forest cover but where a classification as deforested lands was pending and has been resolved, see Section 4.2.6.2.1).

The Marrakesh Accords make provisions for recalculation[33], consistent with the UNFCCC reporting guidelines, and mention that previous estimates should be recalculated using the new methods for all years in the time series. Annual greenhouse gas emissions and removals reported for a given year during the commitment period can be recalculated in subsequent reporting years (up to reporting for 2012). Special attention must be given to those activities under Article 3.4 to which the net-net accounting rule applies, i.e., all activities except Forest Management. For these activities, the use of refined or updated data or changed methods should be peer-reviewed or validated in another way before being implemented, especially if data in the base year will change as a result (see Chapter 7, Section 7.3 Recalculations, in *GPG2000* and Chapter 5, Section 5.6.3 Recalculation and

[32] While Chapter 3 uses the language of emission/removal factors, in Chapter 4 also the term "carbon stock change factor" is in use to refer to carbon emission/removal factors.

[33] See paragraphs 4, 12 (notably 12(d) and12(e)), 13 and 14(e) in the Annex to draft decision -/CMP.1 (Article 5.1), contained in document FCCC/CP/2001/13/Add.3, pp. 5-8.

periodic data, in this report for additional guidance). When recalculating emissions and/or removals, time series consistency must be checked and ensured. It is also *good practice* to report why the new estimates are regarded as more accurate or less uncertain.

One potential problem in recalculating previous estimates is that certain data sets may not be available for the earlier years. There are several ways of overcoming this limitation and they are explained in detail in Chapter 5 (Cross-cutting issues) of this report and Section 7.3 (Recalculations) of the *GPG2000*.

4.2.4.2 UNCERTAINTY ASSESSMENT

According to the Marrakesh Accords, uncertainties should be quantified and all information on anthropogenic greenhouse gas emissions by sources and removals by sinks which result from activities under Articles 3.3 and 3.4 have to be within levels of confidence as elaborated by any IPCC good practice guidance adopted by the COP/MOP.[34] Generally, the approaches provided in Chapters 2 and 3 and Sections 5.2 Identifying and quantifying uncertainties, and 5.3 Sampling, can be used for assessing uncertainties associated with estimates reported under the UNFCCC and under the Kyoto Protocol LULUCF activities. However, some issues and terms which are specific to the Kyoto Protocol require additional uncertainty assessment, for example the identification of the areas subject to Article 3.3 and 3.4 activities or the need to track activities since 1990. For Kyoto Protocol reporting, uncertainty assessment is particularly important in order to support verification in accordance with the Quality Assurance and Quality Control requirements as specified in Chapter 5.[35] In addition, to be consistent with *good practice*, the uncertainties in inventory estimates should be reduced as far as practicable. Moreover, while selecting a particular tier to estimate changes in carbon stocks and non-CO_2 greenhouse gas emissions, it is *good practice* to consider the implications of this choice for the management of uncertainties.

4.2.4.2.1 IDENTIFYING UNCERTAINTIES

For a complete enumeration and explanation of each possible source of uncertainty relevant in the inventory under the UNFCCC, the reader is referred to Chapters 2 and 3. In the context of the Kyoto Protocol the following sources of uncertainties are likely to be significant:

- Definitional errors, such as bias and inconsistencies resulting from the interpretation and implementation of the various definitions in the Kyoto Protocol and the Marrakesh Accords (including the potential mismatch between data available to Parties and their interpretation of the definitions);
- Classification errors, such as land use and land transition classification errors (e.g., forest vs. non-forest classification with possible errors regarding temporarily unstocked forest lands);
- Activity data errors (e.g., distinction between the harvesting-regeneration cycle (Article 3.4) vs. deforestation (Article 3.3) or human-inducement of afforestation and reforestation);
- Estimation errors, such as errors in area estimates (e.g., due to incorrect classification of change events i.e., both omission and commission errors in remote sensing (see below for details), or due to differing scales used to identify lands subject to the various activities, e.g., afforestation/reforestation vs. deforestation, or modifications made to the sampling procedures and/or densities during the course of time);
- Identification errors arising while defining the geographical boundaries of areas encompassing lands and units of lands subject to the activities in Articles 3.3 and 3.4 (although this may not have a direct impact on the uncertainty of the carbon stock change estimates for a given activity);
- Model errors occur whenever models or allometric equations are used to estimate carbon stock changes or non-CO_2 greenhouse gas emissions and removals, which is likely to be the case at higher tiers. It can be very

[34] This refers to paragraph 6 (d) including footnote 5, and paragraph 9 including footnote 7 in the Annex to draft decision -/CMP.1 (Article 7) contained in FCCC/CP/2001/13/Add.3, p.23 and p.24, respectively.

[35] For instance activities under Article 3.3 shall be "*...measured as verifiable changes in carbon stocks in each commitment period...*" and "*...The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner…*". Article 3.4 explicitly mentions uncertainties, i.e., "*...human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, [and] verifiability...*". (Kyoto Protocol Articles 3.3 and 3.4). See also paragraphs 3(a), 3(b) and 3(c) in the Annex to draft decision -/CMP.1 (Article 5.1), contained in FCCC/CP/2001/13/Add.3, pp.4-5.

cumbersome to trace the propagation of errors through complex models chained to each other. In general, this may introduce additional uncertainties, except for those cases where simpler models can be used to estimate typical uncertainty ranges that can be combined with central estimates from complex models.

- Sampling errors associated with the number of samples (number and location) within a "geographical boundary". In this case samples do not sufficiently cover the temporal and spatial variability of the estimated parameters. This is particularly critical when using Reporting Method 1 (as described in Section 4.2.2.2). Sampling issues are described in detail in Section 5.3 (Sampling).

Some notes on factors affecting uncertainty

Natural Variability

Natural variability is a result of variations in natural controlling variables, such as annual climate variability, and variability within units of land that are assumed to be homogenous, e.g., the spatial variability of e.g., forest soils within a given unit of land. When sufficient experimental data are available, *good practice* should permit determination of the resulting combined plot-level and upscaling uncertainties using standard statistical methods (e.g., Tate *et al.*, 2003). In some cases, especially for inter-annual or inter-decadal variability, considerable effects may result that can change the sign of the reported net emissions and removals of an entire country or region. In inventory calculations uncertainty due to natural variability can be reduced by using time average coefficients and by averaging direct measurements over a time period sufficiently long to assess the variability, as discussed in Section 4.2.3.7 above.

Lack of activity data and documentation in time-series consistency

In addition to uncertainties in default carbon emission and removal factors, there are known inaccuracies in the case of missing activity data (cf. Section 4.2.8.1.1). Determining retrospectively the inventory for the base year, i.e., for most Parties the year 1990, may pose a particular challenge for cropland management, grazing land management and revegetation. Where the 1990 base year net carbon emission and removals cannot be established using the default carbon emission and removal factors, they may be estimated by extrapolating a consistent time series. This requires data on the land management history for the past 20 years, because the default method for estimation of the greenhouse gas emissions/removals assumes that it takes 20 years for the soil carbon pool to reach a new equilibrium after a land-use change to agriculture. Options to address the lack of reliable data for the period 1970 to 1990 can be found in Section 4.2.8.1.1 (Base year, Cropland Management).

Resolution of remote sensing and ground truth

The objective of using satellite imagery for land cover assessments is to obtain, for an inventory region, total area estimates, percentages of land-cover classes, or geographical boundaries. Remote sensing is particularly well suited to produce a complete identification of lands and units of land when using Reporting Method 2 (see Section 4.2.2.2). A primary source of uncertainty is the selection of imagery of inadequate resolution. In order to capture changes in areas as small as one hectare, the resolution of the imagery must be finer than one hectare. In addition, improper or insufficient ground truthing can result in classification errors.

Positional errors occur where (a) the geometric correction is not done, incomplete or false, (b) the pixel location and location of ground truth plot do not coincide, and (c) there is insufficient accuracy in the definition of the borderlines. For example, when detecting land-use changes by a time series of remotely sensed images, the spatial displacement of pixels from one sampled image to the next will introduce errors. In the case of detection of a transition from forest to non-forest or vice versa, the associated uncertainties will be larger when forests are fragmented. **Classification errors** arise from an incorrect identification of the real land cover class. They comprise omission errors, i.e., a population element from a given category is omitted and put erroneously into another class, and commission errors, i.e., classifying wrong categories into a given ground truth category.

4.2.4.2.2 QUANTIFYING UNCERTAINTIES

Uncertainties are to be quantified according to methods as described in this report: Chapters 2 and 3 provide the necessary data and methodological advice on estimating uncertainties associated with carbon stock changes and emissions estimation. Chapter 5 (see equations in Section 5.2) shows how to combine these estimates into overall uncertainties.

It is *good practice* to derive confidence intervals by applying a quantitative method to existing data. Confidence intervals at given confidence levels provide a minimum basis for a simple quantitative estimate of uncertainty. To remain consistent with *GPG2000*, uncertainties should be estimated at the 95% confidence limits, using component uncertainties assessed by expert judgement aiming at 95% confidence where quantification is not otherwise possible (see Section 5.2 for guidance on expert judgement).

Uncertainties for the Kyoto activities can be treated in the same way as other uncertainty estimates taking into account that:

- The "since 1990" clause and the use of definitions specific to the Kyoto Protocol and the Marrakesh Accords are likely to cause systematic errors related to the estimation of the required activity data. The potential for differences between the managed forest area and the area subject to forest management, and also between grassland area and area subject to grazing land management implies that the areas whose uncertainties are being assessed may differ between the Kyoto Protocol activities and the corresponding categories of the *IPCC Guidelines.*
- Activity data can also relate to individual practices or ownership structures, e.g., the fraction of cropland farmers using a given amendment on a particular soil. If the fraction is estimated by survey, the survey design should incorporate an uncertainty estimate depending on the level of inventory data disaggregation, otherwise the uncertainty will have to come from expert judgement.
- For cropland management, grazing land management and/or revegetation (if elected) uncertainty estimates are needed also for the base year. These are likely to be higher than for estimates in the commitment period, because this information may often be derived only by backward extrapolations or models, rather than by actual inventories in or near the base year. In addition, determination of activities in the base year, where required, may pose difficulties if pre-base year surveys of land use are not available. Section 4.2.8 (Cropland Management) discusses a default approach to this problem. The associated uncertainties could, in principle, be assessed by formal statistical methods, but more likely by expert judgement which is based on the feasible ranges of backward extrapolation of time trends. Further advice on providing missing data in this way is given in Section 5.6.
- When remote sensing is employed for classification of land use and detection of land-use change including units of land subject to Article 3.3, the uncertainties could be quantified by verifying classified lands with adequate actual ground truth data or higher resolution imagery (see Sections 5.7.2 and 2.4.4). A confusion matrix as described in Section 2.4.4 can be used to assess accuracy.

Separate annual uncertainty estimates need to be made for each activity under Articles 3.3 and 3.4, for each reported carbon pool, each greenhouse gas and geographical location. Estimates should be reported using tables generated following the model of Tables 4.2.6a, 4.2.6b and 4.2.6c as found in Section 4.2.4.3 (Reporting and Documentation). Separate tables should be reported for the base year in case CM, GM and/or RV are elected. Estimates should be expressed as percent of the area and of the emissions by sources or removals by sinks (or changes in stocks) reported in Tables 4.2.6 a, b and c.

Uncertainty associated with areas of lands and units of land need to be estimated. When using Reporting Method 1, it is *good practice* to report a separate estimate of uncertainty for each of the Article 3.3 activities, and each of the elected Article 3.4 activities within a given geographical boundary. Under Reporting Method 2, each geographical boundary is subject to a single activity. Therefore there will only be one uncertainty estimate needed for each geographical boundary.

Where uncertainties are difficult to derive, default values for uncertainties are to be used. Guidance on selecting default carbon emission or removal factors for cropland management can be found in Annex 4A.1, Tool for Estimation of Changes in Soil Carbon Stocks associated with Management Changes in Croplands and Grazing Lands based on IPCC Default Data. Since these factors are taken from the *IPCC Guidelines*, no true uncertainty ranges can be assigned. However, using expert judgement, default uncertainty ranges corresponding to a coefficient of variation (the ratio of the standard deviation and the mean) of 50% can be assigned, based on an analysis of no-till long-term experiments in Europe in which the 95% confidence interval of the mean annual emission or removal estimate was found to be around ±50% of that mean (Smith *et al*., 1998). For revegetation, default uncertainty ranges cannot be specified. It is *good practice* for a Party electing revegetation to provide its own estimates of the uncertainty associated with emissions and removals from all pools for the affected lands. These could be derived from using Tier 2 and 3 methods to assess emissions and removals of carbon due to revegetation (see Section 5.2 Identifying and quantifying uncertainties).

Problems may arise when activity data are lacking or are not well-documented. Activity data necessary to apply scaling factors (i.e., data on agricultural practices and organic amendments) may not be available in current databases/statistics. Estimates of the fraction of farmers using a particular practice or amendment should then be based on expert judgement, and so should the range in the estimated fraction. As a default value for the uncertainty in the fraction estimate, ±0.2 is proposed (e.g., the fraction of farmers using organic amendment estimated at 0.4, the uncertainty range being 0.2–0.6). Chapter 6 in *GPG2000* (Quantifying Uncertainties in Practice) and Chapter 5 of this report (Cross-cutting ssues) provide advice on quantifying uncertainties in practice, including combining expert judgements and empirical data into overall uncertainty estimates.

4.2.4.2.3 REDUCING UNCERTAINTIES

Estimating uncertainties in a quantitative manner helps to identify major sources of uncertainties and to pin-point areas of potential improvements in order to reduce uncertainties in future assessments. In particular, for reporting under the Kyoto Protocol it is recommended to make efforts to convey the overall uncertainty estimates to all agencies and/or firms involved in order to encourage improvement, i.e., reduced uncertainties in estimates of future reports. It is also *good practice* to establish institutional means and procedures that are likely to contribute towards reducing uncertainties. For instance, a country may choose on purpose to estimate uncertainties by more than one procedure. This will produce complementary results for the same country and data category, prompting further research in potential sources of inconsistency and ultimately enhancing the robustness of estimates.

Often, uncertainties can be reduced if areas subject to land-use change are estimated directly as a class by themselves within a stratification scheme, rather than as a difference between two overall estimates of land-use areas.

The extra effort required for area identification should help to reduce uncertainties in the assessment of areas subject to Kyoto Protocol activities.

Uncertainties are likely to be reduced by implementing means to make the design, procedure and frequency of data collection more systematic, for example by establishing – whenever possible – long-term, statistically sound monitoring programmes.

4.2.4.3 REPORTING AND DOCUMENTATION

4.2.4.3.1 REPORTING

The anthropogenic greenhouse gas emissions by sources and removals by sinks from land use, land-use change and forestry activities, estimated using the methods described before and in the activity-specific Sections 4.2.5 – 4.2.10, must be reported as outlined in the Marrakesh Accords.[36] Some information on definitions and elected activities must be reported prior to the first commitment period (by the end of 2006), whereas much supplementary information must be reported annually during the first commitment period. The information to be reported is summarised in Tables 4.2.4a and 4.2.4b, respectively, but excludes information associated with removal unit (RMU) accounting. It is *good practice* to report all information requested in these tables.

Annual reports under the Kyoto Protocol must include estimates of areas of land subject to activities under Article 3.3 and 3.4 (where elected), of emissions by sources and removals by sinks on these areas of land, and the associated uncertainties, using Tables 4.2.5 through 4.2.7. It is *good practice* to include in these reports additional information on methods and approaches used to identify lands and to estimate the emissions and removals.

[36] See paragraphs 4 to 9 of the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, pp.22-24.

TABLE 4.2.4a
SUPPLEMENTARY INVENTORY INFORMATION TO BE REPORTED PRIOR TO 1 JANUARY 2007 OR ONE YEAR AFTER THE ENTRY INTO FORCE OF THE KYOTO PROTOCOL FOR THE PARTY, WHICHEVER IS LATER[37]

Information to be reported	Detailed information	Reference in Marrakesh Accords[38]
Definition of forest by the Party	• A single minimum land area value between 0.05 and 1 hectare; • The minimum width that defines the spatial configuration of that area (see Section 4.2.2.5.1); • A single minimum tree crown cover value between 10 and 30%; • A single minimum tree height value between 2 and 5 metres; • Justification that such values are consistent with the information that has historically been reported to the Food and Agriculture Organization of the United Nations or other international bodies, and if they differ, explanation why and how such values were chosen.	8 (b) and paragraph 16 of the Annex to draft decision -/CMP.1 (LULUCF), FCCC/CP/ 2001/13/Add.1 p.61
Elected activities under Article 3, paragraph 4	• A list of activities elected by the Party • Information on how the Party's national system under Article 5, paragraph 1 will identify land areas associated with the elected activities • Information on how the Party interprets the definition of Art 3.4 activities (e.g., what activities are included under forest management)	8 (b) 8 (c)
The Party's own precedence or hierarchy among Article 3.4 activities	• As outlined in Section 4.1.1 it is *good practice* to establish precedence conditions and/or a hierarchy among 3.4 activities to facilitate the estimation and reporting procedures, and so that lands are allocated only to one of the Article 3.4 activities.	

[37] Paragraph 2 in draft decision -/CMP.1 (Modalities for accounting of assigned amounts), contained in document FCCC/CP/2001/13/Add.2, p.56.

[38] Entries in this column refer to relevant paragraphs in the Annex to draft decision -/CMP.1 (Modalities for the accounting of assigned amounts), contained in document FCCC/CP/2001/13/Add.2, pp.57-72. In the table not necessarily *all* relevant legal texts are referred to.

TABLE 4.2.4b
SUPPLEMENTARY INFORMATION TO BE REPORTED FOR THE ANNUAL GREENHOUSE GAS INVENTORY DURING THE FIRST COMMITMENT PERIOD ACCORDING TO THE MARRAKESH ACCORDS. TEXT IN ITALICS INDICATES A DIRECT QUOTE FROM THE RELEVANT PARAGRAPHS IN THE MARRAKESH ACCORDS

Information to be reported	Detailed information	Reference in Marakesh Accords[39]
Land related information		
Approach for geographical location and identification of units of land	*The geographical location of the boundaries of the areas that encompass:* *(i) Units of land subject to activities under Article 3, paragraph 3;* *(ii) Units of land subject to activities under Article 3, paragraph 3, which would otherwise be included in land subject to elected activities under Article 3, paragraph 4, […];* *(iii) Land subject to elected activities under Article 3, paragraph 4.*	6 (b)
Spatial assessment unit	*The spatial assessment unit used for determining the area of accounting for afforestation, reforestation and deforestation*	6 (c)
Information on methods and approaches to estimate emissions and removals		
Description of methodologies used	The emissions and removals should be estimated using methodologies given in the *IPCC Guidelines* as elaborated by this report, and using the principles as laid out in the draft decision -/CMP.1 (Land use, land-use change and forestry). The methodologies used should be reported with information on the reporting method for lands subject to Articles 3.3 and 3.4 (Reporting Method 1, 2 or a combination thereof), the approach(es) used for land identification, and the tier level(s) for estimating the emissions and removals. National approaches, models, parameters and other related information should be described transparently indicating how they improve the accuracy of the reporting. The assumptions and methodologies used for an inventory should be clearly explained to facilitate replication and assessment of the inventory by users of the report and taking into account the principles in paragraph 1, items (a), (b), (d), (g), (h) in the Marrakesh Accords, draft decision -/CMP.1 (Land use, land-use change and forestry), cf. document FCCC/CP/2001/13/Add.1, p.56.	see 6 (a)
Justification when omitting any carbon pool	*Information on which, if any, of the following pools: above-ground biomass, below-ground biomass, litter, dead wood and/or soil organic carbon were not accounted for, together with verifiable information that demonstrates that these unaccounted pools were not a net source of anthropogenic greenhouse gas emissions*	6 (e)
Information on indirect factors on greenhouse gas emissions and removals	*Information should also be provided which indicates whether or not anthropogenic greenhouse gas emissions by sources and removals by sinks from land use, land-use change and forestry activities under Article 3 paragraph 3 and elected activities under Article 3 paragraph 4 factor out removals from:* *(a) Elevated carbon dioxide concentrations above pre-industrial levels;* *(b) Indirect nitrogen deposition; and* *(c) The dynamic effects of age structure resulting from activities prior to 1 January 1990* (See Section 4.2.3.5.)	7
Changes in data and methods	Any changes in data or methodology since the report of the previous year, e.g., in the choice of methods, activity data collection method, activity data, difficulties of detection (e.g., distinction between harvesting and deforestation when estimating the D area), parameters used in the calculations should be reported in a transparent manner. The reporting should include information on whether these changes have been applied also to reporting on previous inventory years to ensure consistency of the time series.	10

[39] Entries in this column refer to relevant paragraphs in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, pp.21-29. In the table not necessarily *all* relevant legal texts are referred to.

TABLE 4.2.4b (CONTINUED)
SUPPLEMENTARY INFORMATION TO BE REPORTED FOR THE ANNUAL GREENHOUSE GAS INVENTORY DURING THE FIRST COMMITMENT PERIOD ACCORDING TO THE MARRAKESH ACCORDS. TEXT IN ITALICS INDICATES A DIRECT QUOTE FROM THE RELEVANT PARAGRAPHS IN THE MARRAKESH ACCORDS

Information to be reported	Detailed information	Reference in Marakesh Accords[40]
Other generic methodological issues	Any additional relevant information on methodological issues, such as measurement intervals, disturbances, interannual variability (see Section 4.2.3)	
Specific information for activities under Article 3, paragraphs 3 and 4		
Article 3.3 specific information	• *Information that demonstrates that activities under Article 3, paragraph 3, began on or after 1 January 1990 and before 31 December of the last year of the commitment period, and are directly human-induced*; • *Information on how harvesting or forest disturbance that is followed by the re-establishment of a forest is distinguished from deforestation*; • It is good practice to provide information on the size and geographical location of forest areas that have lost forest cover but which cannot be classifed as deforested (and will therefore remain classified as forest with a re-assessment in the next inventory).	8 (a) 8 (b)
Article 3.4 specific information	*A demonstration that activities under Article 3, paragraph 4, have occurred since 1 January 1990 and are human induced*	9 (a)
Information related to the estimates of emissions by sources and removals by sinks (for reporting data, see Tables 4.2.5-4.2.6)		
Estimates for greenhouse gas emissions by sources and removals by sinks	Estimates of greenhouse gas emissions by sources and removals by sinks for human-induced activities under Article 3, paragraphs 3, and, if any, elected activities under Article 3, paragraph 4, and for all geographical locations reported in the current and previous years, since the beginning of the commitment period or the onset of the activity, whichever comes later. In the latter case the year of the onset of the activity must also be included.	see 6 (d)
	[…] Estimates for Article 3, paragraphs 3 and 4, shall be clearly distinguished from anthropogenic emissions from the sources listed in Annex A to the Kyoto Protocol.[…]	5
Afforestation and Reforestation	*Information on emissions and removals of greenhouse gases from lands harvested during the first commitment period following afforestation and reforestation on these units of land since 1990 consistent with the requirements under paragraph 4 of the annex to draft decision –/CMP.1 (Land use, land-use change and forestry).*	8 (c)
Cropland management, grazing land management and revegetation	Anthropogenic greenhouse gas emissions by sources and removals by sinks for **each year of the commitment period** and for the **base year** for each of the elected activities on the geographical locations identified, excluding emissions reported under the Agriculture sector of the *IPCC Guidelines*.	9 (b), and paragraph 9 of the annex to draft decision -/CMP.1 (LULUCF), FCCC/CP/2001/13/Add.1, p.59
Absence of overlap between 3.3 and 3.4 activities	*Information that demonstrates that emissions by sources and removals by sinks resulting from elected Article 3, paragraph 4, activities are not accounted for under activities under Article 3, paragraph 3*.	9 (c)
Uncertainty of emission and removal estimates	Estimates of emissions and removals *shall be within levels of confidence as elaborated by any IPCC good practice guidance adopted by the COP/MOP and in accordance with relevant decisions of the COP/MOP on land use, land-use change and forestry.*	6(d), footnote 5

[40] Entries in this column refer to relevant paragraphs in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, pp.21-29. In the table not necessarily *all* relevant legal texts are referred to.

It is *good practice* to use coordinates as set out in Section 4.2.4.3.2 below for the reporting of the geographical location of the boundaries that encompass the units of land subject to activities under Article 3.3 and the lands subject to elected activities under Article 3.4. This information can be summarised on a map for visual presentation and data sharing. It is also *good practice* to report the land transition matrix below (Table 4.2.5) to demonstrate that the Party has accounted for all areas where afforestation, reforestation and deforestation and, if elected, Article 3.4 activities have occurred. The diagonal cells of the table indicate the area of lands remaining in the same category (e.g., FM land remaining FM land), while other cells indicate the areas of lands converted to other categories (e.g., cropland converted to afforested land). It is *good practice* to explain any changes in the total area over consecutive inventories.

It is *good practice* to use Tables 4.2.6a-c and Table 4.2.7 to submit annual estimates. For Article 3.3 and 3.4 activities (Tables 4.2.6a and 4.2.6b), data must be provided by geographical locations, whereas for projects (Table 4.2.6c) data must be filled in by project. The Marrakesh Accords also require that, in addition to the data for the actual inventory year, a Party also reports this information for the base year for cropland management, grazing land management, and revegetation. No reporting is necessary for those Article 3.4 activities that were not elected by the Party.

When filling in these tables, care should be taken to insert carbon stock changes for each pool with proper signs. Carbon stock changes are to be reported in units of carbon as positive when the carbon stock has increased, and as negative when the carbon stock has decreased. All changes are totalled for each geographic location, and the total values are then multiplied by 44/12 to convert carbon stock changes to CO_2 emissions or removals. This conversion also involves sign change from the equations used to make the estimates. Non-CO_2 greenhouse gas emissions are to be reported as positive, as these represent increases in abundances in the atmosphere.

Table 4.2.7 is a summary table of carbon stock changes resulting from activities under Articles 3.3 and 3.4 for the inventory year. It is *good practice* to use the table also for the base year if cropland management, grazing land management, and/or revegetation have been elected. This table summarises data of the compilation tables by activity across all carbon pools and across all strata within a country.

In addition to the data in the Tables 4.2.6a-c and 4.2.7, respectively, it is *good practice* to report the underlying assumptions and factors used for the calculation of the carbon stock changes and emissions of CH_4 and N_2O, as well as for the calculation of the uncertainties. Such information can be obtained using the worksheets in Chapter 3 or from equivalent information supporting the estimates obtained using higher tiers or other methods.

The Marrakesh Accords contain a clause that carbon stock changes resulting from harvesting of afforestation/reforestation land during the first commitment period will not result in a debit greater than the credit previously accounted for that unit of land (see Table 4.2.4).[41] If such units of land exist for the inventory year, it is *good practice* to distinguish them from other afforestation/reforestation lands and to report them (and the associated carbon stock changes and non-CO_2 greenhouse gas emissions) separately in Tables 4.2.6 to 4.2.7. Although this is an issue related to accounting, it is mentioned here because inventory data are likely to be needed to implement the provision.

Finally, separate annual uncertainty estimates should be reported for each activity under Articles 3.3 and 3.4, for each carbon pool, each greenhouse gas and geographical location. Estimates should be reported using tables generated following the model of Tables 4.2.6a, b and c. Separate tables should be reported for the base year when CM, GM and/or RV are elected. Uncertainty estimates are to be made at the 95% confidence limits expressed as percent of the emissions by sources or removals by sinks (or changes in stocks) reported in Tables 4.2.6a, b and c.

[41] Paragraph 4 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.59.

TABLE 4.2.5
LAND TRANSITION MATRIX: LAND AREA (IN HA) SUBJECT TO THE VARIOUS ACTIVITIES IN THE INVENTORY YEAR AND THE PREVIOUS YEAR

Note that some of the transitions in the matrix may not be possible (e.g., once land has become subject to A, R, or D, it cannot become subject to FM, CM, GM, or RV in the next year)

INVENTORY YEAR:

		Land in inventory year by activity								
		A	**R**	**D**	**FM if elected**	**CM if elected**	**GM if elected**	**RV if elected**	**Other**	**Total**
Land in year prior to inventory by activity	**A**									
	R									
	D									
	FM if elected									
	CM if elected									
	GM if elected									
	RV if elected									
	Other									
	Total									

TABLE 4.2.6a

TABLE FOR REPORTING, FOR THE INVENTORY YEAR, CARBON STOCK CHANGES AND NON-CO_2 EMISSIONS BY SOURCES AND REMOVALS BY SINKS FOR EACH OF THE FOLLOWING ACTIVITIES / LANDS: (I) A AND R[1] NOT HARVESTED DURING THE FIRST COMMITMENT PERIOD; (II) A AND R[1,2] HARVESTED DURING THE FIRST COMMITMENT PERIOD; (III) A AND R[1] THAT ARE ALSO SUBJECT TO ELECTED ARTICLE 3.4 ACTIVITIES[3]; (IV) D; (V) D THAT IS ALSO TO SUBJECT TO ELECTED ARTICLE 3.4 ACTIVITIES[3]; AND (VI) FM IF ELECTED. (I) PLUS (II) EQUALS ALL A AND R LANDS. (IV) EQUALS ALL D LANDS. (I) PLUS (II) PLUS (IV) EQUALS ALL A, R, AND D LANDS (ARTICLE 3.3). (VI) MUST NOT INCLUDE ANY A, R, OR D (ARTICLE 3.3) LANDS. (III) AND (V) ARE PROVIDED ONLY FOR INFORMATION PURPOSES[4].

Activity:

Inventory year:

Geographical Location[5]		Area of Activity	Increases (+) and Decreases (-) in Carbon Stock [6]					Total Carbon Stock Changes[7]	Emissions (+) or Removals (-) from Carbon Stock Changes[8]	CH_4 Emissions	N_2O Emissions
			Above ground biomass	Below ground biomass	Litter	Dead wood	Soil				
Serial No.	**ID[9]**	**(ha)**	**(Gg C/yr)**	**(Gg C/yr)**	**(Gg C/yr)**	**(Gg C/yr)**	**(Gg C/yr)**	**(Gg C/yr)**	**(Gg CO_2e/yr)**	**(Gg/yr)**	**(Gg/yr)**
1											
2											
3											
…											
N											
Total for the activity											

Note that those countries that use Tier 1 or Tier 2 methods that allow separate reporting of increases (such as growth) and decreases (such as harvesting) of a pool should also do so by appropppriately expanding the table. In these cases, the net stock changes should also be reported, and these are subsequently used for the calculation of the total stock changes.

[1] As afforestation (A) and reforestation (R) activities are treated in the same way, they can be reported together. The separation of afforestation and reforestation lands that are harvested from those that are not harvested during the first commitment period is necessary because of the requirement set in paragraph 4 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), cf. FCCC/CP/2001/13/Add.1, p.59.

[2] If A and R lands have been harvested in the inventory year, then special carbon accounting rules apply that allow countries to limit debits from harvesting. This requires the tracking of "credits" earned on these lands in previous inventory years or commitment periods.

[3] Units of land subject to activities under Article 3.3 which would otherwise be included in land subject to elected activities under Article 3.4 must be reported (cf. paragraph 6 item (b) (ii) in the Annex to draft decision -/CMP.1 (Article 7), contained in FCCC/CP/2001/13/Add 3, p.22).

[4] See paragraph 6, in particular 6 (b), of the Annex to draft decision -/CMP.1 (Article 7), contained in FCCC/CP/2001/13/Add 3, p.22.

[5] Geographical location refers to the areas that encompass units of land subject to Article 3.3 and lands subject to Article 3.4 activities.

[6] If a pool is not reported, the text "NR" (for "not reported") must be entered, and it must be demonstrated that the pool is not a source.

[7] "Total carbon stock changes" is the sum of carbon stock changes of all five pools.

[8] Emissions/Removals are calculated by multiplying total carbon stock changes by 44/12 to convert to CO_2 followed by reversing the sign to follow conventions of emissions/removals reporting.

[9] ID: unique identifier of the geographic location.

TABLE 4.2.6b
TABLE FOR REPORTING, FOR THE INVENTORY YEAR, CARBON STOCK CHANGES AND NON-CO_2 EMISSIONS BY SOURCES AND REMOVALS BY SINKS FOR EACH OF THE FOLLOWING ARTICLE 3.4 ACTIVITIES/LANDS: (I) CM; (II) GM; (III) RV. SEPARATE TABLES (OR SEPARATE ROWS IN ONE TABLE) SHOULD BE USED TO REPORT THOSE ACTIVITIES THAT OCCUR ON MINERAL SOILS AND ON ORGANIC SOILS. THE COLUMN "LIMING CO_2 EMISSIONS" IS TO BE FILLED FOR GEOGRAPHICAL LOCATIONS WHERE THESE EMISSIONS APPLY. (SEE SECTIONS 4.2.8 AND 4.2.9 FOR DETAILS.)
THESE TABLES SHOULD ALSO BE PROVIDED FOR THE BASE YEAR

Activity:

Inventory year:

Geographical Location[1]		Area of Activity	Increases (+) and Decreases (-) in Carbon Stock[2]					Total Carbon Stock Changes[3]	Emissions (+) or Removals (-) from Carbon Stock Changes[4]	Liming CO_2 emissions	CH_4 Emissions[5]	N_2O Emissions[5]
			Above ground biomass	Below ground biomass	Litter	Dead wood	Soil					
Serial No.	ID[6]	(ha)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg CO_2e/yr)	(Gg CO_2e/yr)	(Gg/yr)	(Gg/yr)
1												
2												
3												
…												
N												
Total for the activity												

[1] Geographical location refers to the areas that encompass lands subject to Article 3.4 activities.
[2] If a pool is not reported, the text "NR" (for "not reported") should be entered, and it must be demonstrated that the pool is not a source.
[3] "Total carbon stock changes" are the sum of carbon stock changes of all five pools.
[4] Emissions/Removals are calculated by multiplying total carbon stock changes by 44/12 to convert to CO_2 followed by reversing the sign to follow conventions of emissions/removals reporting.
[5] For CM, GM and RV, if elected, methane and nitrous oxide emissions are reported here for transparency purposes only. They are reported and accounted along with the Kyoto Protocol Annex A sources in the Agriculture sector.
[6] ID: unique identifier of the geographic location.

TABLE 4.2.6c

TABLE FOR REPORTING, FOR THE INVENTORY YEAR, CARBON STOCK CHANGES AND NON-CO_2 EMISSIONS BY SOURCES AND REMOVALS BY SINKS FOR PROJECTS UNDER ARTICLE 6. A COPY OF THIS TABLE MUST BE PROVIDED FOR EACH TYPE OF ACTIVITY.

Project activity:

Inventory year:

Serial number	Project ID[1]	Area of Project	Increases (+) and Decreases (-) in Carbon Stock[2]					Total Carbon Stock Changes[3]	Emissions (+) or Removals (-) from Carbon Stock Changes[4]	CH_4 Emissions	N_2O Emissions
			Above ground biomass	Below ground biomass	Litter	Dead wood	Soil				
		(ha)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg CO_2 e/yr)	(Gg/yr)	(Gg/yr)
1											
2											
3											
…											
N											
Total for the activity											

[1] Project ID is a unique identifier of the project.

[2] If a pool is not reported, the text “NR” (for “not reported”) must be entered, and it must be demonstrated that the pool is not a source.

[3] “Total carbon stock changes” is the sum of carbon stock changes of all five pools if temporary plots are used, but if permanent plots are used, the change in stock in each component should be summed by plot and the mean and confidence intervals be computed across all plots. See Section 4.3 for details.

[4] Emissions/Removals are calculated by multiplying total carbon stock changes by 44/12 to convert to CO_2 followed by reversing the sign to follow conventions of emissions/removals reporting.

TABLE 4.2.7
SUMMARY TABLE OF GREENHOUSE GAS EMISSIONS BY SOURCES AND REMOVALS BY SINKS BY ARTICLES 3.3, 3.4 AND 6 ACTIVITIES FOR THE INVENTORY YEAR. NOTE THAT EMISSIONS ARE TO BE REPORTED BY PROPERLY APPLYING ONE OF TWO REPORTING METHODS DETAILED IN SECTION 4.2.2.2.

Inventory year:

Activity		Areas	CO_2 Emissions (+) or Removals (-)	CH_4 [4]	N_2O [4]
		(ha)	(Gg CO_2 e/yr)	(Gg/yr)	(Gg/yr)
A and R not harvested during the first commitment period[1]					
A and R harvested during the first commitment period[1]					
A and R that is also to subject to elected Article 3.4 activities[1, 6]					
D					
D that is also to subject to elected Article 3.4 activities[6]					
Article 3.4 FM if elected					
Article 3.4 CM if elected[2]	Mineral Soils[5]				
	Organic Soils[5]				
	Liming				
Article 3.4 GM if elected[2]	Mineral Soils[5]				
	Organic Soils[5]				
	Liming				
Article 3.4 RV if elected[2]	Mineral Soils[5]				
	Organic Soils[5]				
	Liming				
Article 6 A and R activities[3]					
Article 6 FM activities[3]					
Article 6 CM activities[3]					
Article 6 GM activities[3]					
Article 6 RV activities[3]					

[1] As afforestation (A) and reforestation (R) activities are treated the same way, they can be reported together. The separation of afforestation and reforestation lands that are harvested from those that are not harvested during the first commitment period is necessary because of the requirement set in paragraph 4 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), cf. FCCC/CP/2001/13/Add.1, p.59.

[2] If CM, GM and/or RV is elected, a copy of this table should be completed and reported for the base year.

[3] Emissions and removals related to Article 6 projects hosted by the reporting Party, if any, should be reported in the final five rows, recognizing that they are already implicitly included in the national estimates of activities under Articles 3.3 and 3.4 reported in this table. Double counting will be avoided at the accounting stage when converting Removal Units into Emission Reduction Units.

[4] For Article 3.4 CM, GM and RV, if elected, methane and nitrous oxide emissions are reported here for transparency purposes only. They are reported and accounted along with the Kyoto Protocol Annex A sources in the Agriculture sector.

[5] The headings “Mineral soils” and “Organic Soils” follow the breakdown by sources and sinks in the CM, GM and RV sections of Chapter 4. It should include all C pools, if applicable (i.e., shelterbelts…), occurring on croplands, grazing lands or revegetation lands with mineral and organic soils, respectively and should be equal, for each activity, to the total of the column “Total changes in carbon stocks” of Table 4.2.6b.

[6] Afforestation (A), reforestation (R) and deforestation (D) lands, which are also subject to elected Article 3.4 activities, are already included in the A/R and D totals.

4.2.4.3.2 DOCUMENTATION

Documentation requirements under the Kyoto Protocol are outlined in the Marrakesh Accords as part of the description of the requirements for inventory management.[42]

It is *good practice* to document and archive all information, i.e., the underlying data and description of, or reference to, methods, assumptions and parameters used, which are used to produce estimates of emissions by sources and removals by sinks of greenhouse gases that would allow independent reviewers to follow the process of developing the reported estimates. Documented data and explanation of methods should be provided for both steps: the identification of land and the assessment of carbon stock changes and the emissions of non-CO_2 greenhouse gases.

Documentation should also include information about uncertainty assessment (see also Section 4.2.4.2 Uncertainty Assessment), QA/QC procedures, external and internal reviews, verification activities and key category identification (see Chapter 5, Cross-cutting Issues).

Activities definition and identification

It is *good practice* to explain how the Marrakesh Accords definitions of the elected Article 3.4 activities have been interpreted according to national circumstances. For instance, if only a part of the managed forests reported in the UNFCCC greenhouse gas inventory is included under forest management in the Kyoto reporting, the criteria that are used to distinguish forests under “forest management” from “managed forests” should be provided. Differences between croplands (or grasslands) in the UNFCCC greenhouse gas inventory and lands undergoing cropland management (or grazing land management) under the Kyoto reporting should also be documented.

Data documentation

In particular when using Reporting Method 1, the areas encompassed by the geographical boundaries resulting from the stratification of a country, should be identified by unique serial numbers in the tables. These serial numbers are to be cross-referenced to a database or other archive (the LULUCF Archive) specifying the locations in terms of established legal or administrative boundaries, or by means of an existing coordinate system, for example an established national grid system, the UTM (Universal Transverse Mercator) grid or latitude and longitude.

The documentation of estimates of greenhouse gas emissions and removals must include:

- The sources of all data used in the calculations (i.e., complete citations for the statistical database(s) from which data were collected);
- The information, rationale and assumptions that were used to develop reported data and results, in cases they were not directly available from databases (for instance if interpolation or extrapolation methods have been applied);
- The frequency of data collection; and
- Estimates of the associated uncertainties together with a description of the major sources of the uncertainties.

Description of the methods used in land identification and estimation of emissions and removals

The methods should be documented with the following information:

- Choice of reporting methods for lands subject to Articles 3.3 and 3.4 (Reporting Method 1, 2) or a description of the reporting method, if a combination of the two is used;
- Description of the approach used for geographical location and identification of the geographical boundaries, lands, and units of land; references of maps used, if any;
- Choice of tier(s) used for estimating greenhouse gas emissions and removals;
- Methods used for estimating carbon stock changes, non-CO_2 greenhouse gas emissions and magnitudes of the corresponding uncertainties;

[42] Paragraph 16 (a) in the Annex to the draft decision -/CMP.1 (Article 5.1), contained in FCCC/CP/2001/13/Add.3, p.9.

- Choice of activity data;
- If Tier 1 is used: all values of default parameters and emission/removal factors used;
- If Tier 2 is used: all values and references of default and national parameters and emission/removal factors used;
- If Tier 3 is used: description of, or references to, the scientific basis for the models used, description of the process by which carbon stock changes and emissions or removals are estimated;
- In case of Tier 2 or 3 the documentation should justify the use of specific parameters, factors or models;
- Transparent and verifiable information that demonstrates that the pools not included in the reporting are not sources.

Analysis of fluctuations

It is *good practice* to explain significant fluctuations in reported emissions or removals between years. The reasons for any changes in activity levels and in parameter values from year to year should be documented. If the reason for the changes is an improvement in methods, it is *good practice* to recalculate results for the preceding years by using the new methods, new activity and/or new parameter values (see Chapter 5, Section 5.6 Time series consistency and recalculations).

4.2.4.4 QUALITY ASSURANCE AND QUALITY CONTROL

It is *good practice* to implement quality control checks as outlined in Chapter 5, Section 5.5 (Quality Assurance and Quality Control) on category-specific QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Section 5.5 and quality assurance procedures may also be applicable, particularly if higher-tier methods are used to estimate carbon stock changes and non-CO_2 greenhouse gas emissions. A detailed treatment of inventory QA/QC for field measurement is described in Appendix 4A.3 of the *GPG2000*.

Some important issues are highlighted and summarised below.

When compiling data, it is *good practice* to cross-check estimates of emissions and removals of greenhouse gases against independent estimates. The inventory agency should ensure that estimates undergo quality control by:

- Cross-referencing aggregated production data (e.g., crop yield, tree growth) and reported area statistics with national totals or other sources of national data (e.g., agriculture / forestry statistics);
- Back-calculating national emission/removal factors from aggregated emissions and other data;
- Comparing reported national totals with default values and data from other countries.

It is also *good practice* to verify that the sum of the disaggregated areas used to estimate the various emissions/removals equals the total area under the activity, reported as per guidance in Chapters 2 and 3 (using the LU/LUC matrix).

4.2.4.5 VERIFICATION

Good practice guidance for verification is given in Chapter 5, Section 5.7 (Verification).

4.2.5 Afforestation and Reforestation

This section elaborates on the general discussion of methods applicable to all activities (Section 4.2 Methods for estimation, measurement, monitoring and reporting of LULUCF activities under Article 3.3 and 3.4) and should be read in conjunction with the general discussion presented earlier in this chapter.

4.2.5.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

Under the definitions of the Marrakesh Accords, both afforestation and reforestation refer to direct, human-induced conversion of land to forest from another land use. The definitions do not include replanting or regeneration following harvest or natural disturbance, because these temporary losses of forest cover are not considered deforestation. Harvest followed by regeneration is considered a forest management activity. The distinction between the two activities is that afforestation occurs on land that has not been forest for at least 50 years, while reforestation occurs on land that has been forest more recently, though not since 31 December 1989. For the identification of units of land, afforestation and reforestation will be discussed together because the two definitions differ only by the time since the area was last forested, and because the same carbon reporting and accounting rules apply to both activities. When calculating changes in carbon stocks following afforestation and reforestation, the assumptions about the initial size and composition of the litter, dead wood, and soil organic carbon pools should reflect the preceding land-use type and history, rather than the distinction between afforested and reforested sites.

The annual inventory should, at a minimum, identify (for Reporting Method 1 in Section 4.2.2.2):

- The geographical location of the boundaries of the areas that encompass units of land subject to afforestation/reforestation activities (including those units of land subject to activities under Article 3.3, which would otherwise be included in land subject to elected activities under Article 3.4). The geographical boundaries which are reported should correspond to strata in the estimation of land areas as described in Section 5.3;
- For each of these areas, or strata, estimates of the area of the units of land affected by afforestation/reforestation activities in the two subcategories, namely those subject to Article 3.3, and those subject to Article 3.3 that would otherwise be subject to Article 3.4;
- The year of the start of afforestation/reforestation activities, which will be between 1 January 1990 and the end of the inventory year. Within the boundary of the areas afforestation/reforestation activities may have started in different years. It is *good practice* to group afforestation and reforestation units of land by age and to report the area in each age class separately; and
- The area of units of land subject to afforestation/reforestation in each productivity class and species combination to assign growth rate estimates and to support the calculation of carbon stock changes and non-CO_2 greenhouse emissions.

A more comprehensive system (Reporting Method 2 in Section 4.2.2.2) identifies each unit of land subject to afforestation/reforestation activities since 1990 (again in the two subcategories – Article 3.3 and Article 3.3 that would otherwise be subject to Article 3.4), using the polygon boundaries, a coordinate system (e.g., the Universal Transverse Mercator (UTM) Grid or Latitude/Longitude), or a legal description (e.g., those used by land-titles offices) of the location of the land subject to afforestation or reforestation activities. Chapter 2 (Basis for consistent representation of land areas) discusses in detail the possible approaches for consistent representation of land areas.

4.2.5.2 CHOICE OF METHODS FOR IDENTIFYING UNITS OF LAND SUBJECT TO DIRECT HUMAN-INDUCED AFFORESTATION/ REFORESTATION

Parties need to report on the carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period on areas that have been subject to afforestation and reforestation (AR) activities since 1990. The first step in this process is to make national parameter choices for the forest definition within the ranges allowed by the Marrakesh Accords, namely 0.05 – 1 ha for minimum area, minimum tree crown cover of 10-30% (or equivalent stocking level), minimum height at maturity of 2 to 5 meters and to report on these parameters, in the annual greenhouse gas inventory as set out in Table 4.2.4a. As explained in Section 4.2.2.5.1 it is also *good practice* to choose a parameter for the minimum width of forest areas. Once the parameters have been chosen, they will allow identification of units of land subject to afforestation and reforestation.

The identification of units of land subject to afforestation / reforestation activities requires the delineation of areas that:

- Meet or exceed the size of the country's minimum area in the applied forest definition (i.e., 0.05 to 1 ha), and
- Did not meet the definition of forest on 31 December 1989, and
- Do meet the definition of forest at the time of the assessment and after 1 January 1990 as the result of direct human-induced activities.

Note that the definition of forest can be met by young trees that do not yet meet the minimum height or crown cover criteria, provided that they are expected to reach these parameter thresholds at maturity.

It is *good practice* to distinguish those areas that did not meet the crown cover threshold in the definition of forest on 31 December 1989, for example because of recent harvest or natural disturbances, from those areas that were non-forest on that date, because only the latter areas are eligible for afforestation and reforestation activities under the Marrakesh Accords. The Marrakesh Accords require that Parties provide information on the criteria used to distinguish harvesting or forest disturbance that is followed by the re-establishment of a forest from deforestation.[43] It is *good practice* to apply the same criteria when evaluating whether a unit of land meets the definition of forest. For example, if a country uses the criterion "time since harvest" to distinguish temporary forest cover loss from deforestation, and specifies that a harvested area will regenerate within X years, then only those areas that have been harvested more than X years prior to 31 December 1989 and that have not regenerated would be eligible for reforestation, as only they would be considered non-forest on 31 December 1989. Similarly, areas that have been disturbed by wildfire or other natural disturbances more than X years prior to 31 December 1989 and that have not regenerated to forest are classified as non-forest on 31 December 1989 and would therefore be eligible for reforestation.

As discussed in Section 4.2.2.2 (Reporting methods for land subject to Article 3.3 and 3.4 activities), Parties have the option to either report a complete inventory of all *units of land* subject to Article 3.3 activities, or to stratify the land into areas, i.e., defining the boundaries of these areas, and to then develop for each area estimates or inventories of the units of land subject to afforestation, reforestation and deforestation activities. Combined approaches are also possible: complete spatial inventories of all units of land can be developed for some strata, while estimates based on sampling approaches are developed for other strata in the country.

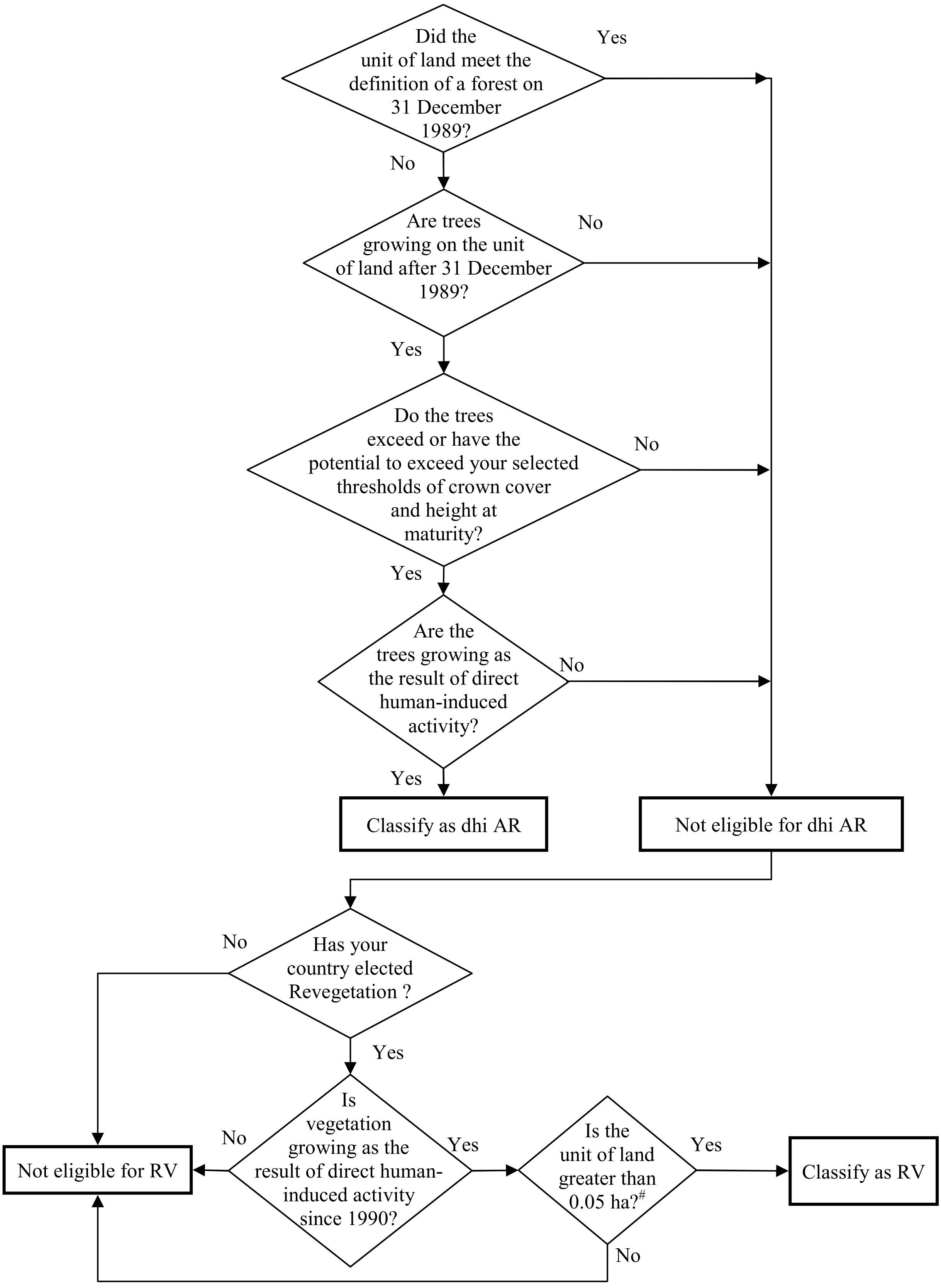
A Party's choice of methods for the development of an inventory of afforestation and reforestation activities will depend on the national circumstances. It is *good practice* to use Approach 3 in Chapter 2 (Basis for consistent representation of land area, Section 2.3.2.3) for the identification of units of land subject to afforestation and reforestation since 1990. As discussed above, this requires that the spatial resolution of the systems in Approach 3 meets the requirements for the identification of the minimum forest area of 0.05 to 1 ha. The methods available to identify lands subject to afforestation and reforestation activities are discussed in Section 4.2.8.2. It is *good practice* to provide information on uncertainties in the estimates of the total area of the units of land subject to afforestation and reforestation as discussed in Section 4.2.4.2 above.

It is *good practice* to provide documentation that all afforestation and reforestation activities included in the identified units of land are direct human-induced. Relevant documentation includes forest management records or other documentation that demonstrates that a decision had been taken to replant or to allow forest regeneration by other means.

In some cases it may not be clear whether newly established trees will pass the forest threshold. The difference between afforestation/reforestation activities and revegetation is that revegetation does not (and will not) meet the Party's definition of a forest (i.e., the height at maturity or the minimum crown closure). Where it is uncertain whether the trees on a unit of land will pass the thresholds of the definition of forest, it is *good practice* not to report these areas as afforested or reforested land, and to await confirmation (at a later time) that these parameter thresholds have been or will be passed. Prior to meeting the definition of afforestation or reforestation, the carbon stock changes on these units of land could be reported in the land-use category in which the land was reported prior to the land-use change, provided that this category is included in the national accounts, e.g., as cropland or revegetation. (Note that this approach is consistent with the treatment of deforestation, i.e., units of land that have not been confirmed as deforested remain in the forest category – see Section 4.2.6.2.1). A decision tree for determining of whether an area will qualify for afforestation/reforestation or for revegetation is given in Figure 4.2.5.

[43] See paragraph 8(b) of the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.23.

Figure 4.2.5 Decision tree for determining whether a unit of land qualifies for direct human-induced (dhi) Afforestation/Reforestation (AR) or Revegetation (RV).



See paragraph 1(e) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

Links with methodologies in this report and the *IPCC Guidelines* on reporting of land areas and carbon stock changes and non-CO_2 greenhouse gas emissions in inventories under the UNFCCC are given in the box below.

BOX 4.2.2

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 2.3 (Representing land areas): Cropland, grassland, wetland, settlements and other land converted to forest land since 1990. Should include all transitions between 1990 and 2008, and in later inventory years, transitions on an annual basis. Note that some areas that have turned into forest since 1990 in the UNFCCC inventory may not have been converted through direct human-induced activity.

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

4.2.5.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 EMISSIONS

Estimation of carbon stock changes from afforestation and reforestation activities should be consistent with the methods set out in Chapter 3 and the equations it contains, and applied at the same or higher tier as used for UNFCCC reporting. Growth characteristics of young trees differ from those of the managed forest as a whole, and special provisions may be needed where the UNFCCC inventory (prepared according to Section 3.2.2, Land converted to forest land) is not sufficiently detailed to provide information that applies to young stands.

On areas subject to Article 3.3 activities, gross-net accounting rules are applied and information on carbon stock changes in the base year (i.e., 1990) is therefore not required. Only the net changes in ecosystem carbon stocks and the non-CO_2 greenhouse gas emissions during each year of the commitment period are estimated and reported.

At Tier 1, biomass growth is determined using the data in Chapter 3, Section 3.2.2 (Land Converted to Forest Land).

At Tier 2, regional or national growth rates will be available as a function of stand age, species or site quality, but data may be missing for stands between 0 and 23 years (the stand age reached in 2012 by trees planted in 1990). Where biomass estimates exist for stands older than 23 years, biomass at younger ages can be estimated by interpolating between the known value and biomass zero at age zero using a sigmoidal growth function fitted to the data that are available for older stands.

At Tier 3, biomass growth rates should be established directly using measured data, validated growth models, or empirical yield tables for the appropriate combinations of species and site conditions. It is *good practice* to include ground-based field measurements as part of any Tier 3 method, either as a component of a national (or project) forest inventory or of a growth and yield forest monitoring system.

Determination of the size and dynamics of litter, dead wood and soil organic carbon pools prior to the afforestation activity may require the use of methods developed for cropland management or other land uses (see Chapter 3).

Links with methodologies in this report and the *IPCC Guidelines* on reporting of carbon stock changes and non-CO_2 greenhouse gas emissions in inventories under the UNFCCC are given in the box below.

BOX 4.2.3

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Chapter 3 Section 3.2.2 (Land converted to forest land)

LINKS WITH THE *IPCC GUIDELINES*

5 A Changes in forest and other woody biomass stocks (afforestation). *To be determined through separate monitoring for afforestation/reforestation activities*

5 C Abandonment of managed lands *(only portion that goes to forest)*

5 D CO_2 emissions and removals from soils *(only afforestation/reforestation proportion)*

5 E Other (CH_4, N_2O in managed forests) *(only afforestation/reforestation proportion)*

The default methods in the *IPCC Guidelines* do not cover belowground biomass, dead wood, litter or emissions of non-CO_2 greenhouse gas.

4.2.5.3.1 POOLS AFFECTED BY AFFORESTATION/REFORESTATION ACTIVITIES

Afforestation/reforestation activities often involve site preparation (slashing and possibly burning coarse biomass residue, and tilling or ploughing on parts of or the whole area), followed by planting or seeding. These activities may affect not only biomass pools, but also soil, as well as dead wood and litter, if (in the latter instances) land with woody shrub or sparse tree cover was afforested.

The Marrakesh Accords require Parties to estimate carbon stock changes in all five pools (see Table 3.1.1) during the commitment period unless the Party can demonstrate by transparent and verifiable information that the pool is not a source,[44] for which *good practice* advice is set out in Section 4.2.3.1. It is *good practice* to include carbon stock changes and non-CO_2 greenhouse gas emissions that result from pre-planting activities, such as site preparation or shrub removals. Soil carbon may show some decline with afforestation of grasslands (e.g., Tate *et al.*, 2003; Guo and Gifford. 2002). Net ecosystem losses of carbon after planting and seeding can persist over many years. Therefore, estimates of pre-activity carbon stocks in the area may be required to initialise the models used to estimate stock changes. Since there is no forest on the area prior to the afforestation/reforestation activity, the assessment should be done by methods described in the appropriate sections of Chapter 3, e.g., Section 3.3 for cropland.

For afforestation or reforestation activities that begin during the commitment period, reporting for that unit of land should begin at the beginning of the year in which the activity commences.[45] Site preparation and seeding/planting activities should be considered part of the activity, and associated emissions during the commitment period should therefore be included.

4.2.5.3.2 HARVESTING OF AFFORESTATION/REFORESTATION LAND DURING THE COMMITMENT PERIOD

Some short rotation forests established through afforestation and reforestation activities may be affected by harvesting during the first commitment period. The Marrakesh Accords allow Parties to limit debits from such harvests during the first commitment period.[46]

Although this is an accounting issue, it has implications for the design of carbon monitoring and reporting systems for units of land subject to afforestation or reforestation since 1990. In particular, it is *good practice* to identify the afforestation and reforestation lands on which harvesting occurs in the inventory year during the commitment period, to track carbon stock changes and non-CO_2 greenhouse gas emissions on these lands on a

[44] Paragraph 21 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.62.

[45] Paragraph 6(d) in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.23.

[46] "*For the first commitment period, debits resulting from harvesting during the first commitment period following afforestation and reforestation since 1990 shall not be greater than credits accounted for on that unit of land.*" (cf. paragraph 4 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.59.

year by year basis during the first commitment period, so that they can be compared with the amount of credits received previously for these units of land.

The methods given in Chapter 3 for estimating non-CO_2 greenhouse gas emissions on lands converted to forest land are applicable for the afforestation and reforestation activities (see Section 3.2.2.4 Non-CO_2 greenhouse gases). If the units of land subject to afforestation and reforestation are subject to disturbances, then the Chapter 3 methods in other sections may also be applicable (see e.g., Section 3.2.1.4.3 Fires).

4.2.6 Deforestation

This section addresses specific methods applicable to deforestation activities and should be read in conjunction with the general discussion in Sections 4.2.2 to 4.2.4.

4.2.6.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

Under the definitions of the Marrakesh Accords, deforestation refers to direct, human-induced conversion of forest to non-forest land. The definitions do not include harvest that is followed by regeneration since this is considered a forest management activity. Forest cover loss resulting from natural disturbances, such as wildfires, insect epidemics or wind storms, are also not considered direct human-induced deforestation, since in most cases these areas will regenerate naturally or with human assistance. Human activities (since 1990) such as cropland management or the construction of roads or settlements, that prevent forest regeneration by changing land use on areas where forest cover was removed by a natural disturbance, are also considered direct human-induced deforestation.

The annual inventory should, at a minimum, identify: (for Reporting Method 1 in Section 4.2.2.2):

- The geographical location of the boundaries of the areas that encompass units of land subject to direct human-induced deforestation activities. The geographical boundaries which are reported should correspond to strata in the estimation of land areas as described in Section 5.3;
- For each of these areas, or strata, an estimate of the area of the units of land affected by direct human-induced deforestation activities, and the area of these units of land that are also subject to elected activities under Article 3.4 (cropland management, grazing land management, revegetation);
- The year of the deforestation activities (1990 or later), which could be estimated through interpolation from a multi-year inventory; and
- The area of units of land subject to direct human-induced deforestation in each of the new land-use categories (cropland, grazing land, settlements) to support the calculation of carbon stock changes and non-CO_2 greenhouse emissions.

A more comprehensive system (Reporting Method 2 in Section 4.2.2.2) identifies each unit of land subject to deforestation since 1990 using the polygon boundaries, a coordinate system (e.g., the Universal Transverse Mercator (UTM) Grid or Latitude/Longitude), or a legal description (e.g., those used by land-titles offices) of the location of the land subject to deforestation activities. Chapter 2 (Basis for consistent representation of land areas) discusses in detail the possible approaches for consistent representation of land areas.

Parties will need to use the methods outlined in Chapter 2 (Basis for consistent representation of land areas), taking into account Section 5.3 and the guidance in Section 4.2.2 to ensure that units of land subject to deforestation are adequately identified in land-use change and other inventory databases. The Marrakesh Accords require that areas subject to direct human-induced deforestation since 1990 be reported separately from areas subject to direct human-induced deforestation since 1990 that are also subject to elected activities under Article 3.4. This will ensure that carbon stock changes in areas that have been deforested since 1990 (Article 3.3) and that are subject to other elected land uses such as cropland management (Article 3.4) are not counted twice.

A Party's choice of methods for the development of an inventory of units of land subject to deforestation activities will depend on the national circumstances. For detecting deforestation areas it is *good practice* to use Approach 3 in Section 2.3.2. Section 4.2.2.2 provides a general discussion of methods for the reporting on units of land subject to Article 3.3 activities.

4.2.6.2 CHOICE OF METHODS FOR IDENTIFYING UNITS OF LAND SUBJECT TO DIRECT HUMAN-INDUCED DEFORESTATION

Annex B Parties to the Kyoto Protocol must report carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period on land areas that have been subject to direct human-induced deforestation activities since 1990 (after 31 December 1989). The definition of deforestation is given by the Marrakesh Accords.[47] Deforestation for the purposes of the Kyoto Protocol involves the conversion of forest land to non-forest land. To quantify deforestation, forest must first be defined in terms of potential height, crown cover and minimum area as already described for afforestation and reforestation activities. The same parameter values for the definition of forest must be used for determining the area of land subject to deforestation.

Once a Party has chosen its parameter values for the definition of forests, the boundaries of the forest area can be identified for any point in time. Only areas within these boundaries are potentially subject to deforestation activities. "Treed areas" that do not meet the minimum requirements of the country-specific forest definition can therefore not be deforested.

The identification of units of land subject to deforestation activities requires the delineation of units of land that

1. Meet or exceed the size of the country's minimum forest area (i.e., 0.05 to 1 ha), and
2. Have met the definition of forest on 31 December 1989, and
3. Have ceased to meet the definition of forest at some time after 1 January 1990 as the result of direct human-induced deforestation.

Units of land can only be classified as deforested if they have been subject to direct human-induced conversion from forest to non-forest land. Areas in which forest cover was lost as a result of natural disturbances are therefore not considered deforested, even if changed physical conditions delay or prevent regeneration, provided that these changes in physical conditions are not the result of direct human-induced actions. If, however, the natural disturbance is followed by a non-forest land use, then this will prevent the regeneration of forest, and the deforestation must be considered direct human induced. Forest areas that have been flooded as a result of changed drainage patterns (e.g., road construction or hydroelectric dams) and where the flooding has resulted in a loss of forest cover, are considered to be subject to direct human-induced deforestation.

Linkages with methodologies in this report and the *IPCC Guidelines* on reporting of land areas related to deforestation (conversion of forest to other land uses) in inventories under the UNFCCC are given in the box below.

BOX 4.2.4

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Forest land converted to cropland, grassland, settlements, wetland, other land since 1990 as determined through Approach 3 in Chapter 2.

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

---

[47] Paragraphs 1(d), 3 and 5, respectively, in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, pp.58-59:

"Deforestation" is the direct human-induced conversion of forested land to non-forested land.

For the purposes of determining the area of deforestation to come into the accounting system under Article 3, paragraph 3, each Party shall determine the forest area using the same spatial assessment unit as is used for the determination of afforestation and reforestation, but not larger than 1 hectare.

Each Party included in Annex I shall report, in accordance with Article 7, on how harvesting or forest disturbance that is followed by the re-establishment of a forest is distinguished from deforestation. This information will be subject to review in accordance with Article 8.

4.2.6.2.1 DISCRIMINATING BETWEEN DEFORESTATION AND TEMPORARY LOSS OF FOREST COVER

Parties must report on how they distinguish between deforestation and areas that remain forests but where tree cover has been removed temporarily[48], notably areas that have been harvested or have been subject to other human disturbance but for which it is expected that a forest will be replanted or regenerate naturally. It is *good practice* to develop and report criteria by which temporary removal or loss of tree cover can be distinguished from deforestation. For example, a Party could define the expected time periods (years) between removal of tree cover and successful natural regeneration or planting. The length of these time periods could vary by region, biome, species and site conditions. In the absence of land-use change, such as conversion to cropland management or construction of settlements, areas without tree cover are considered "forest" provided that the time since forest cover loss is shorter than the number of years within which tree establishment is expected. After that time period, lands that were forest on 31 December 1989, that since then have lost forest cover due to direct human-induced actions and that failed to regenerate, are identified as deforested and the carbon stock changes and non-CO_2 greenhouse gas emissions for this land are to be recalculated and added to those of other deforested areas.

Although the loss of forest cover is often readily identified, e.g., through change detection using remote sensing images, the classification of this area as deforested is more challenging. It involves assessing the unit of land on which the forest cover loss has occurred, as well as the surrounding area, and typically requires data from multiple sources to supplement the information that can be obtained from remote sensing. In some cases a new land use can be determined from remote sensing images, for example where it is possible to identify agricultural crops or infrastructure such as houses or industrial buildings. Information about actual or planned land-use changes and actual or planned forest regeneration activities can be used to distinguish deforestation from temporary loss in forest cover. Where such information is missing or unavailable, only the passage of time will tell whether or not the cover loss is temporary. In the absence of land-use change or infrastructure development, and until the time for regeneration has elapsed, these units of land remain classified as forest. Note that this is consistent with the approach suggested for afforestation and reforestation, i.e., units of land that have not been confirmed as afforested/reforested remain classified as non-forest land. A Party may also choose a more conservative approach. It could calculate, based on regional averages or other data, the proportion of the lands without forest cover that is expected not to regenerate to forest and assign this proportion of the area to lands subject to deforestation.

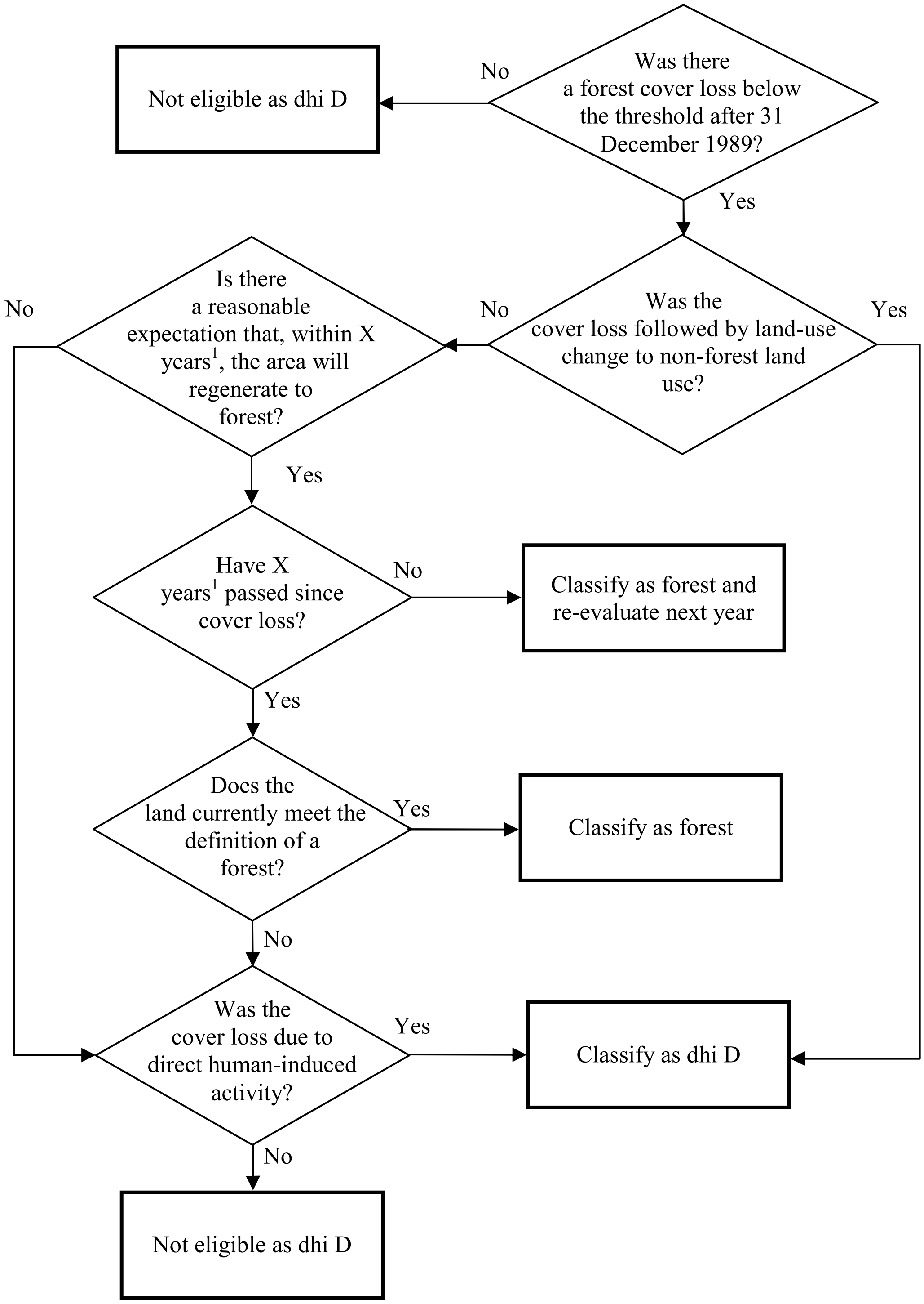
Regardless of the approach selected, it is *good practice* for Parties to identify and track the units of land with loss of forest cover that are not yet classified as deforested, and to report on their area and status in the annual supplementary information (see Table 4.2.4b in Section 4.2.4.3) It is also *good practice* to confirm that, on these units of land, regeneration did occur within the expected time period. Units of land for which, at the end of a commitment period, no direct information was available to distinguish deforestation from other causes of cover loss, could be reassessed annually or at a minimum prior to the end of the next commitment period. If regeneration did not occur or if other land-use activities are observed, then these units of land should be reclassified as deforested and the carbon stock changes recalculated accordingly (see also Chapter 5, Section 5.6 Recalculation and time series consistency).

The task of distinguishing temporary forest cover loss and deforestation can be supported by information on harvested areas and areas subject to natural disturbances. In many countries, information on harvest cut blocks and on natural disturbance events is more readily available than information on deforestation events. Such information can be used to distinguish direct human-induced deforestation from temporary cover loss (e.g., harvest) or non-human induced disturbances (e.g., wildfire or insect outbreak). Attribution of the cause of forest cover loss to the remaining areas would be made easier and would support the identification and verification of units of land subject to deforestation.

A decision tree for determining of whether a unit of land is subject to direct human-induced deforestation is given in Figure 4.2.6.

[48] Paragraph 8(b) in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.23.

Figure 4.2.6 Decision tree for determining whether a unit of land is subject to direct human-induced (dhi) Deforestation (D)



[1] Refer to country-specific criteria for distinguishing harvesting from deforestation.

4.2.6.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK-CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

The Marrakesh Accords specify that all carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period on units of land subject to direct human-induced deforestation since 1990 must be reported. Where deforestation occurred between 1990 and the beginning of the commitment period, changes in the carbon pools after the deforestation event need to be estimated for each inventory year of the commitment period. Post-disturbance losses during the commitment period will result primarily from the continuing decay of dead wood, litter and soil carbon remaining on the site after the deforestation event. These losses can be offset by increases in biomass pools.

If the deforestation occurs during the commitment period, biomass carbon stocks will decrease but, depending on deforestation practices, some of this biomass may be added to litter and dead wood pools. Their increase can initially partly offset biomass carbon losses and delay emissions. In subsequent years, carbon is likely to be released from litter and dead wood pools through decay or burning.

On areas subject to Article 3.3 activities, gross-net accounting rules are applied[49] and information on carbon stock changes in the base year (i.e., 1990) is therefore not required. Only the net changes in ecosystem carbon stocks and the non-CO_2 greenhouse gas emissions during each year of the commitment period are estimated and reported.

For the estimation of carbon stock changes, it is *good practice* to use the same or a higher tier than is used for estimating emissions from forest conversion in Sections 3.3.2/3.4.2/3.5.2/3.6/3.7.2 (Conversion from forest to any other broad land-use category).

Carbon stock changes on lands subject to deforestation activities during the commitment period can be estimated by determining the carbon stocks in all pools prior to and after the deforestation event. Alternatively, the stock changes could be estimated from the carbon transfers out of the forest, e.g., the amount harvested or the fuel consumed in the case of burning. For deforestation events that occur prior to the commitment period, knowledge of pre-deforestation carbon stocks will also be useful for the estimation of post-disturbance carbon dynamics. For example, estimates of emissions from decay of litter, dead wood, and soil organic carbon pools can be derived from data on pool sizes and decay rates. Information about pre-deforestation carbon stocks can be obtained from forest inventories, aerial photographs, satellite data, by comparison with adjacent remaining forests, or can be reconstructed from stumps where these are remaining on the site. Information on the time since deforestation, on the current vegetation and on management practices on that site is required for the estimation of carbon stock changes and non-CO_2 greenhouse gas emissions.

Where units of land subject to deforestation become land under cropland management or grazing land management, the established methodologies described in relevant sections of this report (Sections 3.3 Cropland, 3.4 Grassland, 4.2.8 Cropland management, 4.2.9 Grazing land management and 4.2.10 Revegetation) should be used to estimate carbon stocks changes. The estimation of carbon stock changes on lands going to other categories is covered in sections 3.5 to 3.7. Several of these categories may contain little or no carbon, or the change in carbon may be very small. Box 4.2.5 summarises links with methodologies on estimation of carbon stock changes and non-CO_2 emissions in this report and with the *IPCC Guidelines.*

BOX 4.2.5

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Chapter 3 sections on "lands converted to …" (only portion that comes from forest). (Sections 3.3.2, 3.4.2, 3.5.2, 3.6, 3.7.2 and related Appendices).

LINKS WITH THE *IPCC GUIDELINES*

5 B — CO_2 emissions and non-CO_2 emissions from burning and decay of biomass from Forest and grassland conversion (only portion that comes from forest)

5 D — CO_2 emissions and removals from soils (only D portion)

The default methodologies in *IPCC Guidelines* do not cover belowground biomass and dead organic matter.

[49] Except for Parties that fall under the provisions of the last sentence of Article 3.7.

4.2.7 Forest Management

This section addresses specific methods for the identification of areas subject to forest management and the calculation of carbon stock changes and non-CO_2 greenhouse gas emissions for these areas. This section should be read in conjunction with the general discussion in Sections 4.2.2 to 4.2.4.

4.2.7.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

Under the Marrakesh Accords, "Forest Management" is defined as "*a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner*"[50]. It includes both natural forests and plantations meeting the forest definition in the Marrakesh Accords with the parameter values for forests that have been selected and reported by the Party. Parties must decide by 31 December 2006 whether to include forest management in their national accounts and document their choices in the submission to the UNFCCC Secretariat.

There are two approaches conceivable that countries could choose to interpret the definition of forest management. In the narrow approach, a country would define a system of specific practices that could include stand-level forest management activities, such as site preparation, planting, thinning, fertilization, and harvesting, as well as landscape-level activities such as fire suppression and protection against insects, undertaken since 1990. In this approach the area subject to forest management might increase over time as the specific practices are implemented on new areas. In the broad approach, a country would define a system of forest management practices (without the requirement that a specified forest management practice has occurred on each land), and identify the area that is subject to this system of practices during the inventory year of the commitment period. [51]

Section 4.2.2 (Generic methodologies for area identification, stratification and reporting) explains that the geographical location of the boundaries of the areas containing land subject to forest management activities need to be defined and reported. Two reporting methods are outlined in Section 4.2.2.2.

In Reporting Method 1 a boundary may encompass multiple forest management lands and other kinds of land use such as agriculture or unmanaged forests. Any estimates of carbon stock changes resulting from forest management are for the forest management areas only. In Reporting Method 2, a boundary defines 100% forest management land without other kinds of land-use. In Reporting Method 2, a Party identifies the geographic boundary of all lands subject to forest management throughout the country.

The Marrakesh Accords also specify that lands subject to forest management (Article 3.4) that are also subject to Article 3.3 activities (in this case only afforestation and reforestation) be reported separately from those lands that are subject to forest management only.

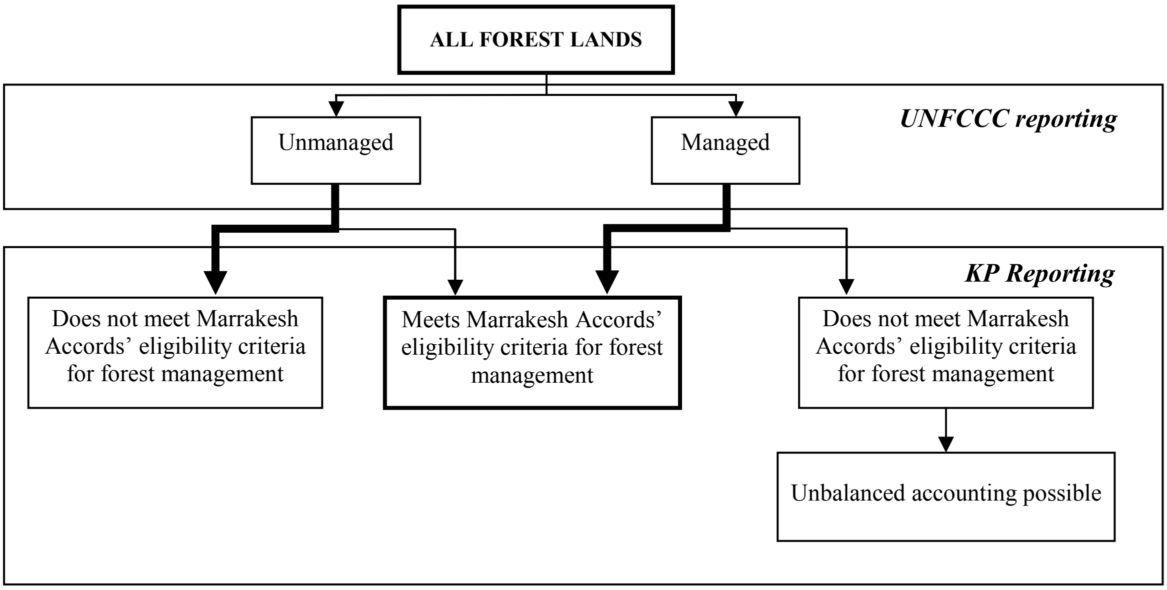
4.2.7.2 CHOICE OF METHODS FOR IDENTIFYING LANDS SUBJECT TO FOREST MANAGEMENT

Land subject to "Forest Management" as defined by the Marrakesh Accords is not necessarily the same area as "managed forests" in the context of the *IPCC Guidelines* used for UNFCCC reporting. The latter includes all forests under direct human influence, including forests that may not meet the requirements of the Marrakesh Accords. Most of the forest area that is subject to forest management under Article 3.4 of the Kyoto Protocol would also be included in the area of "managed forests" of a Party. The relationships are summarized in Figure 4.2.7.

[50] See paragraph 1 (f) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

[51] In practice, the two approaches could lead to very similar results. For example, if the narrow approach includes landscape-level activities such as fire suppression, then the area subject to these and other forest management activities could be the same as the one resulting from the application of the broad approach.

Figure 4.2.7 Relationship between different forest categories. Some of these lands may also be subject to activities under Article 3.3 (afforestation or reforestation) as outlined in Figure 4.1.1. Thick arrows indicate where the majority of the area included in a particular category for UNFCCC reporting is likely to be included for Kyoto Protocol reporting. See Sections 4.2.7 and 4.2.7.1 for further explanations.



It is *good practice* for each Party that elects forest management to provide documentation of how it applies the Marrakesh Accords' definition of forest management in a consistent way, and how it distinguishes areas subject to forest management from areas that are not. Examples of country-specific decisions include the treatment of tree orchards or grazing lands with tree cover. It is *good practice* to base the assignment of land to activities using criteria of predominant land use.

Figure 4.2.7 outlines the relationship between different forest categories. For UNFCCC reporting, countries have subdivided their forest area into managed forests (those that are included in the reporting) and unmanaged forest (not included). The managed forests could further be subdivided into those areas that meet the Marrakesh Accords' eligibility criteria for forest management activities and those (if any) that do not.

Since most countries have in place policies to manage forests sustainably, and/or use *practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner*[52], the total area of managed forest in a country will often be the same as the area subject to forest management. It is *good practice* to define the national criteria for the identification of land subject to forest management such that there is good agreement between the area of managed forest (as reported under the UNFCCC) and the area of forest subject to forest management. Where differences occur between the two, these should be explained and the extent of the differences should be documented. In particular, where areas that are considered managed forest are excluded from the area subject to forest management, the reason for the exclusion should be provided, to avoid the perception of unbalanced accounting (Figure 4.2.7). Unbalanced accounting can occur if areas that are considered a source are preferentially excluded and areas considered a sink are included in the national reporting. The IPCC Report on *Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types* further addresses the issue of unbalanced accounting.

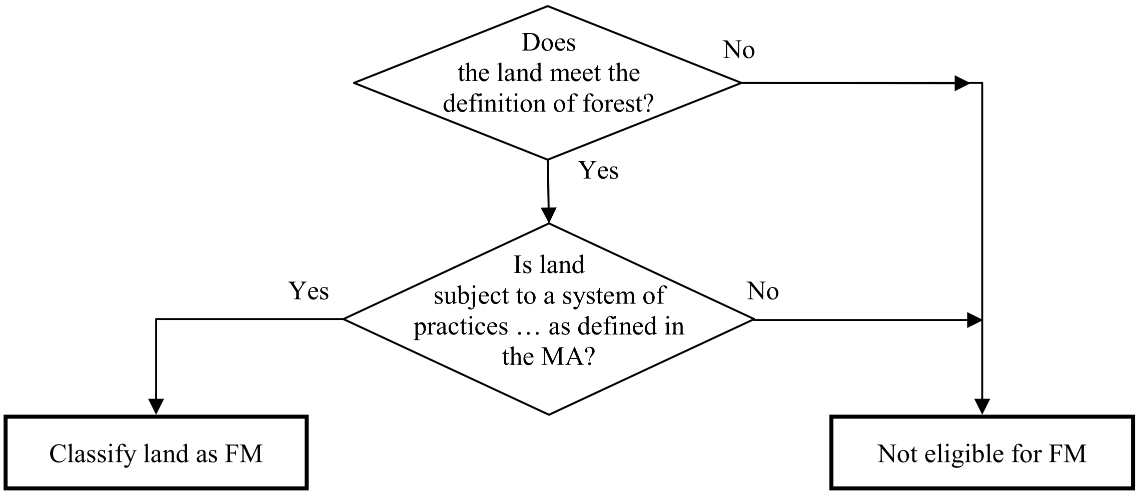
There may be national circumstances that justify the designation of areas that have been considered "unmanaged forest" for UNFCCC reporting as land subject to forest management under the Kyoto Protocol. For example, a Party may have chosen to exclude forested national parks from the area of managed forest because they are not contributing to the timber supply. But where these parks are managed to fulfil relevant ecological (including biodiversity) and social functions, and are subject to forest management activities such as fire suppression, a

[52] See paragraph 1(f) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

country may choose to include these forested national parks as lands subject to forest management (Figure 4.2.7). In such cases, the country should consider including all areas subject to forest management activities in its managed forest area for future UNFCCC reporting years.

Figure 4.2.8 gives the decision tree for determining whether land qualifies as subject to forest management. Land that is classified as subject to forest management must meet the country's criteria for forest. It is possible that more than one direct human activity impacts the land. In such cases, national criteria need to be developed by which such lands are consistently assigned to the appropriate categories.

Figure 4.2.8 Decision tree for determining whether land qualifies as being subject to Forest Management



It is *good practice* to develop clear criteria for the distinction between land subject to forest management, and land subject to other Article 3.4 activities, and to apply these criteria consistently across space and time. For example, forest areas that are predominantly managed for grazing could be included under forest management or grazing land management, but not both. Similarly, fruit orchards can meet the definition of forest, but be under cropland management. It is *good practice* to consider the predominant human influence on land when deciding its classification. Whether land is classified under forest management, or grazing land management/cropland management has implications for the accounting rules that apply, as outlined in Table 4.1.1.

It is *good practice* for each Party to describe its application of the definition of forest management and to delineate boundaries of the areas that encompass land subject to forest management in the inventory year of the commitment period. In most cases, this will be based on information contained in forest inventories including criteria such as administrative, zoning (e.g., protected areas or parks) or ownership boundaries, since the difference between managed and unmanaged forests or, possibly, between managed forest meeting the Marrakesh Accords definition of forest management and managed forest not doing so, may be difficult or impossible to detect by remote sensing or other forms of observation. Lands subject to afforestation and reforestation activities that also qualify as forest management lands must be identified separately from those areas meeting only the criteria of Article 3.3 or those only subject to forest management under Article 3.4. Identification of these areas reduces the possibility of double counting.

The area of land subject to forest management can increase (or decrease) over time. For example, if a country expands its road infrastructure into previously unmanaged forests and initiates harvesting activities, the area of land subject to forest management is increasing and the associated carbon stock changes need to be estimated accordingly. Where changes in area occur over time, it is essential that the methods for carbon stock change calculation are applied in the sequence outlined in Section 4.2.3.2. Failure to use the correct computational methods may result in an apparent but incorrect increase in carbon stocks that is the result of the area change.

Once an area has been included in the carbon stock change reporting under the Kyoto Protocol it cannot be removed, but it can change the reporting category (as outlined in Section 4.1.2). The area subject to forest management can only decrease over time when area is lost through deforestation activities. Units of land that are deforested are, however, subject to the rules of Article 3.3 and future carbon stock changes must be reported. Thus, while the area reported under Article 3.4 would be decreasing, the area reported under Article 3.3 would be increasing by the same amount.

Box 4.2.6 summarises links with methodologies in this report and with the *IPCC Guidelines* for the identification of land areas.

BOX 4.2.6

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Forest land remaining forest land in Chapter 3.

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

4.2.7.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

The methods to estimate carbon stock changes in the various pools follow those in the *IPCC Guidelines* as elaborated in Chapter 3 for above- and belowground biomass and soil organic carbon, with litter being the same as the forest floor pool and dead wood the same as coarse woody debris, both definitions as described in Chapter 3 in Table 3.1.2.

On areas subject to forest management activities, gross-net accounting rules are applied and information on carbon stock changes in the base year (i.e., 1990 in most cases) is therefore not required. Only the net changes in ecosystem carbon stocks and the non-CO_2 greenhouse gas emissions during each year of the commitment period are estimated and reported.

In general, the LULUCF sector methods of the *IPCC Guidelines* as elaborated by Chapter 3 of this report are applicable to forest management lands. They include "*any forest which experiences periodic or on-going human interventions that affect carbon stocks*" (p. 5.14, Reference Manual, IPCC, 1997). The tier structure should be applied as follows:

- Tier 1 as elaborated in Chapter 3 assumes that the net change in the carbon stock for litter (forest floor), dead wood and soil organic carbon (SOC) pools is zero, but the Marrakesh Accords specify that above- and belowground biomass, litter, dead wood and SOC should all be counted unless the country chooses not to count a pool that can be shown not to be a source. Therefore Tier 1 can only be applied if the litter, dead wood and SOC pools can be shown not to be a source using the methods outlined in the Section 4.2.3.1. Tier 1 can also only be applied if forest management is not considered a key category, which can only be the case if "forest land remaining forest land" in Chapter 3 are not a key category.
- Tier 2 and 3 methods should be applied with all pools quantified unless the Party decides to exclude those that can be shown not to be a source, using the methods described in Section 4.3.2.1.

The information requirements for Kyoto Protocol reporting can only be satisfied with the information contained in the national UNFCCC inventory if:

1. The areas subject to forest management are the same as the areas of the managed forest (Figure 4.2.8), (or where these are not the same the area and carbon stock changes of the areas subject to forest management are known), and
2. The area and carbon stock changes of the managed forest within the geographic boundaries of each of the strata used in a country are known, and
3. The area of the managed forest that was the result of direct human-induced afforestation or reforestation since 1990 is known, along with the carbon stock changes on this area.

Where it is possible to extract this information from the UNFCCC inventory, the following steps will be necessary to prepare Kyoto Protocol reporting from the Party's UNFCCC inventory:

1. Calculate and then sum the carbon stock changes for remaining forests and transitions to forest including all pools for each of the strata used in the country.
2. Subtract carbon stock changes on areas (if any) that meet the criteria for managed forests but not for forest management as defined by the Marrakesh Accords. If national circumstances lead to the situation that the area subject to forest management under Article 3.4 contains areas that are not part of the managed forest, then the carbon stock changes on this additional area have to be added.

3. Subtract the carbon stock changes on units of land subject to afforestation and reforestation from the total remaining after Step 2, and report the results using reporting Table 4.2.5 and the means for displaying mapped information.

A possibly more practicable alternative is to calculate and sum the carbon stock changes for each stratum (the areas defined by the location of the geographical boundaries) during each year of the commitment period on all land areas that are subject to forest management. To meet the Kyoto Protocol reporting requirements, national forest carbon accounting systems should be able to track for all forest areas, whether these are classified as managed forest (UNFCCC) or subject to Articles 3.3 and/or 3.4 of the Kyoto Protocol. Such systems can then be used to calculate and report the net carbon stock changes in all relevant categories for both UNFCCC and Kyoto Protocol reporting. Such a comprehensive approach would also ensure consistency among the methods used for calculating and reporting carbon stock changes, because the same forest and land-use change inventories would be the basis for the computations used in both UNFCCC and Kyoto Protocol reporting.

Box 4.2.7 summarises links with methodologies in this report and with the *IPCC Guidelines* to estimate carbon stock changes and non-CO_2 emissions.

BOX 4.2.7

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Chapter 3 Section 3.2.1 (Forest land remaining forest land)

The area subject to forest management may not be the same as the area of "forest land remaining forest land" and estimates may have to be adjusted accordingly.

LINKS WITH THE *IPCC GUIDELINES*

5 A	Changes in forest and other woody biomass stocks (subtract all afforestation and reforestation since 1990 - as determined above - from the 5A category estimate).
5 D	CO_2 emissions and removals from soils
5 E	Other (CH_4, N_2O in managed forests)

The default methodologies in the *IPCC Guidelines* do neither cover belowground biomass, nor dead organic matter.

Methods for estimating non-CO_2 emissions from forests remaining forests are addressed in Chapter 3 (Section 3.2.1). The *good practice guidance* for choosing activity data and emission factors for the estimation of non-CO_2 emissions as discussed in Chapter 3 also applies to forest management lands.

4.2.8 Cropland Management

4.2.8.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

"Cropland management" is the system of practices on land on which agricultural crops are grown and on land that is set-aside or temporarily not being used for crop production.[53] It is *good practice* to include, in land subject to cropland management, all the lands in category (ii) of the land-use (LU) system of Chapter 2 (Section 2.2 Land-use categories), namely Cropland/arable/tillage.

To be included under cropland management are all lands under temporary (annuals) and permanent (perennials) crops, and all fallow lands set at rest for one or several years before being cultivated again. Perennial crops include trees and shrubs producing fruits, such as orchards (see exceptions below), vineyards and plantations such as cocoa, coffee, tea and bananas. If these lands meet the threshold criteria for forests (see Footnote 6 in Section 4.1 for the definition of "forest" given in the Marrakesh Accords), it is *good practice* to include them under cropland management or forest management, but not under both. Rice paddies are also included under croplands, but associated methane emissions will be reported under the Agriculture Sector and not in the LUCF sector in countries' greenhouse gas inventories, as described in the *IPCC Guidelines* and *GPG2000.* Treed areas such as orchards or shelterbelts that were established after 1990 and meet the definition of a forest can qualify as afforestation/reforestation, and if they do, can be included under those categories (see Section 4.1.2 General rules for categorization of land areas under Articles 3.3. and 3.4). Arable land, which is normally used for cultivation of temporary crops but is temporarily used for grazing, can also be included under croplands.[54]

Given the potential diversity in national land use classification systems, it is *good practice* for countries to specify what types of lands are included under cropland management in their national land use system and how they are distinguished from grasslands/rangelands/pastures (as in land-use category (iii) described in Section 2.2) and from the lands subject to afforestation/reforestation, forest management, grazing land management and revegetation they are (or might be) reporting. For example, it is *good practice* to specify whether and to what extent orchards or shelterbelts are included under cropland management. This will enhance the transparency of the reporting and the comparability across Parties.

To use the proposed methodology for determining carbon stock changes on those lands, the total cropland area needs to be subdivided into areas under various sets of management practices (which may overlap both in time and space) for the base year and each of the years in the commitment period. The carbon emission and removal factors depend on both the current and previous management on the land. Some areas may be emitting CO_2, some may be sequestering carbon, others may be in equilibrium, and this may change if management changes.

To obtain more disaggregated data on land uses and practices, a more comprehensive set of definitions of land-use and management systems within croplands for different climatic zones, such as those given in the *IPCC Guidelines,* is needed. Broad families of practices under cropland management that affect carbon stocks include tillage practices, rotations and cover crops, fertility management, plant residue management, erosion control and irrigation management (IPCC, 2000b, p.184). Further details can be found in Chapter 3 of this report.

4.2.8.1.1 1990 BASE YEAR

Cropland management, grazing land management and revegetation activities under Article 3.4 require net-net accounting.[55] For this purpose, greenhouse gas emissions and removals in the base year must be reported for any of these Article 3.4 elected activities (cropland management, grazing land management and revegetation). This entails determining the total areas on which each of the activities occurred in the base year and calculating the carbon stock changes for those areas. The non-CO_2 greenhouse gas emissions are covered in the Agriculture sector of the *IPCC Guidelines* in 1990 for those areas (see the text on non-CO_2 gases in this section and Box 4.1.1, Examples 1 and 2 in Section 4.1.2).

[53] Paragraph 1(g) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

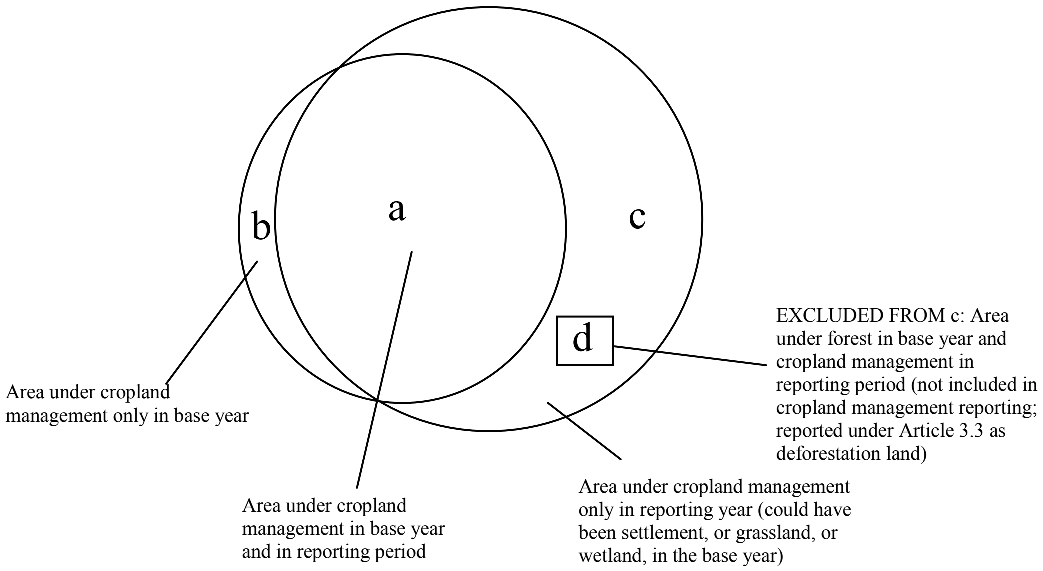
[54] http://www.unescap.org/stat/envstat/stwes-class-landuse.pdf

[55] Net-net accounting refers to the provisions of paragraph 9 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.59-60.

If the area under an Article 3.4 activity changes significantly between the base year and the commitment period, this may lead to unbalanced estimates (that is, subtraction of stock changes on a land base that changes in size over time (see Box 4.2.8)).

BOX 4.2.8
AN EXAMPLE OF CROPLAND MANAGEMENT AREAS IN 1990 AND THE COMMITMENT PERIOD (NET-NET ACCOUNTING)

In this example the area under cropland management in the base year expands to a larger area in the reporting year during the commitment period. Some of the area was under cropland management in both the base year and during the reporting period (a). Some of the area under cropland management in the base year is no longer under cropland management in the reporting year (b). There are also areas under cropland management in the reporting year that were not under cropland management in the base year (c). Area (d) is under cropland management, but was subject to deforestation which takes precedence. Under the Kyoto Protocol, the emissions and removals in areas (a) + (b) in the base year are compared to emissions and removals in areas (a) + (c) – (d) in the reporting year.



This approach avoids having to track the carbon stock changes arising from activities not covered by the Marrakesh Accords. Like other alternatives, it may have some policy implications. For example, a simple change in area without a change in stock change per unit area could yield a credit or debit without there being an actual loss or gain by the atmosphere.

For most Parties with commitments under Annex B of the Kyoto Protocol, the base year is 1990. But under the provisions of Article 4.6 of the UNFCCC, Parties with economies in transition (EITs) are granted some flexibility on the level of historical emissions chosen as a reference. As a consequence five EITs have a base year or period between 1985 and 1990 and hence they will need to assess the CO_2 and other greenhouse gas emissions and removals for those years. Historical data on land-use and management practices in 1990 (or appropriate year) and in years prior to 1990 are needed to establish the 1990 base year net emissions/removals of soil carbon from cropland management. Using the method described in Chapter 3 (Section 3.3.1.2.1.1. Change in Carbon stocks in soils – Mineral soils), land-use/land management change is assumed to have an impact for 20 years; hence, in this approach, the net carbon stock change in 1990 is calculated from management during 1970 to 1990. If area and activity data are available for 1970 to 1990, the net carbon stock change during the 1990 base year can be established using the default carbon emission and removal factors as described above. The duration of impact may be shorter or longer than 20 years. It is *good practice* to use a more appropriate time period, based on country-specific data and measurements (see Tier 2 and Tier 3 approaches in Section 4.2.8.3.1). If area and activity data are not available for 1970 to 1990 (or other appropriate time period) there is no historical data upon which to establish carbon stock change during the base year (1990), which will therefore have to be reconstructed from other data if cropland management is selected for the first commitment period.

The estimate of soil carbon stock change in the base year has a pronounced effect in net-net accounting. Where reliable data are not available for 1970 to 1990 (or other applicable time period), countries can choose the most appropriate of the following options:

- Choose not to elect cropland management as an activity under the Kyoto Protocol for the first commitment period.
- Report an emission (loss of carbon) for 1990 (or appropriate base year) *only* if it can be verified that the land was, in the 20 years prior to the base year, subject to a management change (e.g., cultivation of previously-forested lands) that leads to loss of soil carbon.
- Use a default emission/removal factor of '0' for 1990 if it can be shown that there have been few changes in management practices on the applicable land in the 20 years prior to 1990.
- Use data from another year shown to be a reliable proxy for the base year (e.g., 1989 in place of 1990). The proxy year should be as close to 1990 as possible and, all else being equal, preference should be given to a more recent year.
- Use a country-specific methodology, shown to be reliable, to estimate base year soil carbon stock change in 1990. It is *good practice* to verify that this methodology does not over- or underestimate emissions/removals in the base year (see discussion of Tier 2 and 3 methods in Section 4.2.8.3). In most cases, these methods also require historical data on management practices prior to 1990.

This approach may sometimes result in a conservative estimate of net soil carbon stock change but, in the absence of reliable and verifiable data for calculating 1990 carbon stock change, will help avoid overestimating the net removal of carbon from the atmosphere.

4.2.8.2 CHOICE OF METHODS FOR IDENTIFYING LANDS

General guidance on identification of lands subject to cropland management is provided in Sections 4.1.1, 4.1.2, 4.2.1, and 4.2.2. Under the Marrakesh Accords, the geographical location of the boundaries of the area that encompass land subject to cropland management needs to be reported annually, along with the total land areas subject to this activity.

The geographical location of boundaries may include a spatially explicit specification of each land subject to cropland management, but does not have to. Instead, the boundaries of larger areas encompassing smaller lands subject to cropland management may be provided, along with estimates of the area subject to cropland management in each of the larger areas. In either case, the land subject to cropland management and the management thereon need to be tracked through time because the continuity of management affects carbon emissions and removals. For example, a Party wishing to claim carbon removals due to conversion to no-till of 10% of an area under cropland management must demonstrate that no-till has been practiced on the same land for that period, since carbon accumulation in mineral soil depends on continuity of no-till (and the carbon emission/removal factors have been derived for continuous no-till). The rate of carbon removal for the total area therefore depends upon whether the same 10% of land has remained under no-till or if the 10% of no-till occurs on a different portion of the area in different years; it is not sufficient merely to state that 10% of the cropland management area has been under no-till for the whole period. It is *good practice* to follow continuously the management of land subject to cropland management; this could be achieved either by continuously tracking each land subject to cropland management from 1990 until the end of the commitment period (e.g. see Section 4.2.8.1 Definitional issues and reporting requirements), or by developing statistical sampling techniques, consistent with the advice in Section 5.3, that allow the management transitions on cropland management land to be determined (see also Section 4.2.4.1 Developing a consistent time series).

At the national level criteria that could be relevant to subdivision for the purpose of stratification when setting up a sampling strategy include:

- Climate
- Soil type
- Degree of disturbance (e.g. tillage frequency and intensity)
- Level of organic input (e.g. plant litter, roots, manure, other amendments)
- Temporarily re-grassed lands (e.g. set-aside)
- Fallow lands
- Lands with woody biomass stocks (e.g. shelterbelts, orchards, other perennial plantations)

- Lands converted to croplands since 1990 (land-use change) that are not in any other land-use category.

For all resulting subcategories under cropland management, the areas derived from the conversion of forests (i.e., deforestation) since 1990, need to be tracked separately as these will be reported as units of lands subject to deforestation.

At higher tiers further subdivision of the cropland management area may be necessary.

Methods to identify croplands with adequate disaggregation may include:

- National land-use and management statistics: in most countries, the agricultural land base including croplands is usually surveyed regularly, providing data on distribution of different land uses, crops, tillage practice and other aspects of management, often at sub-national regional level. These statistics may originate, in part, from remote sensing methods.
- Inventory data from a statistically based, plot-sampling system: land-use and management activities are monitored at specific permanent sample plots that are revisited on a regular basis.

Further *good practice guidance* on identifying land areas is given in Chapter 2 (Basis for consistent representation of land areas).

Links to related methods for cropland area identification in other chapters of this report and in the *IPCC Guidelines* are given in Box 4.2.9 below:

BOX 4.2.9

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 2.3.2 (Three Approaches): Croplands that remain croplands or any conversion that leads to croplands in Chapter 2 (except forests to croplands). *Should include all transitions between 1990 (or 1970, where required for base year estimate) and 2008, and in later inventory years transitions on an annual basis.*[56]

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

4.2.8.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

For croplands, the *IPCC Guidelines* identify three potential sources or sinks of CO_2 from agricultural soils:

- Net changes in organic carbon stocks of mineral soil associated with changes in land use and management
- Emissions of CO_2 from cultivated organic soils
- Emissions of CO_2 from liming of agricultural soils

Total annual emissions/removals of CO_2 are calculated by summing emissions/removals from these sources (see Section 3.3.1.2).

Carbon stock changes in other pools (aboveground, belowground biomass, litter and dead wood) should be estimated if applicable (i.e., unless the Party to the Kyoto Protocol chooses not to report on a certain pool and provides verifiable information that carbon stocks are not decreasing). For most crops, annual crop biomass can be neglected, but trees, shelterbelts and woody crops on croplands need to be accounted for either under cropland management, afforestation/reforestation or forest management. Relevant methods for estimating carbon stock changes and non-CO_2 greenhouse gas emissions from aboveground and belowground biomass, litter and dead wood can be found in the afforestation/reforestation or forest management sections (see Table 4.2.8) and Chapter 3 (see Box 4.2.10) of this report. The appropriate references are summarized in Table 4.2.8. The following sections focus largely on the soil carbon pool. For generic decision trees, guiding the choice of methods also for other subcategories, see Figures 3.1.1 and 3.1.2 in Chapter 3.

[56] If more than one land conversion occurs on the same land in the transition period of the matrix, then the transition period may have to be shortened to reflect these transitions.

TABLE 4.2.8
SECTIONS WHERE METHODOLOGIES CAN BE FOUND FOR ESTIMATING DIFFERENT CARBON POOLS ON CROPLAND

Pools to be estimated	Section where methodologies can be found
Aboveground biomass	Section 4.2.5 (Afforestation and Reforestation) and Section 4.2.7 (Forest Management)
Belowground biomass	Section 4.2.5 (Afforestation and Reforestation) and Section 4.2.7 (Forest Management)
Litter and dead wood	Section 4.2.5 (Afforestation and Reforestation) and Section 4.2.7 (Forest Management)
Soil C	Section 4.2.8.3
Non-CO_2	*GPG2000* and Section 4.2.8.3.4 (only for emissions not covered by the *IPCC Guidelines* and *GPG2000* Agriculture chapters)

If the Party chooses not to account for a particular pool, then it needs to verifiably demonstrate that this pool is not a source. Reporting requirements for such a choice can be found in Section 4.2.3.1.

For each of the carbon pools, different methodologies are used at different tiers to estimate net carbon emissions and removals for the 1990 base year and the years during the commitment period. Since different methods may yield different estimates (with different levels of uncertainty), it is *good practice* to use the same tier and methodology to estimate carbon emissions/removals in 1990 and during the commitment period.

Methods used to estimate net soil carbon emissions and removals, both for the 1990 base year and the commitment period, are described in detail in Chapter 3. Links to pertinent methods in Chapter 3 of this report and the *IPCC Guidelines* are given in Box 4.2.10. The following sections provide a brief review of these methods already described earlier, identifying aspects specific to the Kyoto Protocol.

BOX 4.2.10

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 3.3.1.1 Change in biomass

Section 3.3.1.2 Change in carbon stocks in soils

LINKS WITH THE *IPCC GUIDELINES*

4 Non-CO_2 greenhouse gases

5 B Forest and grassland conversion (conversion of grasslands to croplands)

5 D CO_2 emissions and removals from soils

4.2.8.3.1 MINERAL SOILS

For carbon stock change from mineral soils, the decision tree in Figure 4.2.9 should be used to decide which tier to use for reporting of cropland management under the Kyoto Protocol. For Article 3.4 activities it is *good practice* to use Tier 2 or Tier 3 for reporting carbon stock changes from mineral soils, if CO_2 emissions from cropland management is a key category.

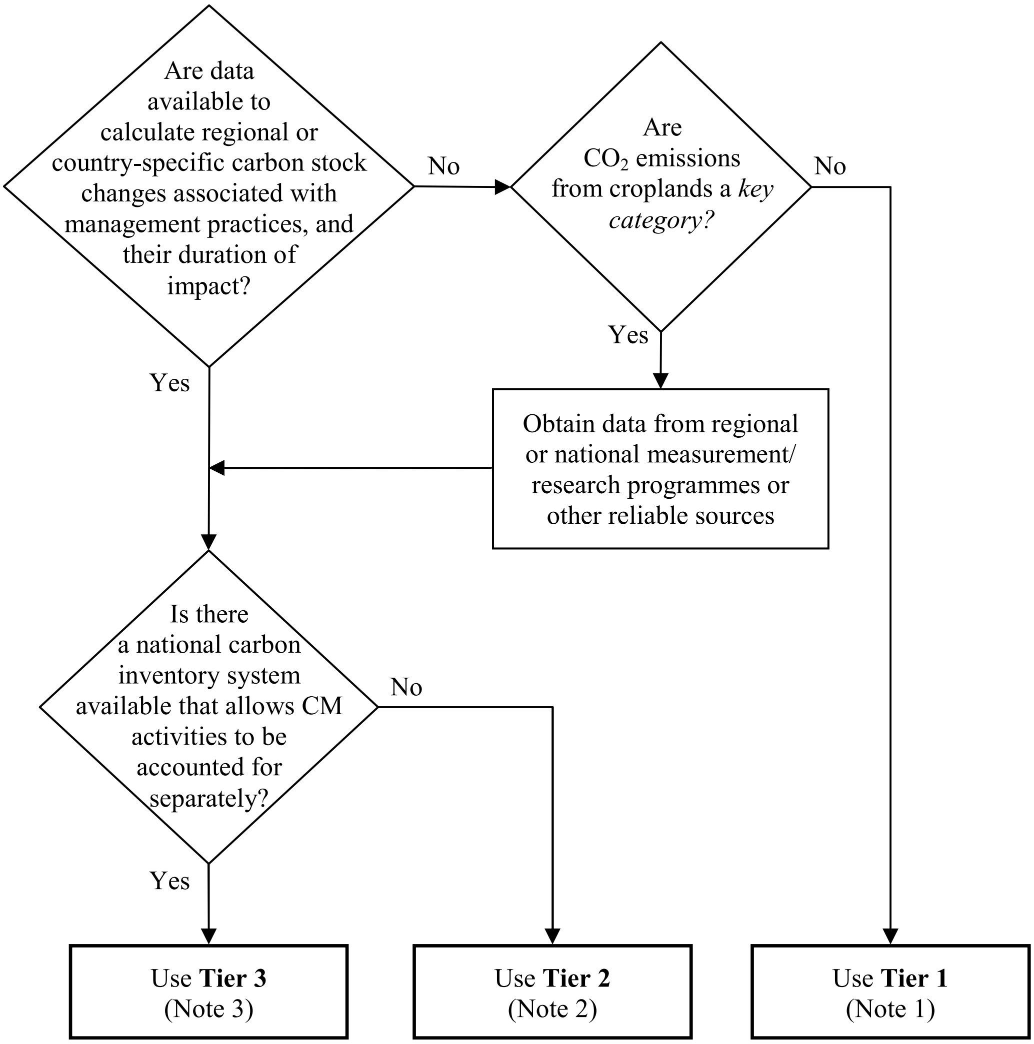
Methods for estimating carbon stock changes in mineral soils

Methods for estimating carbon stock changes fall into one of three tiers. These tiers are to be distinguished from the methods of estimating activity data (land areas). For estimating land areas, it is *good practice* to use the methods following Approach 2 or 3 (Chapter 2), taking into consideration the guidance in Section 4.2.2, for the higher tiers in Chapter 3; for estimating carbon stock changes lower tiers may be used. The decision tree in Figure 4.2.9 guides the choice of a *good practice* methodology.

Tier 1

The Tier 1 method for estimating carbon stock changes in mineral soils is described in Chapter 3 (Section 3.3.1.2: Change in carbon stocks in soils) and is based on the method outlined in the *IPCC Guidelines,* pages 5.35–5.48 of the reference manual (IPCC, 1997). The default values given in the *IPCC Guidelines*, based on a 20-year period, have been updated and used to derive annual carbon stock change factors. These are directly comparable with the Tier 1 methods used for national greenhouse gas inventories given in Chapter 3 (LUCF sector good practice guidance).

Figure 4.2.9 Decision tree for selecting the appropriate tier for estimating carbon stock changes in mineral soils under cropland for Kyoto Protocol reporting (see also Figure 3.1.1)



Note 1: Use the matrix/database of default values.

Note 2: Use regionally specific parameters, soil data and duration of impact.

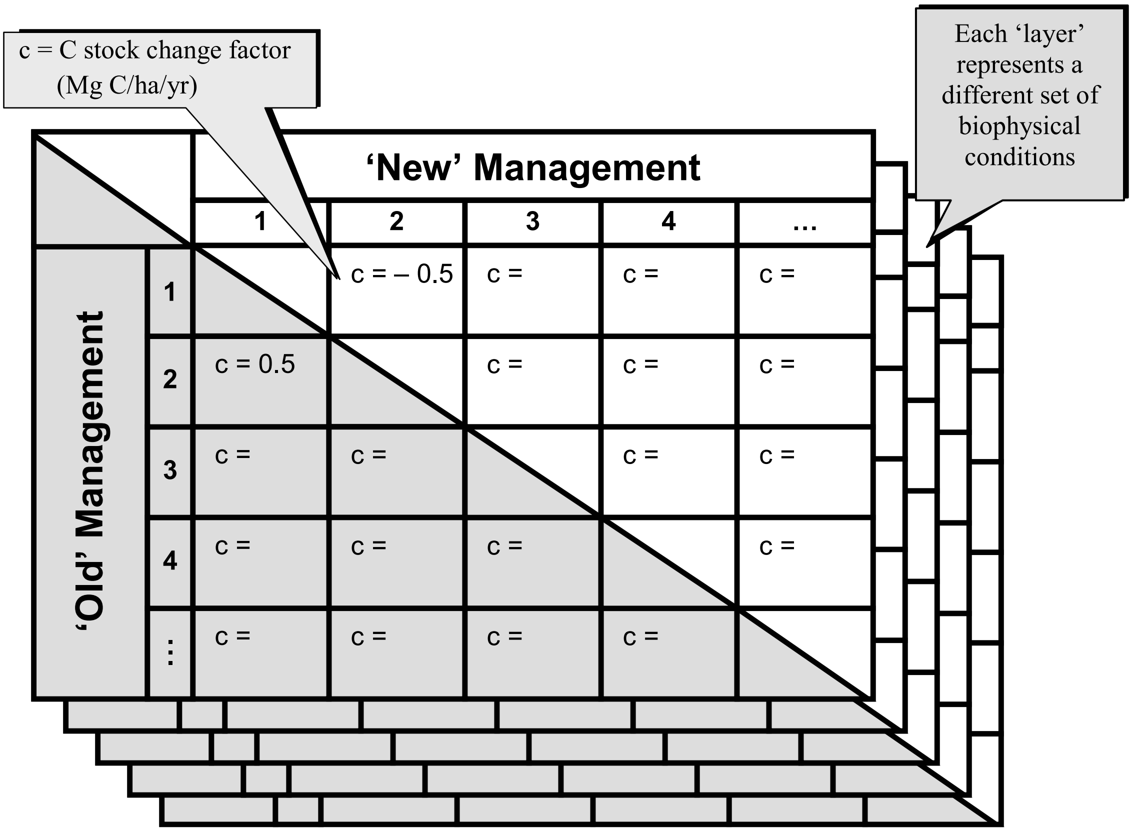
Note 3: Use more sophisticated modelling techniques, often linked to geographical databases.

It is *good practice* to follow continuously the management of land subject to cropland management. This could be achieved either by continuously tracking each land subject to cropland management from 1990 until the end of the commitment period (e.g., see Section 4.2.7.1 Definitional issues and reporting requirements), or by developing statistical sampling techniques, consistent with the advice in Section 5.3, that allow the management transitions on cropland management land to be determined (see Section 4.2.4.1 Developing a consistent time series).

Using the default values given in the *IPCC Guidelines*, average yearly rates of carbon stock change can be calculated for each soil type, climatic region and land-use or management change combination. These can be used as default annual “carbon stock change factors”[57], and can be represented in a series of tables, a matrix or a relational database. Such a system is shown schematically in Figure 4.2.10 where the numbers 1,2,3,… represent different management practices.

[57] See also footnote 32 above.

Figure 4.2.10 Conceptual illustration of the matrix of carbon stock change factors derived for different land-use, land-management transitions for each set of biophysical combinations. These could be accessed via tables or a relational database. For Tier 1, default values (see text above) are used for the carbon stock change factor. Default values for management shifts in opposite direction are the same, but of opposite sign. For example, if a shift from management practice 1 to management practice 2 has a carbon stock change factor of -0.5, then a shift from management practice 2 to management practice 1 has a factor of + 0.5.



The yearly carbon stock change factor will often be more accurate than the default values for absolute carbon stocks.[58]

These default carbon stock change factors have been compiled into a database so that default factors can be accessed for each soil type, input level and land-use and land-management transition considered in the *IPCC Guidelines* without referring to multiple tables. The database can be found in Annex 4A.1 (Tool for Estimation of Changes in Soil Carbon Stocks associated with Management Changes in Croplands and Grazing Lands based on IPCC Default Data) on the attached CD-ROM (including instructions on how to use the database).

Calculating annual carbon stock change factors

The *IPCC Guidelines* assume a linear change in soil carbon stocks over a 20-year period after a change in management, moving the soil carbon stock from an equilibrium position at t_0 (year of management change) to another equilibrium position at t_{20} (20 years after the change in management). The rate of carbon stock change therefore is assumed to remain constant for the first 20 years after a management change and then becomes zero as a new equilibrium has been reached.

[58] The carbon stock change factor reflects a change in carbon stocks, which is much smaller than the absolute carbon stock; the change in carbon stocks can be reasonably correct even if the absolute values are not.

The method for calculating annual carbon stock change factors is described in Chapter 3 (Section 3.3.1.2; Equation 3.3.3). For a summary of the steps and a sample calculation, see Section 3.3.1.2.1.1: Choice of method (mineral soils).

Calculation of carbon stock change resulting from cropland management

Carbon stock change can be used to calculate a yearly emission/removal of carbon for up to 20 years after a land-use or land-management change by multiplying the carbon stock change factor by the area to which the change has been applied as follows:

EQUATION 4.2.1
ANNUAL SOIL CARBON EMISSIONS/REMOVALS FROM CROPLAND MANAGEMENT

$$\Delta C_{CM\ SOC} = CSF \bullet A$$

Where:

$\Delta C_{CM\ SOC}$ = annual change in carbon stock in soil organic carbon, Mg C yr^{-1}

CSF = carbon stock change factor, Mg C ha^{-1} yr^{-1}

A = area, ha

(See also Equation 3.3.4 in Chapter 3)

For net-net accounting, the calculation shown in Equation 4.2.1 has to be performed for both the base year and reporting year. For discussion of the applicable area, see Section 4.1.2 (General rules for categorization of lands areas under Articles 3.3 and 3.4).

Tier 2

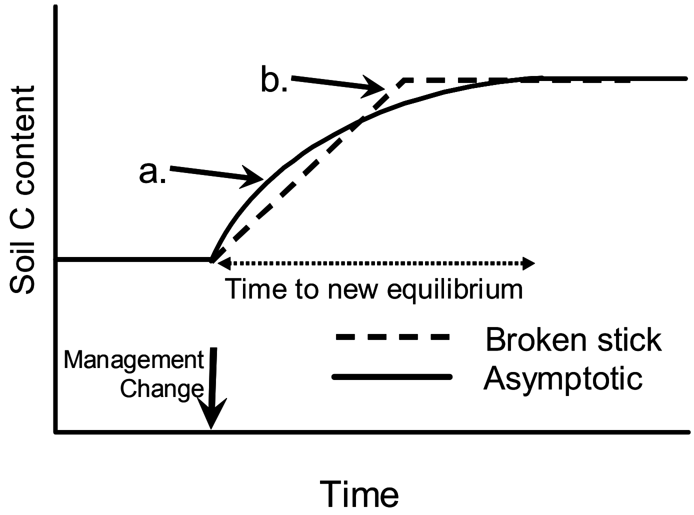
The Tier 2 method also uses the methodology described in the *IPCC Guidelines* (Reference Manual and Workbook), but now the default factors are replaced with country- or region-specific values shown to be more reliable (e.g., from literature values, long-term experiments or the local application of well-calibrated, well-documented soil carbon models). Different regional data for soil carbon content (such as that available from national soil inventories) can also be used. Similarly, it is *good practice* to replace the default value for the duration of change (20 years) with a more appropriate value, if adequate information is available to justify it.

Regionally specific or local carbon stock change factors should be better than default factors at representing actual carbon stock change in a given region. When replacing default carbon factors, rigorous criteria must be applied to demonstrate that any change in factors does not lead to under- or overestimation of the soil carbon change. Regional or country-specific factors should be based on measurements that are conducted frequently enough and over a long enough time period and with sufficient spatial density to reflect variability of the underlying biochemical processes, and documented in accessible publications.

The 20-year period over which soil carbon stock changes are assumed to change from one equilibrium position to another is an approximation: in cooler climates, changes may take more than 20 years to reach a new equilibrium (roughly 50 years); in tropical climates, a new equilibrium may be reached in shorter periods (roughly 10 years; Paustian *et al.*, 1997). At Tier 2, different regional or country-specific values for the duration of impact of land-use or land-management change can be used where these exist or can be reliably estimated.

Alternatively an asymptotic model can also be fitted to data of soil carbon stock changes (see Figure 4.2.11; compare to the "broken-stick" model used in the *IPCC Guidelines* in which a linear change occurs over 20 years after which no further change occurs). Using this method, different carbon stock change factors could be applied in different years after a land-use or management change so that stock changes are not underestimated soon after a change ("a" on Figure 4.2.11), or overestimated as the soil approaches the new equilibrium ("b" on Figure 4.2.11).

Figure 4.2.11 Schematic representation of a change in soil carbon stocks after a carbon-sequestering management change is imposed represented by a broken-stick model of stock change (as used in the *IPCC Guidelines* where the time to a new equilibrium is 20 Years) and by an asymptotic curve (for definitions of 'a' and 'b' see text)

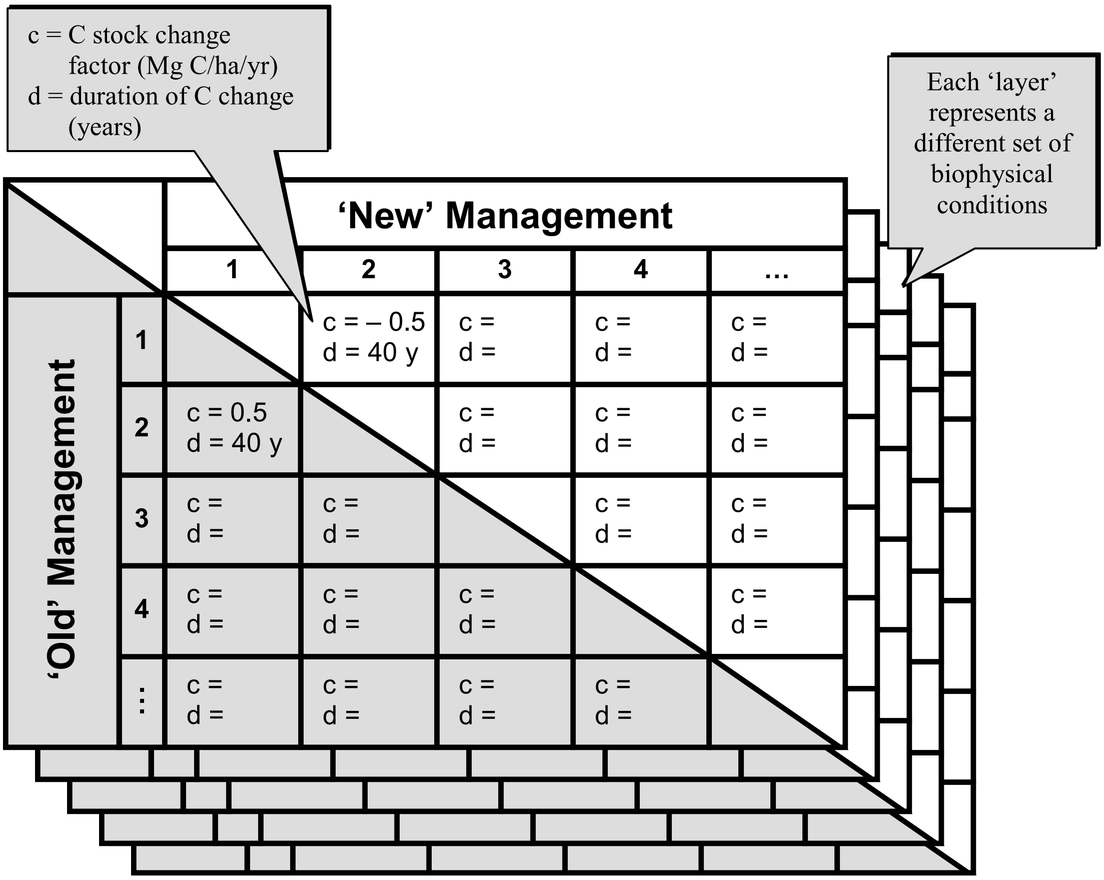


If for the duration of impact a value other than 20 years is used, this needs to be included in the matrix, as represented schematically in Figure 4.2.12.

At Tier 2, default factors (e.g., input factors) associated with a different land-use or land-management change can be replaced by more detailed relationships between the intensity of a practice (e.g., the amount of an organic amendment applied to the soil) and a change in the yearly soil carbon emissions/removals. For example, in Europe Smith *et al.* (2000) have developed such relationships (e.g., average yearly soil carbon stock change (tonnes C ha^{-1}) = 0.0145 x amount of animal manure (tonnes dry matter ha^{-1} yr^{-1}) added; recalculated from data in Smith *et al.*, 1997; $R^2 = 0.3658$, $n = 17$, $p < 0.01$). Similar relationships could be derived from long-term data for different soil types in different climatic regions. Alternatively, well-calibrated and well-evaluated models of soil carbon change (e.g., CENTURY (Parton *et al.*, 1987), RothC (Coleman and Jenkinson, 1996)) could be used to generate either stock change factors, or the intensity relationships described above, for different soils in different climatic regions.

Rigorous criteria must be applied so that any carbon stock change is not under- or overestimated. It is *good practice* that stock change factors be based on experiments sampled according to the principles set out in Section 5.3, and to use the experimental values if they are more appropriate than the default values to the region and management practice. Factors based on models should only be used after the model has been tested against experiments such as those described above and any model should be widely evaluated, well-documented and archived. It is *good practice* to provide confidence limits and/or uncertainty estimates associated with regional, country-specific or local stock change factors.

Figure 4.2.12 Conceptual illustration of the matrix of carbon stock change factors derived for different land-use, land-management transitions for each set of biophysical combinations. The Tier 2 method is extended by using regionally specific estimates of carbon factors or estimates of the duration of impact of land-use/management change. Depending on how they are calculated, carbon stock change factor (c) and duration (d) values for management shifts in opposite direction will often be the same, but the 'c' value will have opposite sign.



Tier 3

Tier 3 methods that can be used for the national UNFCCC inventory (as described in Chapter 3, Section 3.3.1.2.1.1 Choice of method) are also likely to be used for reporting under the Kyoto Protocol. Compared with the static matrix used at Tiers 1 and 2, Tier 3 can often better represent the management history of a land, allowing better calculation of soil carbon changes resulting from multiple changes in management practices over time. Furthermore soils can take much longer than 20 years to reach equilibrium, and Tier 3 (like Tier 2) methods can take this into account. Large scale computing power makes possible a spatially disaggregated system linked to management practice data which could keep track of carbon stock changes over time if linked to rate equations with carbon contents, initialised at some point and cross-checked periodically. Tier 3 can also be based on repeated statistical sampling consistent with the principles set out in Section 5.3 of sufficient density to capture the soil types, climatic regions and management practices that occur. Tier 3 methods, therefore, encompass a range of methodologies, more elaborate than Tier 2, usually based on sophisticated modeling techniques, often linked to geographical databases.

Choice of carbon stock change factors for mineral soils

The carbon emission/removal factors used at each tier are described briefly in the following sections.

Tier 1: At Tier 1, average yearly carbon stock changes in mineral soils are calculated from default values by dividing the 20-year stock change by 20, as set out in Chapter 3, Equation 3.3.3. Full details of these factors and the resulting stock change estimates can be found in the *IPCC Guidelines*, pages 5.35–5.48, and are provided in the database described in Annex 4A.1. (Default values in Annex 4A.1 are slightly modified from those in the

IPCC Guidelines). For a summary of the steps and a sample calculation, see Section 3.3.1.2.1.1, Choice of method (mineral soils).

Tier 2: At Tier 2, some or all of the default values for carbon stock change (Tier 1) are replaced by values shown to be more reliable. These new values may be based on literature values, measured changes in carbon stocks, on simple carbon models, or a combination of these. (See 'Choice of management data for mineral soils' below for some examples). It is good practice to show that the new values, compared to those they replace, are more accurate for the conditions and practices to which they are applied.

Tier 3: For mineral soils, Tier 3 carbon stock change factors are country-derived, and may be calculated using complex models. The carbon models used for Tier 3 are generally more complex than those in Tier 2, taking into account soil (e.g., clay content, chemical composition, parent material), climate (e.g., precipitation, temperature, evapotranspiration), and management factors (e.g., tillage, carbon inputs, fertility amendments, cropping system). *Good practice* requires that the models be calibrated using measurements at benchmark sites, and that models and assumptions used are described transparently.

In all cases, rigorous criteria must be applied so that any change in carbon stocks is neither under- or overestimated; models used to estimate carbon stock changes should be well-documented and should be evaluated using reliable experimental data for conditions and practices to which the models are applied. It is *good practice* to provide estimates of confidence limits or uncertainty. Default carbon stock change factors may also be replaced by values generated as part of national/regional carbon accounting systems (see Section 4.2.7.2 Choice of methods for identification of lands subject to Forest Management).

Choice of management data for mineral soils

Area data on land uses and practices need to be available in accordance with Approach 2 or Approach 3 (Section 2.3.2), and guidance given in Section 4.2.2.3. The data on management required for each of three tiers are outlined briefly here.

Tier 1: Using the IPCC Guidelines (see also Chapter 3, Section 3.3.1.2.1.1), impacts of land-use or land management change are assumed, by default, to have an impact for 20 years. If area and activity data are available for 20 years prior to the base year, a net carbon removal/emission for the base-year can be established using the default carbon stock change factors described above. The land-use changes and management practices at Tier 1 are the same as those given in the IPCC Guidelines: clearing of native vegetation with conversion to cultivated crops or pasture, land abandonment, shifting cultivation, differing residue addition levels, differing tillage systems and agricultural use of organic soils. Within these specific land-use or land-management changes, activities are defined semi-quantitatively, e.g., "high input" vs. "low input" systems. Land-use or management systems are not subdivided into finer levels of detail than this. Areas may be obtained from international data sets (e.g., FAO), though some of these sources lack the spatial explicitness needed for reporting and may only be helpful for cross-checking data. If area and activity data are available for 1970 through 1990, a 1990 baseline net carbon stock change can be established using the default carbon stock change factors described above. If area and activity data are not available for 1970 through 1990, see Section 4.2.7.2 for alternative options for estimating the land areas.

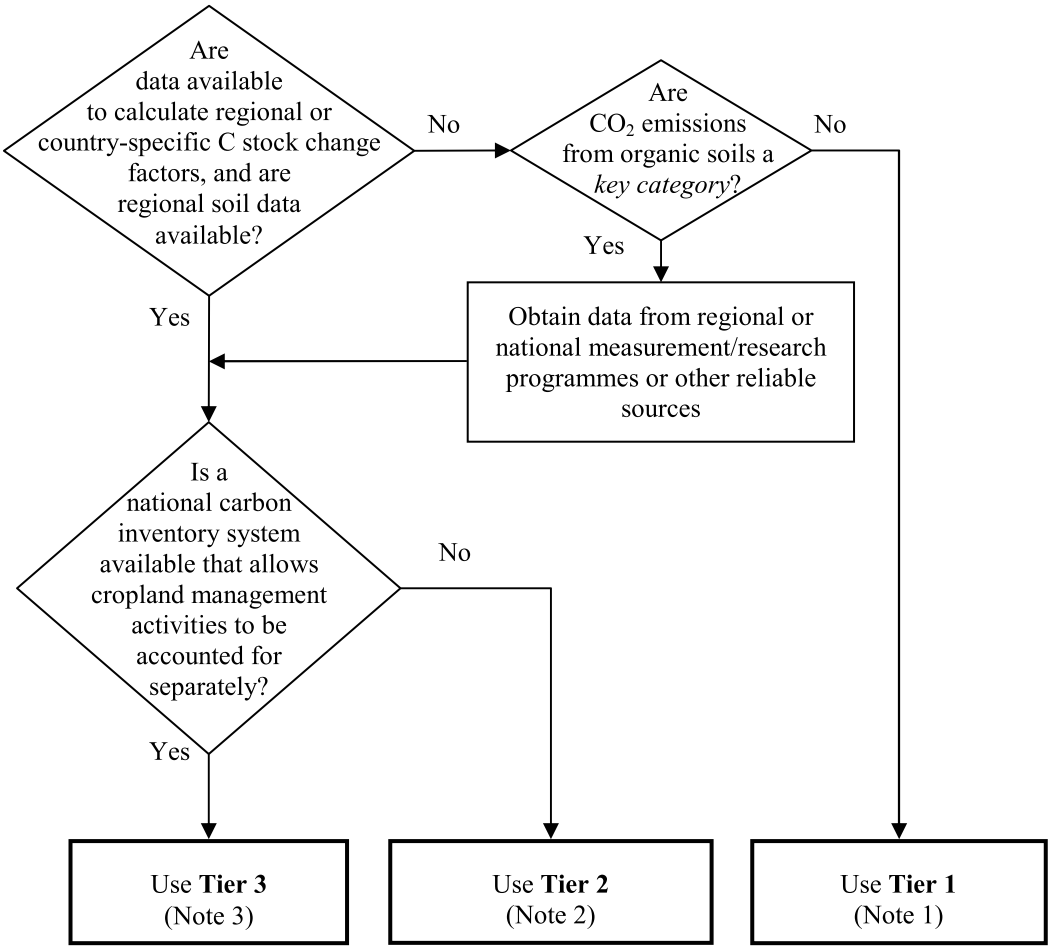
Tier 2: The management practices at Tier 2 are the same as those given in the *IPCC Guidelines* and at Tier 1. But for Tier 2, to make them country-specific, some management practices may be subdivided, or new ones may be added. Within the agricultural management systems described in the *IPCC Guidelines*, management data include descriptors such as "high input" and "low input". These descriptors can be replaced at Tier 2 by more explicit descriptors, for example, high organic amendment rates (e.g., >20 tonnes dry matter ha^{-1} yr^{-1}), medium organic amendment rates (e.g., 10-20 tonnes dry matter ha^{-1} yr^{-1}), low organic amendment rates (e.g., <10 tonnes dry matter ha^{-1} yr^{-1}), and zero organic amendment. Further subdivisions could, for example, reflect different forms of organic amendment, such as animal manure, cereal residues and sewage sludge, where corresponding removal factors are available. An alternative to the use of more detailed descriptor categories is the use of relationships similar to those derived for Europe by Smith *et al.* (1997, 1998, and 2000) and for the USA by Lal *et al.* (1998). These could be based on a new, more comprehensive analysis of global data sets. Figures could include the change in carbon stock associated with a given practice (e.g., zero till), or a relationship between intensity of a practice and soil carbon change, e.g., average yearly soil carbon emission/removal (tonnes C ha^{-1}) = 0.0145 x amount of animal manure (tonnes dry matter ha^{-1} yr^{-1}) added; recalculated from data in Smith *et al.*, (1997; $R^2 = 0.3658$, $n = 17$, $p < 0.01$). Alternatively, well-calibrated and well-evaluated models of soil carbon change (e.g., CENTURY (Parton *et al.*, 1986) RothC (Coleman and Jenkinson, 1996), or others) could be used to generate either default carbon stock change factors, or to generate the intensity relationships described above for each activity, for different soils in different climatic regions. These examples illustrate how practices can be made more country-specific, but other refinements are also possible. Tier 2 methods may require area descriptions of higher resolution than those in Tier 1. In any case, rigorous criteria must be applied so that any change in emissions or removals is neither under- nor overestimated (see 'Choice of carbon stock change factors for mineral soils' for discussion of criteria)

Tier 3: Management data used in the more complex Tier 3 methodologies need to be consistent with the level of detail required by the model. It is *good practice* to use management data at a spatial resolution appropriate for the model, and to have, or be able to estimate reliably, quantitative measures of the management factors required by the model.

4.2.8.3.2 CARBON STOCK CHANGES IN ORGANIC SOILS

For carbon stock changes in organic soils, the following decision tree (Figure 4.2.13) should be used to decide which tier to use for reporting under the Kyoto Protocol.

Figure 4.2.13 Decision tree for selecting the tier at which to report carbon stock changes in organic soils under the Kyoto Protocol (see also Figure 3.1.1)



Note 1: Use the matrix/database of default values.

Note 2: Use region-specific parameters, soil data and duration of impact.

Note 3: Use more sophisticated modelling techniques, often linked to geographical databases.

Methods for estimating CO_2 emissions/removals from organic soils

Tier 1: When organic soils are converted to agriculture, they are typically drained, cultivated, and limed, resulting in the oxidation of organic matter. The rate of carbon release will depend on climate, the composition (decomposability) of the organic matter, the degree of drainage and other practices such as fertilisation and liming. The Tier 1 method is set out in Section 3.3.1.2 which is based on the method given in the *IPCC Guidelines.*

Tier 2: If more reliable country- or region-specific data is available on CO_2 emissions from organic soils it is *good practice* to use these values instead of Tier 1 defaults. Any data used should be shown to be more reliable than defaults.

Tier 3: The complex systems described in Chapter 3 (LUCF sector good practice guidance) for national greenhouse gas inventories may use methods or models for estimating CO2. These emissions may also be used to estimate non-CO2 greenhouse gas emissions in an integrated way. However, the non-CO2 emissions should be reported in the Agriculture sector, and double counting and omission should be avoided. It is good practice to use models which are calibrated using measurements at benchmark sites, and to describe models and assumptions used transparently.

Choice of carbon emission/removal factors for organic soils

Tier 1: The default carbon emission/removal factors for Tier 1 are provided in Chapter 3 (Table 3.3.5; Section 3.3.1.2.1.2).

Tier 2: For organic soils, it is *good practice* to replace the default values identified in Chapter 3 (Table 3.3.5; Section 3.3.1.2.1.2) with country- or region-specific factors if these are shown to be more reliable than the defaults. It is *good practice* to use replacement emission/removal factors based on experimental results derived from experiments that are well-designed, with adequate sampling to give adequate statistical power. Any emission or removal factors based on models should only be used after the model has been tested against experiments, such as those described above, and any model should be widely evaluated, well-documented and archived. It is *good practice* to provide confidence limits and/or uncertainty estimates associated with any replacement emission/removal factors. Replacement emission/removal factors must be shown to better represent local conditions or practice than default factors by comparing both default and replacement factors against measurements or experiments within the region.

Tier 3: For organic soils, CO_2 and non-CO_2 greenhouse gas emissions or emissions/removals may be estimated as part of processed-based modelling using national emission/removal factors. It is *good practice* to use such methods if they have been well-documented and evaluated. Before methods are applied they should be thoroughly tested and evaluated, as described for Tier 2.

Choice of management data for organic soils

The same considerations apply as for management data for cropland management activities on mineral soils, as described earlier in Section 4.2.8.3.1.

4.2.8.3.3 CO_2 EMISSIONS FROM LIMING

Supplementary data provided for the Kyoto Protocol includes CO_2 emissions from liming of croplands only if cropland management is elected.

Methods for estimating CO_2 emissions from liming

Liming is commonly used to ameliorate soil acidification. Carbonate minerals such as limestone $CaCO_3$ and dolomite $CaMg(CO_3)_2$ are usually used. When added to acid soil these compounds release CO_2 at a rate which will vary according to soil conditions and the compound applied. Repeat applications are made every few years but can be averaged out over time and the average annual rate is the basis for inventory calculations.

Tier 1: The Tier 1 method for estimating CO_2 emissions from liming is identical to that described in Chapter 3 (Section 3.3.1.2.1.1).

Tier 2: A Tier 2 method for liming uses national or regional figures in place of the default coefficients described in Chapter 3 (Section 3.3.1.2.1.1) for soil CO_2 emissions due to liming, where these are shown to be more reliable.

Tier 3: The complex methods used at Tier 3 as described in Chapter 3 may account explicitly for liming. These may integrate effects also on non-CO_2 emissions. It is *good practice* to use such methods if they have been well-documented and evaluated.

Choice of carbon emission factors for liming

It is *good practice* to use the default values given in the Chapter 3 (Section 3.3.1.2.1.1). If a Party chooses to use alternative national emission factors (Tier 2), these should be justified by more detailed data on the composition of the lime used. Tier 3 methods may in addition include the integrated effect of liming and management practices on the non-CO_2 emissions. It is *good practice* to use such factors if they have been well-documented and evaluated.

4.2.8.3.4 NON-CO_2 GREENHOUSE GASES

Methodologies for estimating N_2O and CH_4 emissions are given in the Agriculture Chapters of the *IPCC Guidelines* and the *GPG2000*, which give methodologies for the following sources of agricultural emissions that are related to cropland management (the list also applies to grazing land management and revegetation):

1) Direct N_2O emissions from agricultural soils due to
   - Use of synthetic fertilisers,
   - Use of animal excreta as fertiliser,
   - Biological nitrogen fixation due to cultivation of legumes and other nitrogen fixing crops,
   - Crop residue and sewage sludge application,
   - Cultivation of soils with high organic content;
2) Indirect N_2O emissions from nitrogen used in agriculture, including emissions from
   - Volatilisation and subsequent atmospheric deposition of NH_3 and NO_x (originating from the application of fertilisers and manures),
   - Nitrogen leaching and runoff;
3) CH_4 emissions from rice cultivation;
4) Non-CO_2 emissions from burning of vegetation;
5) CH_4 from enteric fermentation;
6) CH_4 and N_2O emissions from manure management.

These emissions should not be reported under cropland management but as agricultural emissions[59] and are covered in Chapter 4 (Agriculture) of the *GPG2000*. Even for Parties that do not elect cropland management under Article 3.4, these emissions should be reported as emissions from sources listed in the Annex A to the Kyoto Protocol. Parties that elect cropland management should also report these emissions in the agriculture sector and not include them under Article 3.4.

Non-CO_2 emissions/removals on deforested lands converted to cropland (Article 3.3) need to be reported separately from those under cropland management (Article 3.4). If non-CO_2 emissions/removals on deforested land cannot be determined directly, they may be estimated as a fraction of total non-CO_2 emissions/removals from cropland, corresponding to the area of total cropland on deforested land. For example, if 10% of the cropland area is on deforested land, then 10% of total cropland non-CO_2 emissions/removals would be ascribed to lands that have been subject to deforestation since 1990.

Some management practices adopted to increase soil carbon may also influence the emissions of non-CO_2 gases. Many of these effects are included in the Agriculture Chapters of the *IPCC Guidelines* and *GPG2000*, but there may be other effects on non-CO_2 gases not considered in the *IPCC Guidelines* and *GPG2000* (see examples presented in Box 4.2.11).

[59] According to the Marrakesh Accords estimates of emissions from sources and removals by sinks from for Article 3.3 and 3.4 activities are to be clearly distinguished from anthropogenic emissions from the sources listed in Annex A to the Kyoto Protocol (cf. paragraph 5 in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.22).

BOX 4.2.11
EXAMPLES OF POSSIBLE INFLUENCES OF CARBON STOCK CHANGES ON EMISSIONS OF NON-CO_2 GASES

Example 1: Influence of reduced tillage on N_2O emission.
Adoption of reduced or no-tillage often increases soil carbon in croplands. However, at the same time it may also alter N_2O emissions, through effects on porosity (and the fraction of the porosity occupied by water), N cycling, temperature, and other factors (e.g., Weier *et al.*, 1996; MacKenzie *et al.*, 1998; Robertson *et al.*, 2000; Smith *et al.*, 2001). The observations are inconclusive, with some studies showing higher N_2O emission under no-till than under tilled systems, and others showing little effect or lower N_2O emissions. The available data suggest that this variable response depends on interactive effects of soil and climate, and that wetter environments with poorer aeration, in which N_2O emissions generally tend to be highest, are also associated with higher emissions under no-till than under conventional tillage (e.g., Linn and Doran, 1984; Weier *et al.*, 1996; Vinten *et al.*, 2002).

Example 2: Links between organic matter turnover and N_2O emission.
Organic matter in soil is continually decomposing, resulting in the release of ammonia, and of nitrate. A portion of this 'available' N may be converted to N_2O. Consequently, practices that increase the rate of organic matter decomposition (e.g., ploughing of grasslands, increased use of 'fallow' periods) may stimulate N_2O emissions. In contrast, re-planting grasslands and reducing 'fallow' frequency may reduce N_2O emissions. The significance and magnitude of these effects, however, are not well-understood and it may not be possible to quantify them reliably at this stage.

Example 3: Effect of cropland management on CH_4 oxidation.
Some practices that enhance soil carbon in croplands may also influence the rate of CH_4 oxidation in soils, negatively or positively (e.g., Smith *et al.*, 2001). Often these effects are smaller than those on N_2O, when expressed in units of CO_2-equivalence.

Example 4: Effect of draining organic soils.
Emissions of CH_4 may decrease as CO_2 losses increase with soil drainage, and N_2O emissions may also be affected. (Note that the *IPCC Guidelines* assume that all carbon is lost as CO_2; if this is departed from, it must be justified by scientifically sound and well-documented data. Methods for estimating N_2O emissions from cultivated organic soils are given in the Agriculture Chapters of the *IPCC Guidelines* and *GPG2000*, and these emissions should be reported as described there to avoid double-counting.).

The effects on non-CO_2 emissions of these and other management practices may be included in higher tier methods for agriculture, as noted in *GPG2000* (Section 4.7, page 4.53 to 4.66). Where estimated, they should still be reported with Agriculture, to avoid double counting. Examples of how these effects could be estimated include:

- Direct measurement of the non-CO_2 greenhouse gases at representative sites;
- Estimation of emission rates based on literature values taking into account management, soil and climate.

4.2.9 Grazing land management

4.2.9.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

Grazing land management is the system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced. Grazing lands are, by definition, 'managed' to some extent, so the lands under grazing land management are in fact potentially all the lands within a country subject to grazing; that is, all lands predominantly used for livestock production, based on criteria decided upon and explicitly described by the country. Note that not all grasslands are necessarily grazing lands.

In order to ensure a comprehensive coverage, it is *good practice* to include all of the following lands in the grazing lands category:

- Improved pastures/grasslands/rangelands: These are lands subject to intensive, controlled grazing. Management practices such as fertilizing/manuring, irrigation, reseeding, liming, or spraying are used to control productivity. Lands used permanently for herbaceous forage crops are also included.

- Unimproved/natural pastures/grasslands/rangelands: These lands are usually composed of native vegetation including hay and bushes, and grazing is mainly extensive. There is no or little grass management except burning in some instances. However, the intensity, frequency, and seasonality of grazing and animal distribution are managed (even by default) or can be specifically managed to prevent loss of stored carbon, for example by avoiding overgrazing.

Pastures, rangelands or savannahs on which trees and shrubs are grown should be included under grazing land management if the growing of forage crops or grazing is the most important activity on the area, based on criteria established and explicitly stated by the country. Where treed lands meet the definition of a forest and the trees have been established since 1990, the land should be included under the afforestation/reforestation category. However, lands that meet the definition of 'forest' can be included in grazing land management, if grazing is the dominant activity, based on the criteria established by the country.

Set-aside lands, such as cultivated lands reverted to perennial grasslands, should be included under cropland management if they are only temporarily set-aside (typically this is for 5 years or less, but any set-aside likely to return to cropland under the national conditions for set-aside should be counted as cropland). They should be included under grazing land management if they are permanently set-aside. Protected lands, such as those subject to permanent cover programmes should be included under grazing land management if they are also used for livestock production. Lands that are only temporarily used for grazing, as part of a cropping rotation, would normally be included under cropland management. For consistency, the criteria used to distinguish between cropland and grazing land and revegetation should be explicitly stated and applied consistently.

Given the potential overlap with other land-use categories, it is *good practice* for countries to specify what types of lands are included under the category grazing land/rangeland/pastures in their national land-use system. Moreover, countries should also specify how these lands differ from (a) lands in land-use category (ii) of Chapter 2 (cropland/arable/tillage), and (b) lands subject to other activities under Article 3.3 (AR) and Article 3.4 (FM, RV, CM – if elected). This will enhance the comparability of reporting across countries.

In addition, all lands that were forest on 31 December 1989 and that are subject to grazing land management in the reporting year need to be identified, tracked and reported as a separate category ('Deforestation' lands that would otherwise be subject to grazing land management).

In order to allow the application of the proposed methodology for determining CO_2 emissions/removals on those lands, (i.e., area times a carbon stock change factor, the factor being positive, negative or null depending on management and land use or land-use change), the total grazing land area needs to be subdivided into areas under various sets of management practices (which may overlap both in time and space) for the base year and the years in the commitment period. The carbon stock change factors depend on both the current and previous management. Some areas may be emitting carbon, others may be sequestering CO_2, others may be in equilibrium and this may change if management changes.

To obtain more disaggregated data on land uses and practices, a more comprehensive definition of land use and management systems within grazing lands/rangelands/pasture for different climatic zones can be developed. Broad families of practices under grazing land management that affect carbon stocks include: herd management, presence of woody plants, fertilization, irrigation, species composition, legume management, and fire management (IPCC, 2000b, p.184 and p. 205). See also Chapter 3 (LUCF sector good practice guidance) and Section 4.2.9.2 below.

4.2.9.1.1 1990 BASE YEAR

See Section 4.2.8.1 Definitional issues and reporting requirements.

4.2.9.2 CHOICE OF METHODS FOR IDENTIFYING LANDS

General guidance on identification of lands relevant to grazing land management is provided in Sections 4.1.1, 4.1.2, 4.2.1, and 4.2.2. Under the Marrakesh Accords, the geographical location of the boundaries of the area that encompass land subject to grazing land management need to be reported annually, along with the total land areas subject to this activity. The geographical location of the boundaries may include a spatially explicit specification of each land subject to grazing land management, but does not have to. This is analogous to the case for cropland management as discussed in Section 4.2.8.1 (Definitional issues and reporting requirements). It is *good practice* to follow continuously the management of land subject to grazing land management. This could be achieved either by continuously tracking each land subject to grazing land management from 1990 until the end of the commitment period (see Section 4.2.8.1), or by using statistical sampling techniques that allow the transitions of management on grazing land to be determined and that, at the same time, are consistent with the requirements of

Section 5.3 (see also Section 4.2.4.1 Developing a consistent time series). At the national level, different layers of breakdown of the total grazing land area are needed, for instance using criteria that concern primary national circumstances, management practices and other subdivisions. These could include:

- Climate
- Soil type
- Degree of disturbance (e.g., compaction, disturbance by livestock foot action, frequency of burning, erosion)
- Level of organic input (e.g., plant litter, roots, manure, other amendments)
- Lands that are intermittently grazed (e.g., set-aside, grass as part of a rotation)
- Grazing intensity (utilization percentage of the pasture)
- Treed lands (shelterbelts, orchards, other perennial plantations)
- Lands converted to grazing-lands since 1990 (land-use change) that are not in any other land-use category.

For all of the resulting subcategories the areas under grazing land management that were derived from conversion of forests (i.e., deforestation) since 1990 need to be tracked separately as these will be reported as units of lands subject to deforestation.

At Tier 3 further subdivision of the area subject to grazing land management may be necessary.

Methods to identify lands subject to grazing land management with necessary disaggregation available in some Annex I countries include the following:

- National land use and management statistics: the agricultural land base including land subject to grazing land management is surveyed in most countries on a regular basis. These may be derived, in part, from remote sensing of pasture and soil surface condition and changes in stocking rate.
- Inventory data from a plot, statistically based, sampling system: land use and management activities are monitored at specific permanent sample plots that are revisited on a regular basis.

Information on these areas would have to be compiled either for all lands affected by grazing land management or summarised as estimates for all the strata (defined by the boundaries of the areas of land) that a Party chooses to apply for the reporting of its land use statistics. Further *good practice guidance* on identifying land areas is given in Chapter 2 (Basis for consistent representation of land areas).

Links to methods for area identification in other chapters of this report and *IPCC Guidelines* are given in Box 4.2.12.

BOX 4.2.12

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 2.3.2 (Three approaches): Grasslands (unmanaged or managed) that become managed grasslands or any conversion that leads to managed grasslands in Chapter 2 (except forests to grasslands), provided that these managed grasslands are subject to grazing land management. *Should include all transitions between 1990 (or 1970, where required for base year estimate) and 2008, and in later inventory years transitions on an annual basis.*[60]

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

[60] If more than one land conversion happens on the same unit of land in the transition period of the matrix, then the transition periods may have to be shortened to account for these transitions.

4.2.9.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

Like for cropland management, methodologies at one of three tiers are used for estimating CO_2 emissions/removals from mineral soils, organic soils and liming. The procedure is identical with different factors being derived and different activity data being used (as described in more detail in the sections below).

Total annual soil emissions/removals of CO_2 are calculated by summing:

- Net changes in organic carbon stocks of mineral soils
- Emissions of CO_2 from organic soils
- Emissions of CO_2 from liming

Carbon stock changes also need to be estimated for other carbon pools, as appropriate. For grazing lands with no woody vegetation, annual crop biomass can be neglected where there is no long-term change in the cover. However, carbon in biomass of trees, shelterbelts and woody crops on grazing lands need to be accounted for under either (but not both) grazing-land management, afforestation/reforestation or forest management (unless an Annex I Party to the Kyoto Protocol chooses not to and provides verifiable information that carbon stocks are not decreasing). Methods for above- and belowground biomass, litter and dead wood can be found in the afforestation/reforestation or forest management sections and Chapter 3 (LUCF sector good practice guidance) of this report. For guidance in estimating carbon emissions/removals in pools other than in the soil, see Box 4.2.13 and Table 4.2.8. Figure 3.1.1 in Chapter 3 provides further guidance on selecting appropriate methods.

BOX 4.2.13

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 3.4.1.1 Change in biomass

Section 3.4.1.2 Change in carbon stocks in soils

LINKS WITH THE *IPCC GUIDELINES*

4 Non-CO_2 greenhouse gases

5 B Forest and grassland conversion (conversion of grazing lands to croplands)

5 D CO_2 emissions and removals from soils

4.2.9.3.1 MINERAL SOILS

The decision tree used for selecting the tier for estimating carbon stock changes in mineral soils under grazing land management is analogous to the one used for croplands – see Figure 4.2.9 above.

Methods for estimating carbon stock changes in mineral soils

The methods used for estimating carbon stock changes in mineral soils under grazing land management are identical to those used for croplands. See the methods under Tiers 1, 2 and 3 described in Section 4.2.8.3.1 (Mineral soils) and also in Chapter 3 (Sections 3.3.1.2, 3.4.1.2, 3.4.2.2). As for cropland management all methods require that the lands subject to grazing land management be tracked continuously through time. At Tier 1, the database of default annual stock change factors in Annex 4A.1, is applicable also for grazing lands (see Section 4.2.8.3.1). However, for Article 3.4 activities it is *good practice* to use Tier 2 or Tier 3 for estimating carbon stock changes from mineral soils if CO_2 emissions from grazing land management is a key category.

Choice of carbon emission/removal factors for mineral soils

The choice of carbon stock change factors at each tier follows the same lines as described under cropland management. The carbon stock change factors are held within the same database. At higher tiers, as for cropland management, carbon stock change factors can be calculated from literature values (e.g., Follett *et al.*, 2000), long-term experiments and model runs. It is *good practice* for replacement stock change factors, if based on experimental results, to be derived from experiments that are well designed, with adequate sampling to give adequate statistical power. Any factors based on models should only be used after the model has been tested against experiments such as those described above, and any model should be widely evaluated, well-documented and archived. It is *good practice* to provide confidence limits and/or uncertainty estimates associated with any emission/removal factors. Emission/removal factors must be shown to represent local conditions or practice, based on measurements or experiments within the region.

Choice of land use and management data for mineral soils

Like for cropland management, if area and management data are available for 1970 through 1990, a base year (1990 or other) net carbon emission/removal can be established using the default carbon emission/removal factors described above. If area and management data are not available for 1970 through 1990 the options available are those already described for cropland (see Section 4.2.8.1.1: 1990 base year). Here only the activity data required for each of three tiers are outlined briefly.

Tier 1: The management practices at Tier 1 are the same as those given in the IPCC Guidelines. The different management impacts defined there are: clearing of native vegetation with conversion to cultivated crops or pasture; land abandonment; shifting cultivation; differing residue addition levels; differing tillage systems; agricultural use of organic soils for grazing. Within these specific land-use or land-management changes, practices are defined semi-quantitatively, e.g., “high input” vs. “low input” systems. Land-use and management systems are not subdivided to finer levels of detail than this. Areas may be obtained from international data sets (e.g., FAO). If area and management data are available for 1970 through 1990, the 1990 base year net carbon stock change can be established using the default carbon emission/removal factors described above. If area and management data are not available for 1970 through 1990 the options available are those described above for cropland (see Section 4.2.8.1.1). If grazing land management is deemed a key category, then it is good practice to use a Tier 2 or 3 method.

Tier 2: The management practices at Tier 2 are the same as those given in the *IPCC Guidelines* and at Tier 1. To make them country-specific, however, some practices may be subdivided, or new ones may be added. For example, within the agricultural management systems described in the *IPCC Guidelines*, management data includes descriptors such as “high input” and “low input”; these descriptors could be replaced at Tier 2 by more explicit descriptors; for example, high grazing level, medium grazing level, low grazing level, and zero grazing. Further subdivision of activities may also be necessary; for example, different forms of grazing. An alternative to the use of more detailed descriptor categories is the use of relationships relating the intensity of a practice (e.g., grazing level) with a change in the carbon emission/removal factor. Alternatively, well-calibrated and well-evaluated models of soil carbon change (e.g., CENTURY (Parton *et al.*, 1986), RothC (Coleman and Jenkinson, 1996), or others) could be used to generate either default carbon emission/removal factors, or to generate the intensity relationships for each activity, for different soils in different climatic regions. These examples show how, at Tier 2, activities can be made more country-specific, but other refinements are also possible. Rigorous criteria must be applied so that any increase in the sink size is not under- or overestimated.

Tier 3: Management data used in the more complex Tier 3 approaches are likely to be subdivided as described for Tier 2 above.

4.2.9.3.2 CO_2 EMISSIONS FROM ORGANIC SOILS

The decision tree for use with organic soils under grazing land management is identical to that from cropland management, cf. Figure 4.2.13. The methods described under Tiers 1, 2 and 3 for cropland also apply to grazing land, cf. Section 4.2.8.3.2 (Carbon stock changes in organic soils) and also Chapter 3 (Sections 3.3.1.2 and 3.4.1.2). As for croplands, non-CO_2 greenhouse gas emissions/removals from organic soils are also important, with some emissions (i.e., methane, CH_4) decreasing as CO_2 losses increase with soil drainage. It is important when calculating changes in carbon emissions/removals from organic soils to also consider non-CO_2 greenhouse gas emissions, bearing in mind that, as a rule, these are covered in the Agriculture sector. However, note that the *IPCC Guidelines* assume that all carbon is emitted as CO_2; if this assumption is departed from, it must be justified by scientifically sound and well-documented data.

Choice of carbon emission/removal factors for organic soils

Factors for organic soils are described in the equivalent subsection for cropland management (Section 4.2.8.3.2 Carbon stock changes in organic soils) and Chapter 3 (Sections 3.3.1.2 and 3.4.1.2).

Choice of management data for organic soils

Management data for organic soils are as for *IPCC Guidelines* as described and amended above for mineral soils.

4.2.9.3.3 CO_2 EMISSIONS FROM LIMING

For carbon emissions from liming, the same methods can be used for land subject to grazing land management as for those under cropland management (see Section 4.2.8.3.3 CO_2 emissions from liming).

4.2.9.3.4 NON-CO_2 GREENHOUSE GASES

Methodologies for N_2O and CH_4 emissions from soils are given in the Agriculture chapter of *GPG2000*, which gives methodologies for sources of agricultural soil emissions that are related to grazing land management (see also Chapter 3, Section 3.4.1.3). Management practices adopted to increase soil carbon may also influence the emission of non-CO_2 greenhouse gases. Often these effects will be covered by the methods described for agriculture. For example, N_2O emissions from adding more fertilizer to build soil organic matter will be directly included. There may be other effects that are not covered by the default methods; for example, increasing the carbon pools could also increase levels of organic nitrogen which, when mineralised, could become available as a substrate for denitrification and thus increase N_2O production. Similarly, the cessation of tillage on conversion of croplands to grazing lands could, at some stage in the development of the grazing land make the soils more anaerobic, thus potentially enhancing denitrification and N_2O production (see Example 1 in Box 4.2.11). These effects can be calculated in higher-tier methods, but still should be reported in the Agriculture sector, to avoid double counting or omission.

Non-CO_2 greenhouse gas emissions/removals on deforested lands converted to grazing land (Article 3.3) need to be reported separately from those under grazing land management (Article 3.4). For further guidance, see corresponding section on cropland management (Section 4.2.8.3.4).

4.2.10 Revegetation

4.2.10.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

“Revegetation” is a direct human-induced activity to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of afforestation and reforestation. Land should be classified under revegetation if it meets the revegetation definition and takes place after 1 January 1990 (see the decision tree in Figure 4.2.5 for further guidance). The methods for estimating carbon stock changes from revegetation differ somewhat from those applied to cropland management or grazing land management, and have similarities to those for afforestation and reforestation activities; even though revegetation is distinct from afforestation/deforestation, it also typically affects the aboveground carbon pool significantly.

Revegetation implies that vegetation is established to replace the previous (sometimes minimal) ground cover that had followed a land disturbance. For example, activities such as reclaiming/restoring herbaceous ecosystems on carbon-depleted soils, environmental plantings, planting of trees, shrubs, grass or other non-woody vegetation on various types of lands including urban areas, might all qualify as revegetation. Moreover, a tree planting may not qualify for afforestation/reforestation because it does not meet (and is not expected to meet during the commitment period) the minimum tree crown cover and/or minimum tree height chosen in the definition of forest, or because the consistent application of spatial configuration criteria (see Section 4.2.2.5) exclude it. In such a case the planting may qualify as revegetation. Note that revegetation does not necessarily entail a change in land use, in contrast to afforestation.

Set-aside lands such as cultivated lands subjected to revegetation should be included under cropland management if they are only temporarily set-aside (typically this is for 5 years or less, but any set-aside likely to return to cropland under the national conditions for set-aside should be counted as cropland).

It is *good practice* for Parties electing revegetation to provide documentation describing how the included areas meet the definition of revegetation and how they can be distinguished from other lands in land-use categories.

4.2.10.2 CHOICE OF METHODS FOR IDENTIFYING LANDS

General guidance on identification of lands subject to revegetation is provided in Sections 4.1.1, 4.1.2, 4.2.1, and 4.2.2. Generally, all lands subject to revegetation since 1 January 1990 should be tracked consistent with the national criteria that establish a hierarchy among Article 3.4 activities (if applicable) as explained in Section 4.1. Under the Marrakesh Accords, the geographical locations of the boundaries of the areas that encompass lands subject to revegetation need to be reported annually, along with the total land area subject to this activity.

The geographical location of the boundaries may include a spatially explicit specification of each land subject to revegetation, but does not have to. Instead, the larger area within which areas of land subject to revegetation are encompassed may be given. In either case, the lands subject to revegetation and the management thereon need to be tracked continuously through time. Continuity in monitoring/reporting of management on land could be achieved either by continuously tracking each land subject to revegetation from 1990 until the end of the commitment period (e.g., see Section 4.2.8.1 and 4.2.8.2), or by developing statistical sampling techniques, consistent with the requirements of Section 5.3, that allow the transition of different types of management on revegetation land to be determined (see Section 4.2.4.1 Developing a consistent time series).

Links to pertinent methods in this report and in the *IPCC Guidelines* are provided in Box 4.2.14.

BOX 4.2.14

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 2.3.2 (Three Approaches): No information on revegetation area in Chapter 2 approaches.

Requires country-specific criteria on what constitutes revegetation. Should include all transitions *between 1990 (or 1970, where required for base year estimate)* and 2008, and in later inventory years transitions on an annual basis.[61]

LINKS WITH THE *IPCC GUIDELINES*

Revegetation is not addressed in the *IPCC Guidelines*.

Guidance on methods to identify/monitor areas for revegetation lands

Methods for monitoring revegetation lands are the same as those used for afforestation/reforestation and deforestation lands (see Sections 4.2.5 and 4.2.6).

4.2.10.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

For mineral soils, organic soils and for limed revegetation lands, the same methods and tier structures can be used as described for cropland management and grazing land management. Methods for aboveground biomass, belowground biomass, litter and dead wood on revegetation land, are described in Chapter 3, based on the *IPCC Guidelines* (see also Box 4.2.15, Table 4.2.8, Figure 3.1.1). For urban soils, methods are described in Annex 3.B, Chapter 3.

[61] If more than one land conversion happens on the same unit of land in the transition period of the matrix, then the transition periods may have to be shortened to account for these transitions.

BOX 4.2.15

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 3.4.2.1 Change in biomass

Section 3.4.2.2 Change in carbon stocks in soils

LINKS WITH THE *IPCC GUIDELINES*

4 Non-CO_2 greenhouse gases

5 A Changes in forest and other woody biomass stocks (grasslands / tundra)

5 C Abandonment of managed lands (grasslands / tundra)

5 D CO_2 emissions and removals from soils

5 E Other (e.g., dispersed trees that are managed but do not constitute a forest such as agroforestry, also referred to as "managed trees outside forests")

(not all five pools are included: belowground biomass and litter are missing)

4.2.10.3.1 CHOICE OF CARBON STOCK CHANGE FACTORS

There are no generic default values for revegetation activities in the *IPCC Guidelines*. A Party electing revegetation may use Tier 1 methods to estimate changes in soil carbon since default values may exist (see Section 4.2.8.3 (for cropland management), Section 4.2.9.3 (for grassland management) and also pertinent sections in Chapter 3: Sections 3.3.1.2, 3.4.1.2, 3.4.2.2). However, for all other pools default values do not exist, so it is *good practice* for a Party electing revegetation to provide country-specific values for stock change in each carbon pool and for pools not reported, to provide verifiable data that demonstrate that these are not declining in carbon (see Section 4.2.3.1 Pools to be reported). If revegetation is deemed a key category, then it is *good practice* to use a Tier 2 or 3 method.

At Tier 2, it is *good practice* to provide verifiable methods and documentation to show how the carbon stock change has been estimated for each pool elected under revegetation. For any carbon pool not elected, it is *good practice* to provide verifiable data that demonstrate that these are not declining (see Section 4.2.3.1 Pools to be reported).

At Tier 3 ecosystem carbon models, parameterised for the relevant plant functional types and soils included in the selected revegetation area, could be used to estimate annual carbon emissions and removals. As with models used for cropland management and grazing land management, they should be evaluated by testing against experiments, well-documented and archived.

4.2.10.3.2 CHOICE OF MANAGEMENT DATA

It is *good practice* to provide detailed documentation specifying the practices included under revegetation and the carbon emission/removal factors associated with each practice for each pool elected.

4.2.10.3.3 NON-CO_2 GREENHOUSE GASES

Methodologies for estimating N_2O and CH_4 emissions are given in the Agriculture chapters of the *IPCC Guidelines* and the *GPG2000*, which give methodologies for sources of agricultural soil emissions on revegetation land (the list of sources is similar to that described for cropland management – see Section 4.2.8.3).

These emissions should not be reported under revegetation but as emissions in the Agriculture sector from sources listed in Annex A to the Kyoto Protocol, and they should clearly be distinguished from emissions from revegetation reported under Article 3.4 of the Protocol.

It is *good practice* to report the non-CO_2 greenhouse gas emissions from sources on revegetation lands that might be affected by land-use practices under the Annex A sources inventory for the Kyoto Protocol. These sources belong to the inventory for the Agriculture sector (the list of sources is similar to that described for cropland management – see Section 4.2.8.3.4). Tier 3 methodologies may account for the detailed relationship between carbon storage and non-CO_2 greenhouse gas emissions if data are available to do so. Some examples of relevant activities are given in Box 4.2.11. These emissions should still be reported in the Agriculture sector.

Chapter 3 (Sections 3.3.2.2, 3.4.1.3, 3.4.2.3) provides further information on procedures for estimating non-CO_2 greenhouse gas emissions.

Non-CO_2 greenhouse gas emissions/removals on deforested lands subject to revegetation (Article 3.3) need to be reported separately from those under revegetation (Article 3.4). For further guidance, see corresponding section under cropland management (Section 4.2.8.3.4).

4.3 LULUCF PROJECTS

4.3.1 Introduction

This section provides *good practice guidance* for defining project boundaries, measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gases, implementing plans to measure and monitor, and developing quality assurance and quality control plans. The material is intended for use with projects under Article 6 (Joint Implementation)[62] and Article 12 (Clean Development Mechanism) of the Kyoto Protocol. It does not address issues that are, at the time of writing, under the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC)[63], in the context of Article 12 of the Kyoto Protocol.

Guidance is provided for those elements for which standard methods exist and are applicable for project activities under Articles 6 and 12. In addition, guidance and/or recommendations are given on how to define project boundaries and on aspects to be considered within a project's baseline for activities under Article 6. However, other elements of Article 12 project activities, such as definitions for "project boundary" and "baseline", depend on decisions scheduled to be made at the ninth session of the Conference of the Parties (COP). These are not included in this *good practice guidance*. In general the application of this *good practice guidance* in respect of Article 6 and Article 12 projects depends on the requirements of the relevant COP decisions, including notably those relevant to Article 6 and the decisions which, at the time of writing, are under negotiation in respect of LULUCF projects under Article 12.

Section 4.1.1 provides an overview of the steps required by Annex I Parties to meet the requirements for reporting changes in carbon stocks and emissions and removals of greenhouse gases associated with Article 6 projects under the Kyoto Protocol. Emissions and/or removals resulting from Article 6 projects are also part of an Annex I host country's annual inventory, and Section 4.1.3 elaborates the relationship between the estimation and reporting of Article 3.3 and elected Article 3.4 activities on the one hand, and Article 6 project activities on the other.

Reporting for project activities under Article 12 (comprising the validation, monitoring and verification reports) involves the project participants, their contracted designated operational entity, the Parties involved and the CDM Executive Board. The reports are also made publicly available upon transmission to the CDM Executive Board. The modalities and procedures for reporting under Article 12 are also, at the time of writing, being considered by the SBSTA. Hence, reporting requirements for Article 12 project activities are not included as part of this *good practice guidance*.

Estimating and monitoring anthropogenic changes in carbon stocks and non-CO_2 greenhouse gas emissions and removals at the project level involve several challenges and specific circumstances, which may not be appropriately captured within *good practice guidance* developed for national inventories. It is therefore recommended to apply higher-tier methods, based on field measurements or field measurements in combination with models (e.g., allometric equations, simulation models). The recommended multiple methods, presented as a series of practical steps within a measuring, monitoring, and estimation plan, are detailed in Section 4.3.3 and its subsections. Options for standard sampling and field measurement techniques are described, along with the advantages and disadvantages of each. As clarified under Section 4.1.3, some areas with activities under Articles 3.3 and 3.4 can also be projects under Article 6. In such cases, it is *good practice* to use the same tier or a higher tier for estimating carbon stock changes and greenhouse gas emissions as was used for the same land in the UNFCCC inventory as specified in Chapter 3 of this report (refer to Section 4.2.3.4, Choice of method).

[62] Guidelines for the implementation of Article 6 of the Kyoto Protocol are found in the Annex to the Draft decision –/CMP.1 (Article 6), contained in document FCCC/CP/2001/13/Add.2, pp. 8-19.

[63] In Decision 17/CP.7, the SBSTA was requested to develop definitions and modalities for including afforestation and reforestation project activities under the CDM in the first commitment period, taking into account the issues of non-permanence, additionality, leakage, uncertainties, and socio-economic and environmental impacts, including impacts on biodiversity and natural ecosystems. A decision on these definitions and modalities will be adopted at the ninth session of the COP.

4.3.1.1 DEFINITION OF PROJECTS AND RELEVANCE TO ARTICLES 6 AND 12

A LULUCF project can be defined as a planned set of eligible activities within a specific geographic location that have the purpose of resulting in net greenhouse gas removals that are additional to those that would occur in the absence of the proposed project. A LULUCF project may be implemented by public or private entities, or a combination of the two, including private investors, private enterprises, local and national governments, other public institutions, and non-government organisations (NGOs).

For the first commitment period, eligible activities under Article 6 may include afforestation and reforestation, forest management, grazing land management, cropland management, and revegetation. Under Article 12, eligible activities for the first commitment period are limited to afforestation and reforestation. Under either article, projects can comprise multiple activities. For example, under Article 6, a project could consist of a combination of changes in both grazing and forest land management; under Article 12, a project could consist of afforestation with timber species and multipurpose tree species.

4.3.2 Project Boundaries

The Marrakesh Accords specify that the project boundary for Article 6 shall "encompass all anthropogenic emissions by sources and/or removals by sinks of greenhouse gases under the control of the project participants that are significant and reasonably attributable to the Article 6 project".[64] The definition for project boundary for LULUCF activities under Article 12 remains, at time of writing, under consideration by SBSTA. Therefore, it is *good practice* to identify all anthropogenic emissions by sources of greenhouse gases and removals by sinks arising from activities and practices associated with LULUCF projects. In a general sense, project boundaries can be thought of in terms of geographical area, temporal limits (project duration), and in terms of the project activities and practices responsible for greenhouse gas emissions and removals that are significant and reasonably attributable to the project activities.

4.3.2.1 GEOGRAPHIC AREA

Projects may vary in size and may be confined to a single or several geographic areas. Depending on the rules agreed for projects the area could be one contiguous block of land having a single owner or many small blocks of land spread more widely, perhaps having a large number of small land owners all being joined in some form of a cooperative or association. It is *good practice* to specify and clearly define spatial boundaries of the project lands so as to facilitate accurate measuring, monitoring, accounting, and verifying the project. These boundaries need to be identifiable by all stakeholders including project developers and Parties. It is *good practice*, when describing physical project boundaries, to include the following information:

- Name of the project area (e.g., compartment number, allotment number, local name, etc.)
- Map(s) of the area (paper format and/or digital format, if available)
- Geographic coordinates
- Total land area
- Details of ownership
- Land use and management history of the selected site(s).

The expectation is that boundaries remain unchanged during the duration of the project. In the event that boundary changes are inevitable, subject to the rules agreed for projects, then these would need to be reported and inclusions and/or exclusions of physical land area need to be surveyed using the above described methods (this would mean adjusting the net emissions or removals of greenhouse gases attributable to the project).

There are many different methods and tools that can be employed to identify and delineate physical project boundaries. These include, amongst others, the following:

- Permanent boundary markers (e.g., fences, hedgerows, walls, etc.);

[64] See Appendix B, paragraph 4(c) to draft decision -/CMP.1 (Article 6), contained in document FCCC/CP/2001/13/Add.2, p.19.

- Remote sensing data e.g., satellite imagery from optical and/or radar sensor systems, aerial photographs, airborne videos, etc.;
- Cadastral surveys (ground-based surveys to delineate property boundaries);
- Global Positioning Systems;
- Land records;
- National certified topographic maps with clearly defined topographic descriptions (e.g., rivers/creeks, mountain ridges); and
- Other nationally recognized systems.

Parties may opt to use any of these methods or tools, alone or in combination, provided accuracy is maintained.

4.3.2.2 TEMPORAL BOUNDARIES

Temporal boundaries (i.e., time boundaries), which are defined by the project starting and ending dates, should be set so that the boundaries encompass all changes in carbon stocks and non-CO_2 greenhouse gases emissions and removals that are reasonably attributable to project practices. Different project types have different patterns and rates of carbon accumulation as described in detail in the IPCC Special Report on LULUCF (Brown *et al.*, 2000b). For afforestation and reforestation projects activities under Article 12, the issue of project duration and its relation to permanence is not discussed here because it is being addressed by SBSTA (see Section 4.3.1).

4.3.2.3 ACTIVITIES AND PRACTICES

Different LULUCF projects have different direct human-induced changes in carbon stocks and non-CO_2 greenhouse gases. Examples of different project types and the likely changes in carbon stocks and non-CO_2 greenhouse gas emissions are provided in Box 4.3.1 (applicable to Articles 6 and 12, subject to the negotiations) and Boxes 4.3.2—4.3.4 (applicable to Article 6). Steps for identifying greenhouse gas emissions and removals caused by the project include the following:

- List and describe the greenhouse gas emissions and removals resulting from the primary project practices—e. g. tree planting, crop tillage, changed forest harvesting, etc.
- List and describe the greenhouse gas emissions and removals resulting from ancillary practices related to project operation and management—e. g. land preparation, nursery management, planting, thinning, logging—and describe these practices.
- Evaluate and report the emissions and removals of project-related greenhouse gases (CO_2, CH_4, and N_2O).

BOX 4.3.1
AFFORESTATION OR REFORESTATION PROJECTS

Tree planting on non-forested sites generally increases carbon stocks. These tree-planting projects could include planting with commercial timber species, planting with non-commercial native species, planting with multipurpose species (e.g., fruit trees, shade trees for coffee), or a combination of these species groups. Tree planting may also change emissions of greenhouse gases, in particular CO_2, CH_4 and N_2O.

The list below contains factors that may be relevant for measuring and monitoring in addition to changes in carbon stocks in pools defined by the Marrakesh Accords and decisions of the COP:

- Changes in emissions of greenhouse gases by burning of fossil fuels or biomass resulting from site preparation, monitoring activities, tree harvesting, and wood transportation.
- Changes in nitrous oxide emissions caused by nitrogen fertilization practices.
- Changes in nitrous oxide emissions from planting of leguminous trees.
- Changes in methane oxidation due to alteration of groundwater table level (particularly in high organic soil types), tree planting and soil management.

BOX 4.3.2
CROPLAND MANAGEMENT PROJECTS:
CONVERSION FROM CONVENTIONAL TO ZERO TILLAGE IN AGRICULTURE

Switching from conventional to reduced or zero tillage may cause modifications in soil physical, chemical and biological properties, as well as in water regimes, nutrient dynamics, fossil fuel use, and other factors related to the greenhouse gas balance of the system. The list below contains factors that may be taken into consideration for measuring and monitoring, in addition to changes in the soil organic carbon pool:

- Changes in nitrous oxide and methane emissions from soil.
- Changes in carbon dioxide emissions by transportation of agro-chemicals used in addition to those in the baseline case.
- Changes in carbon dioxide emissions by burning of fossil fuels in farm equipment.

BOX 4.3.3
FOREST MANAGEMENT PROJECTS: REDUCED IMPACT LOGGING

Some logging practices in forests can cause damage to both vegetation and soils that seriously impair regeneration. If adopted as part of sustainable forest management, reduced impact logging is a technique that aims at minimizing these negative impacts, thus reducing carbon dioxide emissions and improving the carbon removal capacity of regrowth. The list below contains factors that may be taken into consideration for measuring and monitoring in addition to changes in carbon stocks in relevant pools, particularly dead wood and soil organic carbon pools:

- Changes in carbon dioxide emissions from burning of fossil fuels due to improved harvesting and logging logistics.
- Changes in nitrous oxide and methane emissions from soil.

BOX 4.3.4
FOREST IMPROVEMENT PROJECTS:
ENRICHMENT PLANTING ON LOGGED-OVER FOREST OR SECONDARY GROWTH FOREST

Certain forest harvesting practices, such as selective logging, may cause poor residual tree growth. Enrichment planting with high-growth, commercially-valuable, or multipurpose species usually increases carbon stocks. The list below contains factors that may be taken into consideration for measuring and monitoring in addition to changes in carbon stocks in relevant carbon pools:

- Changes in nitrous oxide emissions from soils due to nitrogen inputs (fertilizers or use of leguminous trees).
- Changes in carbon dioxide emissions by burning of fossil fuels for site preparation, logging and wood transportation, in addition to those in the baseline case.
- Changes in methane oxidation caused by changes in vegetation and soil management.

4.3.3 Measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gas emissions[65]

A key aspect of implementing LULUCF projects for mitigating greenhouse gas emissions is the accurate and precise estimation of greenhouse gas emissions and removals that are directly attributable to project activities. Techniques and methods for measuring, monitoring, and estimating terrestrial carbon pools that are based on commonly accepted principles of forest inventory, soil sampling, and ecological surveys are well established and applicable to LULUCF projects (Paivinen *et al.*, 1994; Pinard and Putz, 1997; MacDicken, 1997; Post *et al.*, 1999; Brown *et al.*, 2000a, 2000b; Schlegel *et al.*, 2001; Brown, 2002; Segura and Kanninen, 2002). These techniques and methods will be elaborated further in this section.

Methods for measuring and estimating non-CO_2 greenhouse gas emissions and removals are less well developed. However, projects could include practices that affect non-CO_2 greenhouse gases. Such practices include fertilizer application to enhance tree growth (possible N_2O emissions), wetland restoration (possible increase in CH_4 emissions), use of nitrogen-fixing plants (possible increase in N_2O emissions) and biomass burning during site preparation (possible change in N_2O and CH_4 emissions). Section 4.3.3.6 gives further advice on measuring, monitoring, and estimating emissions of non-CO_2 greenhouse gases for LULUCF projects.

Although the methods described here are appropriate for most situations at present, scientists are constantly developing new, and often more cost-effective, methods, and it is recommended to maintain awareness of the progress in this area. For example, remote sensing technology is a fast developing field and new sensors are being tested and launched (e.g., higher resolution sensors, radar systems) that could prove to be useful for planning, stratifying, and measuring and monitoring projects more cost-effectively. Furthermore, costs could be defrayed if measuring and monitoring carbon was combined with multipurpose resource inventories (Lund 1998).

Selective or partial accounting systems of the pools may be appropriate for projects as long as all pools for which emissions are likely to increase as a result of the project (loss of carbon or emission of non-CO_2 greenhouse gases) are included (Brown *et al.*, 2000b). However, for Article 12, the decision regarding the application of selective accounting of the pools is still under discussion by SBSTA. Possible criteria affecting the selection of carbon-accumulating pools to measure and monitor include the following: magnitude of the pool and its rate of change; availability of appropriate methods; cost to measure; attainable accuracy and precision (cf. Section 4.3.3.3).

There is a trade-off between the desired precision level of carbon-stock estimates and cost that is related to the spatial variability of the carbon-stock changes within the project boundary. The more spatially variable the carbon stocks in a project, the more sampling plots are needed to attain a given precision at the same confidence level. This may result, in principle, in cost implications to implement the measuring and monitoring plan. Stratification of the project lands into a reasonable number of relatively homogeneous units can reduce the number of plots needed for measuring, monitoring, and estimating. In general, the costs will increase with: the number of pools that need to be monitored; frequency of monitoring; precision level that is targeted; and the complexity of monitoring methods. The frequency of monitoring that is needed to detect change is related to the rate and magnitude of change: the smaller the expected change, the greater the potential that frequent monitoring will not detect a significant change. That is, frequency of monitoring should be determined by the magnitude of expected change—more frequent monitoring is applicable if the expected magnitude of change is large.

It is also necessary to monitor the overall performance of the project site to demonstrate that the project has accomplished what was originally proposed (e.g., that the project has achieved the targeted total planted area.) Measuring carbon at sampling plots only will not accomplish this, and additional steps are needed to monitor the overall performance of the project area.

Practical steps for designing and implementing a carbon measuring and monitoring plan are provided below, with multiple methods for various carbon pools. All methods provided are a combination of default data, field measurements, and models. In other words, the methods described here are multi-tier approaches.

[65] According to paragraph 53 in the Annex to the draft Decision -/CMP.1 (Article 12), project participants of Article 12 project activities are required to include the monitoring plan that provides for the collection and archiving of all relevant data necessary for estimating or measuring anthropogenic emissions by sources or removals by sinks of greenhouse gases occurring within the project boundary, cf. document FCCC/CP/2001/13/Add.2, p.38.

The recommended practical steps for designing and implementing a plan to measure, monitor, and estimate carbon-stock changes and non-CO_2 greenhouse gas emissions are[66]:

- Develop the baseline.
- Stratify the project area.
- Identify the relevant carbon pools and non-CO_2 greenhouse gases (this applies presently for Article 6 only; pools to be included in Article 12 are presently being discussed by the SBSTA).
- Design the sampling framework.
- Identify the methods (field and models) for monitoring carbon pools and non-CO_2 greenhouse gases.
- Develop the monitoring plan, including the quality assurance/quality control plan.

The details on each one of these steps are described next.

4.3.3.1 BASELINE

The baseline for an Article 6 project is the scenario that reasonably represents the anthropogenic emissions by sources and anthropogenic removals by sinks of greenhouse gases that would occur in the absence of the proposed project. This implies the need to assess potential greenhouse gas emissions and removals in a manner consistent with those associated with the project. For Article 12, issues related to the definition, which pools, gases, and activities the baseline shall include, how the baseline will be established, and choices of a baseline methodology are presently under consideration by SBSTA.

Changes in the carbon stocks in the relevant carbon pools and the non-CO_2 greenhouse gas emissions associated with the project need to be measured and monitored and then compared to those of the project's baseline. There are two aspects that have to be considered:

- The relevant carbon pools and non-CO_2 greenhouse gas emissions prior to the start of project activity need to be estimated. This estimation should preferably be based on measurements made on the same site where the project will be established. It is possible to use alternative ways for estimating carbon stocks and non-CO_2 greenhouse gas emissions, including for example, measurements on sites that are considered to reproduce, as far as possible, the initial condition of the project site (i.e., sites with similar soil type, vegetation cover and land-use history). Another possibility consists of using simulation models that have been calibrated for local conditions.
- A projection[67] of the carbon stocks in the relevant carbon pools and non-CO_2 greenhouse gas emissions in the project area has to be elaborated to estimate their trajectory without the project activity. The projection of the carbon stocks and non-CO_2 greenhouse gas emissions in the project area can be developed through the use of either, or both, of the following:
  - Peer-reviewed simulation models (e.g., CO2fix —Masera *et al.*, 2003; CENTURY—Parton *et al.*, 1987; or a locally developed model). Such models project the changes in carbon stocks of those components to be measured in the project case in each land-use category over time, and in some cases, project non-CO_2 greenhouse gas emissions too. It is recommended that these models be used to simulate changes in the selected carbon stocks and non-CO_2 greenhouse gas emissions without the project activity at the start of the project.
  - Control areas where the selected carbon pools and non-CO_2 greenhouse gases are measured and monitored over time. Data from the control areas can also be used in combination with the models in the previous step to improve the simulation results.

---

[66] For Article 12, it is recognized that leakage is an additional element in the monitoring plan; however, it has not been addressed here due to the ongoing work by SBSTA. For Article 6, leakage outside the project boundary is less of an issue because it should be accounted for in national greenhouse gas inventories (Brown *et al.*, 2000b).

[67] The projection may require consideration of socio-economic and other factors that go well beyond the scope of inventory guidance as set out in Appendix B to the draft decision -/CMP.1 (Article 6) (cf. document FCCC/CP/2001/13/Add.2, p.18), and (for non-LULUCF projects) in section G of the draft decision -/CMP.1 (Article 12) dealing with the CDM (cf. document FCCC/CP/2001/13/Add.2, pp.36-37). Provisions for LULUCF baseline projections are expected to be agreed upon at COP10.

4.3.3.2 STRATIFICATION OF THE PROJECT AREA[68]

At the start of a project, it is *good practice* to collect basic background information and data about the important bio-physical, and socio-economic characteristics of the project area. The information and data include, e.g.,: land-use history; maps of soil, vegetation, and topography; and land ownership. It is *good practice* that the land proposed for the project be geo-referenced. A geographic information system (GIS) would be useful for integrating the data from different sources, which can then be used to identify and stratify the project area into more or less homogeneous units.

It is *good practice* to stratify the project area (population of interest) into sub-populations or strata that form relatively homogenous units, if the project is not homogenous. Stratification can be done prior to implementing the measuring and monitoring plan (pre-stratification) or after (post-stratification) (see also Section 5.3.3). Post-stratification defines the strata using auxiliary data after the field measurements have been made.

Stratification of the project area can increase the accuracy and precision of the measuring and monitoring in a cost-effective manner. The size and spatial distribution of a project does not influence this step – one large contiguous block of land or many small parcels are considered the population of interest and are stratified in the same manner. In general, stratification decreases the costs of measuring and monitoring because it is expected to diminish the sampling effort necessary to achieve a given level of confidence caused by smaller variance in each stratum than in the project area itself. The stratification should be carried out using criteria that are directly related to the variables to be measured and monitored, e.g., the change in carbon stocks in trees for afforestation, or soil for cropland management.

For pre-stratification of an afforestation/reforestation project, the strata may be defined on the basis of one or more variables such as the tree species to be planted (if several), age class (as generated by delay in practical planting schedules), initial vegetation (e.g., completely cleared versus cleared with patches or scattered trees), and/or site factors (soil type, elevation, and slope etc.). For some afforestation/reforestation projects, the project site may appear to be homogeneous in all these and any other characteristics. However, it is possible that after the first monitoring event, the change in carbon stocks is highly variable and that on further analysis it is found that the measurements can be grouped into similar classes—in other words can be post-stratified.

There is a trade-off between the number of strata and sampling intensity. The goal is to balance the number of strata identified against the total number of plots needed to adequately sample each stratum. There is no hard and fast rule, and project developers need to use their expert judgement in deciding on the number of strata to include.

4.3.3.3 SELECTION OF CARBON POOLS AND NON-CO_2 GREENHOUSE GASES[69]

The major carbon pools in LULUCF projects are: aboveground biomass, belowground biomass, litter, dead wood, and soil organic carbon, which in turn, can be further subdivided (Table 4.3.1; see also Chapter 3 and Glossary). The major non-CO_2 greenhouse gases in LULUCF projects are N_2O and CH_4. For different types of LULUCF projects, a decision matrix that illustrates the possible choices of carbon pools for measuring and monitoring is shown in Table 4.3.1.

The selection of which pools to measure and monitor under agreed rules[70] is likely to depend on several factors, including expected rate of change, magnitude and direction of the change, availability and accuracy of methods to quantify change, and cost to measure. Provisions could include that all pools that are expected to decrease as a result of project activities must be measured and monitored, or that all pools that are expected to increase need not be measured and monitored. In practical terms, the latter provision could be the case if monitoring costs are high relative to the expected increase in carbon stocks—which might be the case, for example, with understorey herbaceous vegetation in an afforestation/reforestation project.

---

[68] See Chapter 5, Section 5.3.3.1 for further discussion on stratification.

[69] In paragraph 21 of the Annex to the draft decision -/CMP.1 (Land use, land-use change and forestry) it is stated: "A Party may choose not to account for a given pool in a commitment period, if transparent and verifiable information is provided that the pool is not a source." (cf. document FCCC/CP/2001/13/Add.1, p. 62). The discussion in this section refers to Article 6, and may also be applicable to Article 12, depending upon the decisions to be made by SBSTA.

[70] For Article 6 projects, see paragraph 21 of the Annex in the draft decision -/CMP.1 (Land use, land-use change and forestry), cf. document FCCC/CP/2001/13/Add.1, p. 62; rules for Article 12 projects are scheduled for adoption at COP9.

TABLE 4.3.1
A DECISION MATRIX TO ILLUSTRATE POSSIBLE SELECTION CRITERIA OF POOLS TO MEASURE AND MONITOR IN LULUCF PROJECTS (FOR EXPLANATION OF LETTERS AND NUMBERS IN THIS TABLE, SEE IMMEDIATELY BELOW THE TABLE)

Project type	Carbon pools					
	Living biomass			Dead Organic Matter		Soil Organic Carbon
	Aboveground: trees	Aboveground: non-tree	Below-ground	Litter	Dead wood	
Afforestation/reforestation	Y1	M2	Y3	M4	M4	M5
Forest management	Y1	M2	Y3	M4	Y4	M5
Cropland management	M1	M2	M3	M4	N	Y5
Grazing land management	M1	Y2	M3	M4	N	Y5
Revegetation	M1	Y2	M3	M4	M4	M5

Letters in the above table refer to the need for measuring and monitoring the carbon pools:

Y= Yes – the change in this pool is likely to be large and should be measured.

N = No – the change is likely to be small to none and thus it is not necessary to measure this pool.

M = Maybe – the change in this pool may need to be measured depending upon the forest type and/or management intensity of the project.

Numbers in the above table refer to different methods for measuring and monitoring the carbon pools:

1= Use the method for aboveground biomass of trees in Section 4.3.3.5.1.

2 = Use the method for aboveground biomass of non-trees vegetation in Section 4.3.3.5.1.

3 = Use the method for belowground biomass in Section 4.3.3.5.2.

4 = Use the method for litter and dead wood in Section 4.3.3.5.3.

5 = Use the method for soils in Section 4.3.3.5.4.

Source: modified from Brown *et al.*, 2000b.

Changes in emissions of non-CO_2 greenhouse gases may result from all project activities under Article 6; the sources of the non-CO_2 greenhouse gases are biomass burning, fossil fuel combustion, and soil (see Boxes 4.3.1–4.3.4). Furthermore, changes in grazing land management to enhance soil carbon, for example, can also change emissions of non-CO_2 greenhouse gases due to effects on livestock production (Sampson and Scholes, 2000). Under Article 12, afforestation/reforestation activities may also change emissions of non-CO_2 greenhouse gases through practices such as those given in Box 4.3.1 (see also Section 4.3.3.6).

4.3.3.4 SAMPLING DESIGN

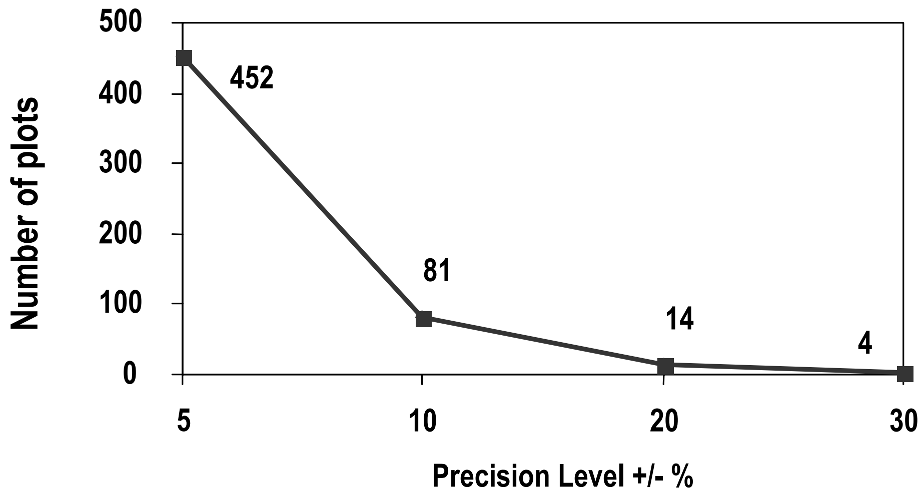
A discussion of general issues related to sampling design is given in detail in Section 5.3. For LULUCF projects, permanent or temporary sampling plots could be used for sampling over time to estimate changes in the relevant carbon pools and non-CO_2 greenhouse gases. Both methods have advantages and disadvantages. Permanent sample plots are generally regarded as statistically more efficient in estimating <u>changes</u> in forest carbon stocks than temporary plots because typically there is high covariance between observations at successive sampling events (Avery and Burkhart, 1983). Disadvantages of permanent plots are that their location could be known and they could be treated differently (such as by fertilizer, irrigation, etc. to enhance the carbon stocks), or that they could be destroyed or lost by disturbances over the project interval. The advantages of temporary plots is that they may be established more cost-effectively to estimate the carbon stocks of the relevant pools, their location changes after each sampling interval, and they would not be lost by disturbances. The main disadvantage of temporary plots is related to the precision in estimating the <u>change</u> in forest carbon stocks. Because individual trees are not tracked (see Clark *et al.*, 2000, for further discussion), the covariance term is non-existent and it will be more difficult to attain the targeted precision level without measuring more plots. Thus any cost advantage gained by using temporary over permanent forest plots may be lost by the need to install more temporary plots to achieve the targeted precision. For non-forestry based projects, where changes in carbon stocks of only soil or herbaceous vegetation are measured and monitored, temporary plots could be used because the statistical advantage of permanent plots (high covariance) is lost (see next Section 4.3.3.4.1).

4.3.3.4.1 THE NUMBER AND TYPE OF SAMPLE PLOTS

It is *good practice* to define the sample size for measuring and monitoring in each stratum on the basis of the estimated variance of the carbon stock in each stratum and the ratio of the area of the stratum to the total project area. Typically, to estimate the number of plots needed for measuring and monitoring, at a given confidence level, it is necessary to first obtain an estimate of the variance of the variable (for example, carbon stock of the main pools – trees in an afforestation/reforestation project or soil in a cropland management project) in each stratum. This can be accomplished either from existing data of the type of project to be implemented (e.g., a forest or soil inventory in an area representative of the proposed project) or by making measurements on an existing area representing the proposed project. For example, if the project is to afforest/reforest agricultural lands and the project will last for 20 years, then a measure of the carbon stocks in the trees of about 10-15 plots (for plot dimensions see Section 4.3.3.4.2) of an existing 20 year forest would possibly suffice. If the project area comprises more than one stratum, then this procedure needs to be repeated for each of them. Such measurements will provide estimates of the variance in each stratum.

The sample size (number of sample plots) needed can be calculated when the estimated variance in each stratum, area of each stratum, targeted precision level (based on sampling error only), and estimation error are known (see Section 5.3.6.2; Freese, 1962; MacDicken, 1997; Schlegel *et al.*, 2001; Segura and Kanninen, 2002). These sources provide methods and equations to compute the number of sample plots within each stratum, taking into account the variance and area of each stratum and the targeted precision at a given confidence level. Figure 4.3.1 illustrates the relationship between targeted precision level and number of sample plots (taking into consideration the variance and area of each of the six strata present in this forest) and shows that to attain increasing levels of precision (expressed as plus/minus a given percentage of the mean with 95% confidence), an increasingly high number of plots is needed. It is also recommended that an additional 10% of the calculated number of plots be installed to account for unexpected events that may make it impossible to re-locate all plots in the future.

Figure 4.3.1 An example of the relationship between the number of plots and the precision level (+/- % of total carbon stock in living and dead biomass, with 95% confidence) for all strata combined, for a complex tropical forest in Bolivia (the Noel Kempff Pilot Project); the project encompassed six strata and 625 plots were actually installed (from data in Boscolo *et al.*, 2000, and Brown *et al.*, 2000a).



Experience has shown that in the LULUCF sector, carbon stocks and the change in carbon stocks in complex forests can be estimated to precision levels of within ±10% of the mean, with 95% confidence, at a modest cost (Brown, 2002; http://www.winrock.org/REEP/NoelKmpff_rpt.html). National and regional forest inventories that are used to assess growing stock of timber typically target precision levels of less than 10% of the mean (see IPCC, 2000b).

The procedure described in the previous paragraph provides an estimate of the number of plots for various levels of precision based only on sampling error. There are other sources of error when estimating carbon stocks, for example, the errors from the use of allometric equations (model error) and from field and laboratory measurements (measurement error). In general, the sampling error is the largest source of error and can account for up to 80% of the total error (Phillips *et al.*, 2000). See Section 5.3.6.3 for more details on how to account for other sources of error.

When permanent sample plots are used to monitor changes in carbon stocks over time, it is *good practice* to locate them systematically (e.g., a uniform gid) with a random start, especially if stratified sampling is being used. The goal is to avoid subjective choice of plot locations (plot centres, plot reference points, movement of plot centres to more “convenient” positions). In the field, this is usually accomplished with the help of a GPS. Permanent sample plots may also be located in control areas (i.e., in areas adjacent to the project area that are biophysically similar to the project area) if it is expected that the reference case is likely to change over time (e.g., abandoned agriculture land).

In the case of projects where planting of trees may occur over several years, it is *good practice* to measure and monitor carbon stocks and non-CO_2 greenhouse gases in age-class cohorts (a group of trees of similar age), treating each cohort class as a population. It is recommended to combine no more than two to three age classes into a one-cohort class.

The carbon stocks and non-CO_2 greenhouse gases can be measured in reference plots if needed. If this is done, a number of plots similar to the number used in the project case will be required to maintain the targeted level of precision when comparing the with-project case to the baseline.

Estimating changes in carbon stocks over time from plot data

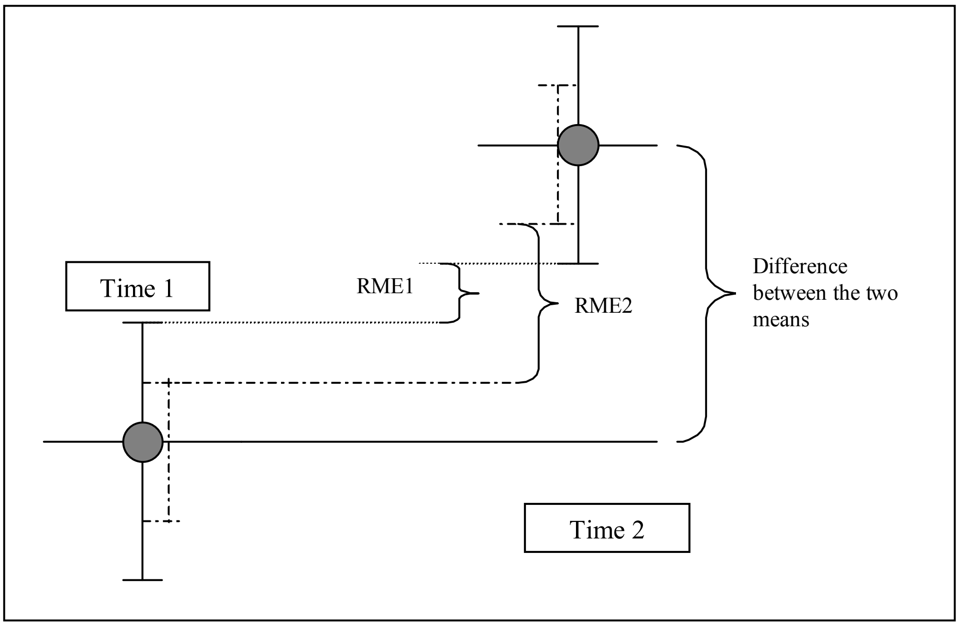
A key component of a project is to measure, monitor, and estimate the quantity of carbon accruing on the project area over the length of the project and over separate time periods. This is accomplished by estimating the changes in carbon stocks over time. Projections of the amount of carbon accumulating can be made by combining field measurements and models. However, if models are used, it is recommended to validate them with field measurements and to recalibrate as necessary.

For monitoring forests using permanent plots, it is *good practice* to measure the growth of individual trees at each time interval, keeping track of growth of survivors, mortality, and growth of new trees (ingrowth). Changes in carbon stocks for each tree are then estimated and summed per plot. Changes in carbon stocks in dead organic matter are also measured per plot and added to those for trees. Statistical analyses are then performed on net carbon accumulation in biomass per plot. As discussed above, because these plots undergo repeated measurements on basically the same components, there will be a high covariance term in the statistical analysis and the uncertainty around the estimates of change should be within the level targeted by the sampling design.

For soil or non-forest vegetation (e.g., croplands or grazing lands), in contrast to the procedure indicated for forests, the same soil or plant sample cannot be monitored over time. Instead, on each sample collection, the unit sampled (soil or plant sample) is destroyed for the analysis of its relevant components. Also, as variability among samples can be high even at small spatial scales, the statistical concept of paired samples, even if collected only centimetres apart, cannot be reliably employed. Thus the changes in the mean carbon content between two temporally-separated sample pools are best quantified by comparing means, via, for instance, the Reliable Minimum Estimate (RME) approach (Dawkins, 1957), or by directly calculating the difference between the means and associated confidence limits (Sokal and Rohlf, 1995). (The following discussion uses soil as an example, but it could easily apply for vegetation on cropland and grazing land management projects).

The objective is to estimate the number of plots needed to establish the *minimum* change in the mean carbon stocks, with 95% confidence, that has taken place from one monitoring event to the next, rather than to estimate the number of plots needed to establish that the two means are significantly different from each other. For the RME approach (Figure 4.3.2), the monitoring results from plots are pooled to derive a mean for the sample population at Time 1 and Time 2. Change in soil carbon is estimated by subtracting the maximum estimate of the population mean at Time 1 (mean at Time 1 plus half the 95% confidence interval at Time 1) from the minimum mean estimate at Time 2 (mean at Time 2 minus half the 95% confidence interval at Time 2). The resulting difference represents, with 95% confidence, the minimum reliable change in mean soil carbon from Time 1 to Time 2 (Figure 4.3.2).

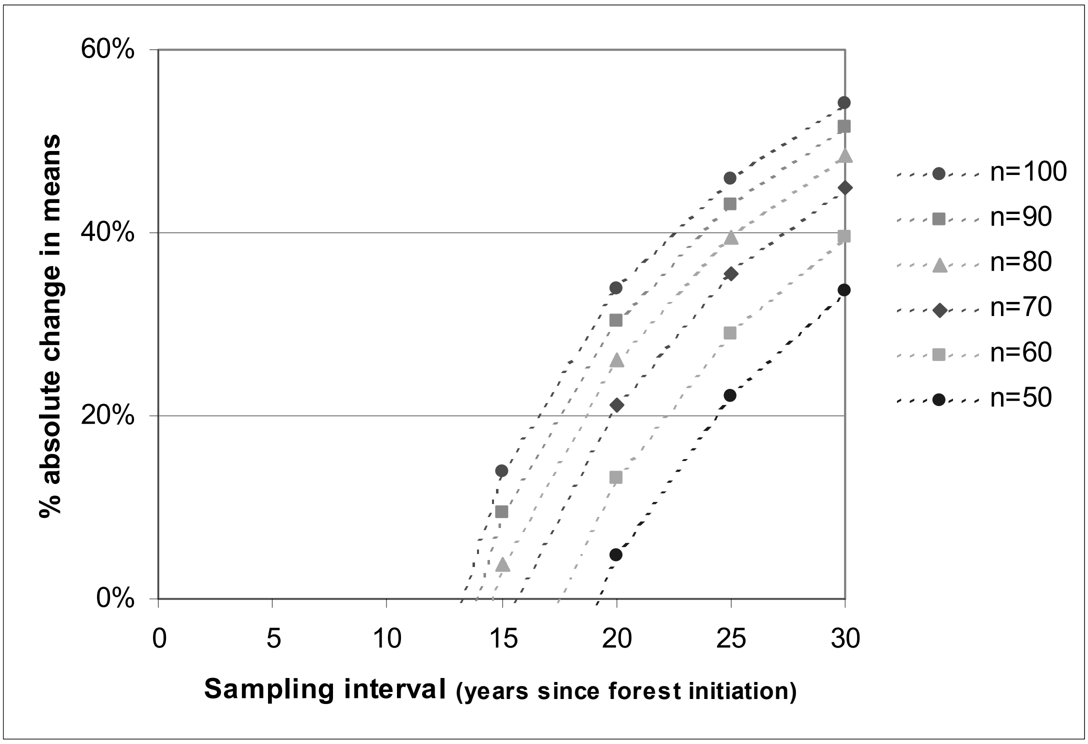
Figure 4.3.2 Illustration of the relationship between the magnitude of the Reliable Minimum Estimate (RME) between Time 1 and Time 2 sampling periods and the 95% confidence interval (the solid and dashed bars) around the mean soil carbon content (shaded circle). The confidence interval is a function of the standard error, defined as the ratio between the standard deviation and the square root of the sample size. The larger the sample size the smaller the standard error and thus the smaller the 95% confidence interval. Hence, RME1 is smaller than RME2 as a result of fewer samples.



Both sampling intensity (i.e., number of soil samples) and frequency of sampling must be taken into consideration when attempting to estimate changes in soil carbon over time. The minimum estimated change in soil carbon stocks between two means at a given level of confidence can be expressed as a percentage of the absolute difference between the means. A targeted estimate (e.g., 80% of the absolute difference between the means), or alternatively, a targeted magnitude of change in soil carbon (not to exceed the absolute difference between the means), can be achieved by adjusting sampling intensity, sampling frequency, or a combination of both (Figure 4.3.3).

In general, increasing the number of soil samples reduces the standard error around means separated in time, and better distinguishes the change that takes place (Figure 4.3.3). As high levels of variability in carbon among sample units are typical of soils (coefficient of variation of ~ 30%), high sampling intensity is generally needed to discern change. The resolution of change detection also depends on the magnitude of the change itself, and as this is time-dependent, it is appropriate to consider frequency of sampling. Increasing the time interval between sampling events is expected to increase the magnitude of the change that takes place, assuming the variance around the means stays the same. Thus, the percentage and magnitude of the absolute change estimated also increases (Figure 4.3.3). This is an important consideration, in that small changes expected with short sampling intervals may be undetectable, even with high sampling intensity. By assuming a rate of soil carbon accumulation, sampling intervals can be designed to achieve a targeted estimate of the minimum change in soil carbon. It is *good practice* to estimate the number of plots and sampling interval needed based on the variability in carbon stocks and an assumed rate of carbon accumulation. For the details on how to estimate sample size for soil sampling, refer to the RME method as described in MacDicken (1997), or by adapting the Minimum Detectable Difference calculation (Zar, 1996) to solve for sample size for a targeted difference in means.

Figure 4.3.3 An example of how the percent absolute change in mean soil carbon (with 95% confidence) for an afforestation project varies in relation to the sampling interval and sample size (n), assuming constant coefficient of variation (30%), constant annual rate of soil carbon accumulation of 0.5 tonnes C per hectare and year, and initial soil carbon of 50 tonnes C per hectare (generated from unpublished data).



4.3.3.4.2 PLOT SHAPE AND SIZE

The type of plots used in vegetation and forest inventories include: fixed area plots that can be nested or clustered, variable radius or point sampling plots (e.g., prism or relascope plots), or transects. It is recommended to use permanent nested sample plots containing smaller sub-units of various shapes and sizes, depending on the variables to be measured. For instance, in an afforestation/reforestation project, saplings could be measured in a small circular plot; trees between 2.5 to 50 cm diameter at breast height (dbh) could be measured in a medium circular plot; trees above 50 cm dbh could be measured in a larger circular plot; and understorey and fine litter could be measured in four small square or circular plots located in each quadrant of the sample plot. The radius and diameter limits for each circular plot would be a function of local conditions and expected size of the trees through time.

The size of the sample plot is a trade-off between accuracy, precision, and time (cost) of measurement. The size of the plot is also related to the number of trees, their diameter, and variance of the carbon stock among plots. The plot should be large enough to contain an adequate number of trees per plot to be measured. In general, it is recommended to use a single plot varying between 100 m^2 (for densely planted stand of 1,000 trees/ha or more) and 600 m^2 (for sparsely planted stand of multi-purpose trees) in area for even-sized stands. For projects where it is expected that the forest will be uneven-sized (e.g., through a combination of planting and natural regeneration), it is recommended to use nested plots or even clusters of nested plots depending upon the forest characteristics. Whether one uses circular or rectangular plots depends on local conditions. There are cases (e.g., rows of trees to serve as windbreaks or sand dune stabilisation) where a number of transects may be the most appropriate sampling method to use; and, the number of transects needed should be based on the variance, as described above.

4.3.3.5 FIELD MEASUREMENTS AND DATA ANALYSIS FOR ESTIMATING CARBON STOCKS

It is *good practice* to use standard techniques for field measurements of vegetation and soil. Details of such techniques are described in detail in MacDicken (1997) and Schlegel *et al.* (2001), among others. Any *good practice* method that requires ground-based field measurements should have a formal quality control plan (see

Section 4.3.4). This section focuses on what constitutes *good practices* in conducting these measurements and analysing them for carbon stock estimation.

For field measurements of carbon pools, the recommended sample unit is a permanent sample plot of nested fixed radius subplots (see above). The project area should be stratified as described in Section 4.3.3.2, and the number of sample plots to be established for each stratum should be calculated.

All the biomass data obtained in field measurements must be expressed on an oven-dry basis, and converted to carbon by multiplying the oven-dry matter values by the carbon fraction of dry biomass. This value varies slightly depending on species and biomass component in question (trunk, branches, roots, understorey vegetation etc.) (see Chapter 3, Section 3.2). However, the value of 0.50 for the conversion is the approximation indicated in the *IPCC Guidelines*, and should be applied if no local values are available.

4.3.3.5.1 ABOVEGROUND BIOMASS

Trees

There are two approaches for estimating aboveground biomass in trees: a direct approach using allometric equations, and an indirect approach using biomass expansion factors. For LULUCF projects, it is *good practice* when using permanent sample plots to estimate the carbon stock of trees through the direct approach. The indirect approach is often used with temporary plots, a common practice in forest inventories. The details of both approaches are presented next.

Direct approach

Step 1: The diameter at breast height (dbh; typically measured at 1.3 m above ground) of all the trees in the permanent sample plots above a minimum diameter is measured. The minimum dbh is often 5 cm, but can vary depending on the expected size of trees —for arid environments where trees grow slowly, the minimum dbh may be as small as 2.5 cm, whereas for humid environments where trees grow rapidly it could be up to 10 cm.

For afforestation/reforestation projects, small trees (e.g., saplings with dbh less than the minimum, but yet taller than breast height) will likely dominate during the early stages of establishment. These can be readily included in this approach by counting their number in a subplot.

Step 2: Biomass and carbon stock are estimated using appropriate allometric equations applied to the tree measurements in Step 1. There are many multi-species allometric equations for native temperate and tropical forest species (e.g., Araújo *et al.*, 1999; Brown, 1997; Schroeder *et al.*, 1997; Pérez and Kanninen, 2002 and 2003; Tables 4.A.1 to 4.A.3 of Annex 4A.2). These equations are developed using variables, singly or in combination, such as dbh, wood density, and total height as independent variables and aboveground biomass of trees as the dependent variable. Further discussion regarding the development of these equations and their use can be found in Brown (1997) and Parresol (1999).

The minimum diameter tree included in most of the allometric equations (Tables 4.A.1–4.A.3 in Annex 4A.2) is smaller than the recommended minimum dbh given in Step 1 above, thus the biomass of these small trees can be estimated from the same allometric regressions. A typical approach is to estimate the common dbh of the saplings, usually the mid-point between the smallest size observed and the minimum diameter, estimate the biomass for this diameter sapling, and multiply this estimated biomass by the number of saplings counted. If the allometric equation does not include trees of the small size classes, an alternative approach to estimating the aboveground biomass is to grow and harvest about 10-15 such saplings planted in a site nearby the project area.

Step 3: When allometric equations developed from a biome-wide database, such as those in Annex 4A.2, Tables 4.A.1 and 4.A.2, are used, it is *good practice* to verify the equation by destructively harvesting, within the project area but outside the sample plots, a few trees of different sizes and estimate their biomass and then compare against a selected equation. If the biomass estimated from the harvested trees is within about +/- 10% of that predicted by the equation, then it can be assumed that the selected equation is suitable for the project. If this is not the case, it is recommended to develop local allometric equations for the project use. For this, a sample of trees, representing different size classes, is destructively harvested, and its total aboveground biomass is determined. The number of trees to be destructively harvested and measured depends on the range of size classes and number of species—the greater the heterogeneity the more trees are required. If resources permit, the wood density (specific gravity) and the carbon content can be determined in the laboratory. Finally, allometric equations are constructed relating the biomass with values from easily measured variables, such as the dbh and total height. Further discussion of the development of local allometric equations is presented in Brown (1997), MacDicken (1997), Schlegel *et al.* (2001) and Segura and Kanninen (2002).

Table 4.A.1 of Annex 4A.2 presents general allometric equations for estimating the aboveground biomass (kg dm/tree) for different forest types using the diameter at breast height as the independent variable. These equations are based on a multi-species database that contains biomass data for more than 450 individuals.

In many tropical regions, palm trees of various species are common, both in restored forests and in abandoned pastures. Table 4.A.2 (Annex 4A.2) presents some allometric equations for estimating the aboveground biomass of several common palm species in tropical America. Biomass of palms does not relate well to their dbh; instead height is used alone as the independent variable.

Table 4.A.3 (Annex 4A.2) presents examples of allometric equations for individual species commonly used in the tropics. However, as discussed above, any project would need to assess the applicability of particular allometric equations for local conditions. This will be particularly important if species are grown in mixtures. If not, it is *good practice* either to validate existing equations with data collected at the project site or to develop local allometric equations based on field measurements.

Indirect approach

An alternative approach for estimating aboveground biomass of forests, particularly commercial plantations, is to base it on the volume of the commercial component[71] of the tree for which there are often many equations or methods available for estimating this component. The indirect method is based on factors developed at the stand level, for closed canopy forests, and cannot be used for estimating biomass of individual trees. There are two ways of obtaining estimates of the commercial volume in this approach:

Method 1:

Step 1: As with the direct approach, the diameter of all trees above some minimum diameter is measured.

Step 2: The volume of the commercial component of each tree is then estimated based on locally derived methods or equations. The volume is then summed for all trees and expressed as volume per unit area (e.g., m^3/ha).

Method 2:

Steps 1 and 2 combined: There are field instruments (e.g., relascope) that measure volume directly. Using this instrument or other appropriate means, the volume of each tree in the plots is measured. The sum for all trees is then expressed as volume per unit area.

Once the volume of the commercial component is estimated, it then needs to be converted to biomass and then estimates of the other tree components, such as branches, twigs, and leaves need to be added. This method is expressed in Equation 4.3.1 (Brown, 1997) (see also Section 3.2.1.1 on use of BEF and Annex 3A.1, Table 3A.1.10):

EQUATION 4.3.1
ESTIMATION OF ABOVEGROUND BIOMASS OF FORESTS

$$\text{Aboveground biomass} = \text{Commercial tree volume} \bullet D \bullet BEF$$

Where:

Aboveground biomass, tonnes of dry matter ha^{-1}

Commercial tree volume, m^3 ha^{-1}

D = volume-weighted average wood density, tonnes of oven-dry matter per m^3 of green volume

BEF = biomass expansion factor (ratio of aboveground oven-dry biomass of trees to oven-dry biomass of commercial volume), dimensionless.

Wood density values of most commercially important species are generally available (see, for example, Brown, 1997; Fearnside, 1997; and Annex 3A.1 Table 3A.1.9) or relatively straightforward to measure. Most published density values are for mature individuals; if wood densities are not available for young individuals, it is recommended that measurements be made. The BEF is significantly related to the commercial biomass for most forest types (in these examples, volume is over-bark for all trees with a dbh of 10 cm and above), generally starting high (>4.0) at low volumes, then declining at an exponential rate to a constant low value (about 1.3-1.8) at high volumes. Thus, using one value for the BEF for all values of standing volume is incorrect. It is recommended to either develop a local regression equation for this relationship or use those in Annex 3A.1 Table 3A.1.10 or from published sources (e.g., Brown, 1997; Brown and Schroeder, 1999; Fang et al., 2001). Additional discussion on the topic of converting commercial volume to biomass is provided in Section 3.2.1.1 of this report.

[71] It is important to state whether the volume is estimated as over or under bark; in case of under-bark volume, the expansion factor needs to take bark into account.

If a significant amount of effort is required to develop local BEFs, involving, for instance, harvest of trees, then it is recommended not to use this approach but rather to use the resources to develop local allometric equations as described under the direct approach above. The direct approach generally results in more precise biomass estimates than the indirect approach because the calculations of the former involve only one step (e.g., dbh to biomass), whereas the indirect approach involves several steps (diameter and height to volume, volume to volume-based biomass, estimation of BEF based on volume, product of three variables to biomass).

Non-tree vegetation

Non-tree vegetation such as herbaceous plants, grasses, and shrubs can occur as components of a forestry project or of cropland and grazing land management projects. Herbaceous plants in forest understorey can be measured by simple harvesting techniques of up to four small subplots per permanent or temporary plot. A small frame (either circular or square), usually encompassing about 0.5 m^2 or less, is used to aid this task. The material inside the frame is cut to ground level, pooled by plot, and weighed. Well-mixed sub-samples from each plot are then oven dried to determine dry-to-wet matter ratios. These ratios are then used to convert the entire sample to oven-dry matter. For cropland and grazing land management projects, the same approach can be used in temporary plots because, as mentioned above, there is no statistical advantage over using permanent plots (Section 4.3.3.4.1).

For shrubs and other large non-tree vegetation it is *good practice* to measure the biomass by destructive harvesting techniques. A small sub-plot depending on the size of the vegetation is established and all the shrub vegetation is harvested and weighed. An alternative approach, if the shrubs are large, is to develop local shrub allometric equations based on variables such as crown area and height or diameter at base of plant or some other relevant variable (e.g., number of stems in multi-stemmed shrubs). The equations would then be based on regressions of biomass of the shrub versus some logical combination of the independent variables. The independent variable or variables would then be measured in the sampling plots.

4.3.3.5.2 BELOWGROUND BIOMASS

Trees

Methods for measuring and estimating aboveground biomass are relatively well established. However, the belowground biomass (roots) is difficult and time-consuming to measure and estimate in most ecosystems, and methods are generally not standardized (Körner, 1994; Kurz *et al.*, 1996; Cairns *et al.*, 1997; Li *et al.*, 2003). A review of the literature shows that typical methods include spatially distributed soil cores or pits for fine and medium roots, and partial ones to complete excavation and/or allometry for coarse roots. Live and dead roots are generally not distinguished and hence root biomass is generally reported as the total of live and dead.

A comprehensive literature review by Cairns *et al.* (1997) included more than 160 studies covering native tropical, temperate, and boreal forests that reported both belowground biomass and aboveground biomass. The average belowground to aboveground dry biomass ratios based on these studies was 0.26, with a range of 0.18 (lower 25% quartile) to 0.30 (upper 75% quartile). The belowground to aboveground dry biomass ratios did not vary significantly with latitudinal zone (tropical, temperate, boreal), soil texture (fine, medium, coarse), or tree type (angiosperm, gymnosperm). Further analyses of the data produced a significant regression equation of belowground biomass density versus aboveground biomass density when all data were pooled. Inclusion of age or latitudinal belt significantly improved the model (Cairns *et al.*, 1997). Given the lack of standard methods and the time-consuming nature of monitoring belowground biomass in forests, it is *good practice* to estimate belowground biomass from either estimated aboveground biomass based on the equations in Table 4.A.4, Annex 4A.2, or from locally derived data or models.

The data used to develop the belowground biomass equations in Table 4.A.4 were based on native forests, and may not apply to plantations. Ritson and Sochacki (2003) reported that belowground to aboveground biomass ratios of plantations of *Pinus pinaster* varied between 1.5 and 0.25, decreasing with increasing tree size and/or age. For commercial plantation species, it is likely that research on belowground biomass exists that could be used. Failing that, it is *good practice* to use an estimate for belowground biomass by using the average belowground to aboveground biomass ratios, such as those in Annex 3A.1, Table 3A.1.8.

Non-tree vegetation

In non-forest project types (e.g., cropland and grazing land management), where large changes in the belowground biomass from non-tree vegetation are expected to occur, the carbon stock in the belowground biomass pool needs to be estimated (Table 4.3.1). For non-tree vegetation, it is not possible to estimate belowground biomass from aboveground biomass data and therefore, on-site measurements may be required.

Direct measurement of belowground biomass requires collecting soil samples, usually in the form of cores of known diameter and depth, separating the roots from soil, and oven-drying and weighing the roots. It is recommended to perform the following steps for direct measurement of belowground biomass in the field:

- The sampling design should follow the procedures detailed earlier in Section 4.3.3.4.
- Because a large proportion of non-tree root biomass is usually present in the upper soil layers, in most situations sampling to a depth of 0.3-0.4 m should suffice. In cases where samples are collected at deeper depths, it is recommended to split the sample into two or more layers, clearly recording the depth of each layer.
- Separation of roots from soil can be performed by using root washing devices (Cahoon and Morton, 1961; Smucker *et al.*, 1982) for maximum recovery. If these devices are not available, simpler procedures (e.g., placing soil samples on a sieve and washing roots with high pressure water) may yield recovery of a relatively large proportion of root biomass.
- Non-root belowground biomass (e.g., stolons, rhizomes and tubers) should be considered as part of the belowground biomass pool.
- Roots should be oven-dried at 70 ^{o}C until dry and then weighed. The resulting weight should be divided by the cross sectional area of the sample core to determine belowground biomass on a per-area basis.

The core-break method has been found to be a rapid method for evaluating root distributions in the field (Böhm, 1979; Bennie *et al.*, 1987). With this technique, cores are removed from different soil depths, broken in half, and the visible root axes on each cross-sectional surface area are counted and averaged. To convert root counts to estimates of root length density or biomass requires calibration equations for each crop species, soil type, and management practice. Calibration equations should be developed locally and may change with crop development or soil depth (Drew and Saker, 1980; Bennie *et al.*, 1987; Bland, 1989).

4.3.3.5.3 DEAD ORGANIC MATTER

Litter

Litter can be directly sampled using a small frame (either circular or square), usually encompassing an area of about 0.5 m^2, as described above for herbaceous vegetation (four subplots within the sample plot). The frame is placed in the sample plot and all litter within the frame is collected and weighed. A well-mixed sub-sample is collected to determine oven dry-to-wet weight ratios to convert the total wet mass to oven-dry mass.

An alternative approach for systems where the litter layer is well-defined and deep (more than 5 cm), is to develop a local regression equation that relates depth of the litter to the mass per unit area. This can be done by sampling the litter in the frames as mentioned above and at the same time measuring the depth of the litter. At least 10-15 such data points should be collected, ensuring that the full range of the expected litter depth is sampled.

Dead wood

Dead wood, both standing and lying, does not generally correlate well with any index of stand structure (Harmon *et al.*, 1993). Methods have been developed for measuring biomass of dead wood and have been tested in many forest types and generally require no more effort than measuring live trees (Brown, 1974; Harmon and Sexton, 1996; Delaney *et al.*, 1998). For dead wood lying on the ground, the general approach is to estimate the volume of logs by density class (often related to its decomposition state, but not always) and then convert to mass as a product of volume and density, for each density class. There are two approaches that can be used to estimate the volume of dead wood present, depending upon the expected quantity present.

Method 1 – when the quantity is expected to be a relatively small proportion of the aboveground biomass (i.e., about 10-15%, based on expert judgement): A time-efficient method is the line-intersect method, and it is *good practice* to use at least 100 m length of line, generally divided into two 50 m sections placed at right angles across the plot centre. The diameters of all pieces of wood that intersect the line are measured and each piece of dead wood is also classified into one of several density classes. If the intersected log is elliptical in shape the minimum and maximum diameters need to be measured. The volume per hectare is estimated for each density class as follows (for more details on the derivation of this equation see Brown (1974)):

EQUATION 4.3.2
VOLUME OF LYING DEAD WOOD

$$\text{Volume } (m^3/ha) = \pi^2 \bullet (D_1^2 + D_2^2 + \ldots + D_n^2) / (8 \bullet L)$$

Where:

$D_1, D_2, \ldots, D_n$ = diameter of each of n pieces intersecting the line, in centimetres (cm). The round equivalent of an elliptically shaped log is computed as the square root of ($D_{minimum} \bullet D_{maximum}$) for that log.

L = the length of the line, in metres (m).

An additional multiplier is often introduced to Equation 4.3.2 to correct the bias introduced by the non-horizontal orientation of the pieces (Brown and Roussopolos, 1974). However, this correction is not required for coarse dead wood, as this bias decreases with piece diameter. For more details see Harmon and Sexton (1996).

Method 2 – when the quantity is expected to be a relatively large proportion of the aboveground biomass (i.e., more than about 15%, based on expert judgement): When the quantity of dead wood lying on the forest floor is expected to be high and variably distributed, as in slash left behind after logging, it is *good practice* to do a complete inventory of the wood in the sampling plots. It is recommended to measure all the dead wood in a subplot of the sampling plots (see also Harmon and Sexton, 1996, for details on the methods). For a complete census, the volume of each piece of dead wood lying within the circle is calculated based on the diameter measurements taken at 1 m intervals along each piece of dead wood in the plot. The volume of each piece is then estimated as the volume of a truncated cylinder based on the average of the two diameter measurements and the distance between them (usually 1 m). As with Method 1, each piece of dead wood is also classified into a density class. The volume is summed for each density class and, using the appropriate factor (based on the area of the plot), expressed on a m^3/ha basis for each density class.

Density measurements: Experience shows that three density classes are sufficient—sound, intermediate and rotten. An objective and consistent way to distinguish between them is needed. A common practice in the field is to strike the wood with a "machete"—if the blade bounces off it is sound, if it enters slightly is it intermediate, and if it causes the wood to fall apart it is rotten ("machete test"). Samples of dead wood in each density class are then collected to determine their wood density. Mass of dead wood is then the product of volume per density class (from above equation) and the wood density for that class. Thus a key step in this method is to classify the dead wood into its correct density class and then to adequately sample a sufficient number of logs in each class to represent the wood densities present. It is *good practice* to sample at least 10 logs of each different density class. In forests with palms or early colonizers or hollow logs, it is also *good practice* to treat these as separate groups and sample them the same way.

For projects based on few species and where the rate of decomposition of wood is well known for given species or forest types, models could be locally developed for estimating the density of the dead wood at different stages of decomposition (Beets *et al.*, 1999). Volume of wood would still need to be estimated based on either Method 1 or 2 above, but the density could be estimated based on the model of decomposition.

Standing dead wood is measured as part of the tree inventory. Standing dead trees should be measured according to the same criteria as live trees. However, the measurements that are taken and the data that are recorded vary slightly from live trees. For example, if the standing dead tree contains branches and twigs and resembles a live tree (except for leaves) this would be noted in the field data. From the measurement of its dbh, its biomass can be estimated using the appropriate allometric equation as for live trees, subtracting out the biomass of leaves (about 2-3% of aboveground biomass). However, a dead tree can contain only small and large branches, or only large branches, or no branches – these conditions need to be recorded in the field measurements and the total biomass can be reduced accordingly; in particular if only large branches remain, the biomass estimated from the appropriate allometric equation is reduced by about 20% to account for the absence of smaller branches and twigs. When a tree has no branches and is just the bole, then its volume can be estimated from measurements of its basal diameter, height, and an estimate of its top diameter; and its biomass can be calculated with its density class.

4.3.3.5.4 SOIL ORGANIC CARBON

The soil organic carbon pool is estimated from soil samples taken in the sample plots. Soil samples are usually taken with a metallic cylinder at different depths or by the excavation method. It is *good practice* to collect a composite sample (recommended to collect about two to four such samples per composite) in each plot and depth. These are then mixed and homogenized to make one composite sample for each depth and plot. To estimate the soil carbon stock, an additional composite sample needs to be collected for bulk density measurements at each depth and plot (see also Section 3.2.1.3.1.1 and Section 3.2.1.3.1.2 for further discussion on soil organic carbon).

In coarse textured, stony soils, sampling bulk density by soil cores is inadequate and will probably overestimate the bulk density of the fine soil in the horizon (Blake and Hartage, 1986; Page-Dumroese *et al.*, 1999). Instead, the excavation method is recommended, supplemented with an estimate of the percent volume occupied by stones. If significant non-soil areas (e.g., large rocky outcrops) exist in the project site, these should be eliminated at the start of the project during stratification; estimates of soil carbon should only be scaled to the area where soil exists.

The depth to which the soil carbon pool should be measured and monitored may vary according to project type, site conditions, species, and expected depth at which change will take place (see Chapter 3 and other sections in Chapter 4 for additional details). In most cases, soil organic carbon concentrations are highest in the uppermost layer of soil and decrease exponentially with depth. However, the relationship of soil organic carbon concentrations with soil depth can vary as a result of such factors as the depth distribution of roots, transport of soil organic carbon within the soil profile, and erosion/deposition. It is *good practice* to measure the soil carbon pool to a depth of at least 30 cm. This is the depth where the changes in the soil carbon pool are likely to be fast enough to be detected during the project period. In cases where a project is using deep-rooted plants, it may be useful to measure and monitor the soil carbon pool to depths greater than 40 cm. However, this increases the costs of measuring and monitoring.

If soils are shallower than 30 cm then it is important that the depth of each soil sample collected be measured and recorded. Calculations to estimate the soil carbon stocks need to account for varying soil depth over the project area and soil depth should therefore be taken into account in the stratification.

The two most commonly used methods for soil carbon analysis are: the dry combustion method and the Walkley Black method (wet oxidation method). MacDicken (1997) discusses advantages and disadvantages of these methods for soil analysis. The Walkley Black method is commonly used in laboratories that have few resources, as it does not require sophisticated equipment. However, in many countries, professional labs exist that use the dry combustion method, and the cost can often be modest. It is *good practice*, especially where soil carbon is a significant aspect of the project, to use the dry combustion method. Because the dry combustion method includes carbonates, it is important that the soils that could contain carbonates be pre-tested and the inorganic carbon be removed by acidification.

There are two ways to express soil carbon – on an equal mass or equal volume basis. There are advantages and disadvantages to both methods. To express changes in soil carbon on an equal mass basis requires that the change in the soil bulk density be known ahead of the sampling so that adjustments can be made to collect an equal mass of soil. Alternatively, the adjustments can be made as part of the calculations. It is likely that projects designed to enhance soil organic carbon will also cause the soil bulk density to decrease. If it is expected that the soil bulk density will change significantly during the course of the project, it is recommended to assess the impact of expressing the changes in soil carbon on an equal mass or equal volume basis on the total projected change in soil carbon stocks. Otherwise, it is recommended that the changes in soil carbon stocks be reported on an equal volume basis, as it is commonly done.

The soil carbon stock per unit area on an equal volume basis is then calculated as:

EQUATION 4.3.3
SOIL ORGANIC CARBON CONTENT

$$SOC = [SOC] \bullet \text{Bulk Density} \bullet \text{Depth} \bullet \text{CoarseFragments} \bullet 10$$

Where:

SOC = the soil organic carbon stock for soil of interest, Mg C ha^{-1}

[SOC] = the concentration of soil organic carbon in a given soil mass, g C $(kg\,soil)^{-1}$ (from lab analyses)

Bulk Density = the soil mass per sample volume, Mg m^{-3}

Depth = sampling depth or thickness or soil layer, m

CoarseFragments = 1 – (% volume of coarse fragments / 100) [72]

The final multiplier of 10 is introduced to convert units to Mg C ha^{-1}.

4.3.3.6 ESTIMATING CHANGES IN NON-CO_2 GREENHOUSE GAS EMISSIONS AND REMOVALS

Although the primary purpose of LULUCF projects is to increase carbon stocks relative to a baseline, practices included as part of LULUCF projects may also result in changes in non-CO_2 greenhouse gas emissions and

[72] In soils with coarse fragments (e.g., soils developed on till or coarse alluvium, or with high concentration of roots), SOC is adjusted for the proportion of the volumetric sample occupied by the coarse fraction (>2 mm fraction).

removals. Such practices, associated with the LULUCF sector, include, for instance, biomass burning (e.g., during site preparation); change in livestock production (caused, for example, by changes in forage species in grazing land management); application of synthetic and organic fertilizers to soils; cultivation of nitrogen fixing trees, crops, and forages; flooding and drainage of soils. In addition, land-use practices that disturb soils, e.g., tillage for crop cultivation or for afforestation/reforestation site preparation, may affect non-CO_2 emissions and removals from soils. Table 4.3.2 lists possible LULUCF project practices that can affect non-CO_2 emissions and removals. However, the definitions and modalities for Article 12, which are under negotiation at the time of this writing, may determine which of these practices are to be included in measurement, monitoring, and reporting of Article 12 project activities.

TABLE 4.3.2
POSSIBLE LULUCF PROJECT PRACTICES THAT MAY RESULT IN EMISSIONS OR REMOVALS OF NON-CO_2 GREENHOUSE GASES

Practice	Effect on non-CO_2 gases	Emission or removal process
Biomass Burning	Source of CH_4 and N_2O[a]	Combustion[b]
Synthetic and Organic Fertilizer Application	Source of N_2O	Nitrification/denitrification of fertilizers and organic amendments applied to soils
	Reduced CH_4 removal	Suppression of soil microbial oxidation of CH_4
Cultivation of N-Fixing Trees, Crops, and Forages	Source of N_2O	Nitrification/denitrification of soil N from enhanced biological N fixation
Soil Re-Flooding	Source of CH_4	Anaerobic decomposition of organic material in soils
	Reduced/Eliminated source of N_2O	Reduces mineralization of soil organic matter
Soil Drainage	Reduced/Eliminated source of CH_4	Reduction of anaerobic decomposition of organic material
	Source of N_2O	Mineralization of soil organic matter and subsequent nitrification/denitrification of mineralised nitrogen
Soil Disturbance	Source of N_2O	Mineralization of soil organic matter and subsequent nitrification/denitrification of mineralised nitrogen
	Reduced CH_4 removal	Suppression of soil microbial oxidation of CH_4
Changes in Grazing Land Management[c]	Increased or decreased source of CH_4 and N_2O from effects on livestock	Animal digestion (CH_4)
		Anaerobic decomposition of manure stored in manure management systems and applied/deposited on soils (CH_4)
		Nitrification/denitrification of N in manure stored in manure management systems and applied/deposited on soils (N_2O)

[a] Biomass burning is also a source of carbon monoxide, oxides of nitrogen, and non-methane volatile organic compounds. These emissions are not addressed here because these gases are not considered under the Kyoto Protocol.

[b] Some experiments have indicated that open biomass burning (i.e., field burning of vegetation) results in elevated emissions of N_2O from soils for up to six months after burning (cf. Chapter 5 of Volume 3 of the *IPCC Guidelines*). However, other experiments have found no long-term effect on soil N_2O emissions, so this process is not addressed further here.

[c] Changes in the species mix of grazing land plants for enhancing soil carbon, for example, could affect livestock production and thus the non-CO_2 greenhouse gases they produce.

In general, it is recommended to estimate the net greenhouse gas emissions and removals from these practices with project-specific activity data and site-specific emission factors. It is also recommended to derive the emission factors from either well-designed and well-implemented field measurements at either the project site(s) or at sites that are considered to reproduce the conditions of the project site(s); or from validated, calibrated, and well-documented simulation models implemented with project site-specific input data. The *IPCC Guidelines*, as amended by *GPG2000*, and Chapter 3 of this report provide default Tier 1 methods and emission factors for estimating emissions from many of these practices at the national level (see Table 4.3.3). However, these documents provide limited *good practice guidance* for either measurement of, or simulation modelling of, emissions and removals from many of these practices. Because these practices fall within IPCC national inventory sectors other than Land-Use Change and Forestry (e.g., the Energy or Agriculture sectors), it is beyond the scope of this report to provide detailed *good practice guidance* for measuring, monitoring, and estimating emissions and removals from these practices.

Changes in non-CO_2 greenhouse gas emissions or removals caused by these practices may be small relative to net changes in carbon stocks over the lifetime of the LULUCF project. Therefore, when any of these practices are part of a LULUCF project, it is recommended first to estimate the likely annual net changes in non-CO_2 emissions or removals over the lifetime of the project based upon project activity data and the default IPCC methods and emission factors provided in the *IPCC Guidelines*, as amended by *GPG2000* and Chapter 3 of this report. If the expected average annual net change in non-CO_2 emissions or removals is relatively small, e.g., less than about 10% of expected average total annual net carbon stock changes on a CO_2-equivalent basis, use of the default IPCC emission factors may be adequate. However, if the expected average annual net change in non-CO_2 emissions or removals from an activity is relatively large, e.g., greater than about 10% of expected average annual net carbon stock changes on a CO_2-equivalent basis, it is recommended to develop project-specific emission factors, either through measurement or simulation models.

TABLE 4.3.3
LOCATION OF IPCC DEFAULT METHODS AND DATA FOR ESTIMATION OF NON-CO_2 GREENHOUSE GAS EMISSIONS AND REMOVALS

Practice	Location of IPCC Default Methods and Data
Biomass Burning	• Emission ratio methodologies and emission ratios for confined burning for energy production in the Energy chapter of the *IPCC Guidelines* and the *GPG2000.* • Emission ratio methodologies and emission ratios for open field burning in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. • Emission ratio and emission factor methodology, and combustion efficiencies, emission ratios, and emission factors for open field burning in forest, grassland, and savanna ecosystem types in Chapter 3 of this Report (see Section 3.2.1.4, Section 3.4.1.3, and Annex 3A.1).
Synthetic and Organic Fertilizer [a] Application	• Emission factor method, fertilizer nitrogen contents, volatilisation and leaching/runoff rates, and default emission factors for N_2O emissions in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. Note: Both direct and indirect N_2O emissions should be estimated, even though some of the indirect emissions may occur outside of a project's geographic boundaries. • N_2O emissions from fertilized soils may be affected by liming (see Section 3.2.1.4 of this Report). However, because liming has been found to both enhance and reduce N_2O emissions from fertilization, default emission factors for fertilizer application to limed soils are not provided
Cultivation of N-Fixing Trees, Crops, and Forages	• Emission factor method, biomass nitrogen content, and emission factor for crops and forages in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. The method is based on the amount of nitrogen in the aboveground biomass produced annually, which is used as a proxy for the additional amount of nitrogen available for nitrification and denitrification. Default methods have not been developed for leguminous trees (see Section 3.2.1.4 of Chapter 3 of this Report).
Soil Re-Flooding and Drainage	• Methods and area-based N_2O emission factors for drainage of forest soils and drainage of wetlands in Appendix 3a.2 and Appenddix 3a.3, respectively, of this Report. • Methods and emission factors for CH_4 are not provided.
Soil Disturbance	• Method and N_2O emission factors for cultivation of organic soils (i.e., histosols) in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. • For disturbance of mineral soils, methods and emission factors for estimating increases in N_2O emissions in lands converted to croplands in Section 3.3.2.3 of this Report. • Methods and emission factors for CH_4 are not provided.
Changes in Grazing Land Management	• Emission factor methodologies for animal digestion and manure application/deposition in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. Emission factors and data for deriving emission factors, as well as emission estimation models for some animal types are also provided. Project-specific emission factors for some animal types can be developed by applying project-specific data (e.g., animal weight and feed digestibility) to the IPCC emission estimation models.

a The term fertilizer is used here to encompass both synthetic and organic fertilizers, e.g., urea and compost, as well as organic soil amendments such as uncomposted crop residues.

4.3.3.7 MONITORING CHANGES IN GREENHOUSE GAS EMISSIONS AND REMOVALS FROM PROJECT OPERATION PRACTICES

Greenhouse gas emissions from the direct use of energy in project operations can be significant. Such direct energy use includes both fuels and electricity consumed in both mobile and stationary equipment. Examples of mobile sources include tractors used for site preparation, fertilizer application, tillage, or planting; road transport to and from sites for monitoring; light-rail transport such as for the transport of logs out of the forest; air transport such as in helicopter logging; and water transport of logs from the forest. Stationary equipment, which, for most LULUCF projects, will typically constitute a less significant source of greenhouse gas emissions than mobile sources, could include machinery such as soil mixers and potting equipment in nurseries, irrigation pumps, and lighting. Project operators need to determine and report the greenhouse gas emissions from direct fossil fuel and electricity use in mobile and stationary equipment.

Carbon dioxide is the primary greenhouse gas emitted from fossil fuel consumption in stationary and mobile equipment. Because N_2O and CH_4 emissions are likely to make up a relatively small proportion of overall energy use emissions from projects, estimation of these emissions is at the discretion of the user.

Greenhouse gas emissions from stationary sources can be estimated by applying appropriate emission factors to the fuel quantity or electricity consumed (see the Energy chapters of the *IPCC Guidelines* and the *GPG2000*). Emissions from mobile sources can be estimated with either a fuel-based approach, or a distance-based approach (see Box 4.3.5 and the Energy chapters of the *IPCC Guidelines* and the *GPG2000*).

BOX 4.3.5
GUIDANCE ON ESTIMATING GREENHOUSE GAS EMISSIONS FROM MOBILE SOURCES

Direct greenhouse gas emissions from the use of vehicles can be estimated through either of two methodologies:

Fuel-based approach

Distance-based approach

The choice of methodology is dependent on data availability. However, the fuel-based method is the preferred method for all modes of transport as the method is associated with lower uncertainty. In this case, the quantity of fossil fuel, usually gasoline and/or diesel fuel that is combusted during project practices needs to be monitored and recorded. For a detailed description of the methodologies, see the *IPCC Guidelines* and the *GPG2000*.

4.3.3.8 CONSIDERATIONS FOR THE MONITORING PLAN

The monitoring plan has specific meaning in the context of Articles 6 and 12 of the Kyoto Protocol. The plan includes, but is not limited to, planning of the measurement that will show how the project affects carbon stocks and emissions of non-CO_2 greenhouse gases over time. This subsection provides general advice relevant to measurement aspects of the plan only.

4.3.3.8.1 MONITORING PROJECTS WITH SMALL-SCALE LANDOWNERS

Monitoring projects that could involve multiple small-scale landholders, working on small but discrete parcels of land spread over a region requires attention. As described above (Section 4.3.3.2), whether the project is one contiguous parcel made up of one or two large land owners or many small parcels spread over a large area with many small land owners, the project land can be delineated and stratified using standard techniques. It is not expected that each parcel would be monitored as if constituting a separate project, but instead can be treated as one project and monitored for carbon at the project level as described above. However, because the project is spread out over many land owners, it is *good practice* to develop monitoring protocols for the project level, and then to develop indicators that can be monitored at the parcel level to ensure project-level performance (see Box 4.3.6).

BOX 4.3.6
MONITORING PROJECTS INVOLVING MULTIPLE SMALL-SCALE LANDHOLDERS

Monitoring the changes in carbon stocks and non-CO_2 greenhouse gas emissions and removals when projects are constituted by multiple small-scale landholders will require the monitoring system to be split between two levels: (1) the project level and (2) the parcel level, as follows:

Level 1: project level

For each activity to be implemented within the project area, it is *good practice* to develop a technical description, setting out the management objectives, the species, the soil, climatic and vegetation conditions suitable for the activity, the expected inputs in terms of materials and labour and the expected outputs in terms of growth and yield of products. The technical descriptions should also include tables relating readily measured indicators at the parcel level (for example *diameter at breast height* or *top height*) to estimates of carbon stocks. These tables may be produced with reference to Section 4.3.3.5, using either direct or indirect methods. *Good practice* also entails establishment of a number of sample plots within the project area to maintain and improve the calibration of these tables (according to Section 4.3.3.4). Each technical description should also include a set of parameters used to determine the baseline carbon stocks, against which the carbon uptake is to be measured. A similar set of indicators that are readily measured at the plot level should be tabulated against baseline carbon stocks.

Level 2: parcel level

Within each parcel the following measurements can then be taken: 1) cross-check to determine whether the activity implemented in the parcel falls within the parameters set out in the technical description (e.g., correct species, planting density, climate, etc); 2) measurement of baseline indicators; and 3) measurement of activity indicators.

The changes in carbon stocks are then estimated with reference to the tables in the relevant technical descriptions. Quality assurance procedures should examine the data collection procedures at both levels within such projects.

4.3.3.8.2 FREQUENCY OF CARBON MONITORING

The frequency of monitoring should take into consideration the carbon dynamics of the project and costs involved. In the tropics, changes in the carbon stock in trees and soils in an afforestation/reforestation project can be detected with measurements at intervals of about 3 years or less (Shepherd and Montagnini, 2001). In the temperate zone, given the dynamics of forest processes, they are generally measured at 5-year intervals (e.g., many national forest inventories). For carbon pools that respond more slowly, such as soil, even longer periods could be used. Thus it is recommended that for carbon accumulating in the trees, the frequency of monitoring should be defined in accordance with the rate of change of the carbon stock, and be in accordance with the rotation length (for plantations) and cultivation cycle (for croplands and grazing lands).

4.3.3.8.3 OVERALL PROJECT SITE PERFORMANCE

Monitoring only the changes in carbon stocks and non-CO_2 greenhouse gases in the permanent monitoring plots does not necessarily provide the information for assessing whether the project is accomplishing the same changes in carbon stocks across the entire project and whether the project is accomplishing what it set out to do— e.g., plant several thousand hectares of trees. Periodic visits to the carbon monitoring plots will only show that the carbon in those plots (which were randomly located and should be representative of the population) is accumulating with known accuracy and precision at a given confidence level. As the project developers will know the location of the plots, it is also important that through time comprehensive checks are made to ensure that the overall project is performing the same way as the plots. This can be accomplished through third-party field verification using indicators of carbon stock changes, such as tree height for afforestation/reforestation projects and crop productivity for cropland management projects. It is *good practice* for project developers to produce such indicators that can readily be field-verified across the project area. To monitor overall project site performance (i.e., project activities are being performed over the entire project area), one of several methods can be used, depending upon the level of technology and resources available, such as:

- Visual site visits with photographic documentation. It is recommended to thoroughly inspect the total area planted in each region and that a selection of photographs be taken and dated. The field reports and photos should be part of the permanent record.

- Digital aerial imagery, using multi-spectral sensors (particularly infra-red), of GPS located transects across each planted area. As above, full documentation and digital photographs, dated, should be part of the project's records.
- Remote sensing with use of very high-resolution satellite data (e.g., Ikonos, QuickBird) or high resolution satellite data (e.g., Spot, Landsat, RadarSat, Envisat ASAR). The decision on which satellite imagery to use will depend on size of project (100s to 1,000s of ha), location (mostly under high cloud cover or often free of clouds), and project resources.

4.3.4 Quality Assurance and Quality Control Plan

Monitoring requires provisions for quality assurance (QA) and quality control (QC) to be implemented via a QA/QC plan. The plan should become part of project documentation and cover procedures as described below for: (1) collecting reliable field measurements; (2) verifying methods used to collect field data; (3) verifying data entry and analysis techniques; and (4) data maintenance and archiving. If after implementing the QA/QC plan it is found that the targeted precision level is not met, then additional field measurements need to be conducted until the targeted precision level is achieved.

4.3.4.1 Procedures to ensure reliable field measurements

Collecting reliable field measurement data is an important step in the quality assurance plan. Those responsible for the measurement work should be fully trained in all aspects of the field data collection and data analyses. It is *good practice* to develop Standard Operating Procedures (SOPs) for each step of the field measurements, which should be adhered to at all times. These SOPs should detail all phases of the field measurements and contain provisions for documentation for verification purposes and so that future field personnel can check past results and repeat the measurements in a consistent fashion.

To ensure the collection of reliable field data, it is *good practice* to ensure that:

- Field-team members are fully cognisant of all procedures and the importance of collecting data as accurately as possible;
- Field teams install test plots if needed in the field and measure all pertinent components using the SOPs;
- All field measurements are checked by a qualified person in cooperation with the field team and correct any errors in techniques;
- A document is filed with the project documents that show that these steps have been followed. The document will list all names of the field team and the project leader will certify that the team is trained;
- New staff are adequately trained.

4.3.4.2 Procedures to verify field data collection

To verify that plots have been installed and the measurements taken correctly, it is *good practice*:

- To re-measure independently every 8-10 plots, and to compare the measurements to check for errors; any errors found should be resolved, corrected and recorded. The re-measurement of permanent plots is to verify that measurement procedures were conducted properly.
- At the end of the field work, to check independently 10-20% of the plots. Field data collected at this stage will be compared with the original data. Any errors found should be corrected and recorded. Any errors discovered should be expressed as a percentage of all plots that have been rechecked to provide an estimate of the measurement error.

4.3.4.3 Procedures to verify data entry and analysis

Reliable carbon estimates require proper entry of data into the data analyses spreadsheets. Possible errors in this process can be minimised if the entry of both field data and laboratory data are reviewed using expert judgement and, where necessary, comparison with independent data to ensure that the data are realistic. Communication between all personnel involved in measuring and analysing data should be used to resolve any apparent anomalies before the final analysis of the monitoring data is completed. If there are any problems with the monitoring plot data that cannot be resolved, the plot should not be used in the analysis.

4.3.4.4 DATA MAINTENANCE AND STORAGE

Because of the relatively long-term nature of these projects, data archiving (maintenance and storage) will be an important component of the work (see also Section 5.5.6). Data archiving should take several forms and copies of all data should be provided to each project participant.

Copies (electronic and/or paper) of all field data, data analyses, and models; estimates of the changes in carbon stocks and non-CO_2 greenhouse gases and corresponding calculations and models used; any GIS products; and copies of the measuring and monitoring reports should all be stored in a dedicated and safe place, preferably offsite.

Given the time frame over which the project will take place and the pace of production of updated versions of software and new hardware for storing data, it is recommended that the electronic copies of the data and report be updated periodically or converted to a format that could be accessed by any future software application.

Annex 4A.1 Tool for Estimation of Changes in Soil Carbon Stocks associated with Management Changes in Croplands and Grazing Lands based on IPCC Default Data

(see the attached CD-ROM)

Annex 4A.2 Examples of allometric equations for estimating aboveground biomass and belowground biomass of trees

TABLE 4.A.1
ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVEGROUND BIOMASS (KG DRY MATTER PER TREE) OF TROPICAL AND TEMPERATE HARDWOOD AND PINE SPECIES

Equation	Forest type[a]	R^2/sample size	DBH range (cm)
$Y = \exp[-2.289 + 2.649 \bullet \ln(DBH) - 0.021 \bullet (\ln(DBH))^2]$	Tropical moist hardwoods	0.98/226	5 - 148
$Y = 21.297 - 6.953 \bullet (DBH) + 0.740 \bullet (DBH)^2$	Tropical wet hardwoods	0.92/176	4 - 112
$Y = 0.887 + [(10486 \bullet (DBH)^{2.84}) / ((DBH^{2.84}) + 376907)]$	Temperate/tropical pines	0.98/137	0.6 - 56
$Y = 0.5 + [(25000 \bullet (DBH)^{2.5}) / ((DBH^{2.5}) + 246872)]$	Temperate US eastern hardwoods	0.99/454	1.3 - 83.2

Where

Y= aboveground dry matter, kg $(tree)^{-1}$
DBH =diameter at breast height, cm
ln = natural logarithm
exp = "e raised to the power of"

[a] Tropical moist generally represent areas with rainfall of between 2000 to 4000 mm/year in the lowlands; tropical wet is suited for areas with rainfall greater than 4000 mm/year in the lowlands (see Brown, 1997 for further discussion).

Sources: Updated from Brown, 1997; Brown and Schroeder, 1999; Schroeder *et al.*, 1997

TABLE 4.A.2
ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVEGROUND BIOMASS OF PALM TREES (KG DRY MATTER PER TREE) COMMON IN TROPICAL HUMID FORESTS OF LATIN AMERICA. THE NUMBER OF HARVESTED TREES WAS 15 FOR EACH SPECIES

Equation	Palm species	R^2	Height range (HT in m)
$Y = 0.182 + 0.498 \bullet HT + 0.049 \bullet (HT)^2$	*Chrysophylla* sp	0.94	0.5-10.0
$Y = 10.856 + 176.76 \bullet (HT) - 6.898 \bullet (HT)^2$	*Attalea cohune*	0.94	0.5-15.7
$Y = 24.559 + 4.921 \bullet HT + 1.017 \bullet (HT)^2$	*Sabal* sp	0.82	0.2-14.5
$Y = 23.487 + 41.851 \bullet (\ln(HT))^2$	*Attalea phalerata*	0.62	1-11
$Y= 6.666 + 12.826 \bullet (HT^{0.5}) \bullet \ln(HT)$	*Euterpe precatoria & Phenakospermun guianensis*	0.75	1-33

Where

Y = aboveground dry matter, kg $(tree)^{-1}$
HT = height of the trunk, meters (for palms this is the main stem, excluding the fronds)
ln = natural logarithm

Source: Delaney *et al.*, 1999; Brown *et al.*, 2001

TABLE 4.A.3
EXAMPLES OF ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVEGROUND BIOMASS (KG OF DRY MATTER PER TREE) OF SOME INDIVIDUAL SPECIES COMMONLY USED IN THE TROPICS

Equation	Species	R^2	Height for DBH/BA (cm)[a]	Diameter range (cm)	Source
$Y = 0.153 \bullet DBH^{2.382}$	*Tectona grandis* [b]	0.98	130	10-59	1
$Y = 0.0908 \bullet DBH^{2.575}$	*Tectona grandis* [c]	0.98	130	17-45	2
$Y = 0.0103 \bullet DBH^{2.993}$	*Bombacopsis quinatum* [d]	0.97	130	14-46	3
$Y = 1.22 \bullet DBH^2 \bullet HT \bullet 0.01$	*Eucalyptus sp.* [e]	0.97	130	1-31	4
$Y = 0.08859 \bullet DBH^{2.235}$	*Pinus pinaster* [f]	0.98	10	0-47	5
$Y = 0.97 + 0.078 \bullet BA - 0.00094 \bullet BA^2 + 0.0000064 \bullet BA^3$	*Bactris gasipaes* [g]	0.98	100	2-12	6
$Y = -3.9 + 0.23 \bullet BA + 0.0015 \bullet BA^2$	*Theobroma grandiflora* [g]	0.93	30	6-18	6
$Y = -3.84 + 0.528 \bullet BA + 0.001 \bullet BA^2$	*Hevea brasiliensis* [g]	0.99	150	6-20	6
$Y = -6.64 + 0.279 \bullet BA + 0.000514 \bullet BA^2$	*Citrus sinensis* [g]	0.94	30	8-17	6
$Y = -18.1 + 0.663 \bullet BA + 0.000384 \bullet BA^2$	*Bertholletia excelsa* [g]	0.99	130	8-26	6

Where

Y = aboveground dry matter, kg $(tree)^{-1}$
DBH =diameter, cm
HT = total height of the tree, meters
BA = basal area, cm^2

[a] Height for DBH/BA is height above ground where diameter or basal area was measured, cm

[b] 87 individuals at ages of 5-47 years.

[c] 9 individuals at age of 20 years.

[d] 17 individuals at ages of 10-26 years.

[e] Pooled values for 458 individuals of *Eucalyptus ovata*, *E. saligna*, *E. globulus* and *E. nites* at ages of 2-5 years.

[f] 148 individuals at ages of 1-47 years.

[g] 7-10 individuals at age of 7 years.

Sources: (1) Pérez and Kanninen, 2003; (2) Kraenzel *et al.*, 2003; (3) Pérez and Kanninen, 2002; (4) Senelwa and Sims, 1998; (5) Ritson and Sochacki, 2003; (6) Schroth *et al.*, 2002.

TABLE 4.A.4
ALLOMETRIC EQUATIONS FOR ESTIMATING BELOWGROUND OR ROOT BIOMASS OF FORESTS
ALTHOUGH ADDITION OF AGE AND LATITUDE DID NOT INCREASE THE R^2 BY VERY MUCH, THE COEFFICIENTS WERE HIGHLY SIGNIFICANT

Conditions and independent variables	Equation	Sample size	R^2
All forests, ABD	Y=exp[–1.085 + 0.9256 • ln(ABD)]	151	0.83
All forests, ABD and AGE	Y=exp[–1.3267+0.8877•ln(ABD)+0.1045•ln(AGE)	109	0.84
Tropical forests, ABD	Y=exp[–1.0587 + 0.8836 • ln(ABD)]	151	0.84
Temperate forests, ABD	Y=exp[–1.0587 + 0.8836 • ln(ABD) + 0.2840]	151	0.84
Boreal forests, ABD	Y=exp[–1.0587 + 0.8836 • ln(ABD) + 0.1874]	151	0.84

Where

Y= root biomass in Mg ha^{-1} of dry matter
ln = natural logarithm
exp = "e to the power of"
ABD = aboveground biomass in Mg ha^{-1} of dry matter
AGE = age of the forest, years

Source: Cairns et al., 1997

References

METHODS FOR ESTIMATION, MEASUREMENT, MONITORING AND REPORTING OF LULUCF ACTIVITIES UNDER ARTICLES 3.3 AND 3.4

Coleman K. and Jenkinson D.S. (1996). RothC-26.3- A Model for the turnover of carbon in soil. In: Powlson D.S., Smith P., and Smith J.U. (eds.) Evaluation of Soil Organic Matter Models Using Existing, Long-Term Datasets, NATO ASI Series I, Vol.38, Springer-Verlag, Heidelberg, pp. 237-246. 34

Flanagan L.B., Wever L.A., and Carlson P.J. (2002). Seasonal and interannual variation in carbon dioxide exchange and carbon balance in a northern temperate grassland. *Global Change Biology,* 8: pp. 599-615.

Follett R.F., Kimble R.F., and Lal R. (2000). The potential of U.S. grazing lands to sequester carbon. In: Follett R.F., Kimble J.M. and Lal R. (eds).The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. Lewis Publishers, Boca Raton: pp. 401-430.

Griffis T.J., Rouse W.R., and Waddington J.M. (2000). Interannual variability of net ecosystem CO_2 exchange at a subarctic fen. *Global Biogeochemical Cycles,* 14: pp. 1109-1121.

Guo, L.B. and Gifford R.M. (2002). Soil carbon stocks and land use change: a meta analysis. *Global Change Biology,* 8: pp. 345-360.

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

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK.

Kurz W.A. and Apps M.J. (1999). A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector. *Ecological Applications,* 9(2): pp. 526-547.

Kurz W.A., Apps M.J., Webb T.M., and McNamee P.J. (1992). The carbon budget of the Canadian forest sector: phase I. Forestry Canada, Northwest Region. Information Report NOR-X-326, 93 pp.

Lal R.,Kimble J.M., Follet R.F., Cole C.V. (1998). The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press, Chelsea, MI. 128pp.

Linn D.M., Doran J.W. (1984). Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. *Soil Science Society of America Journal*, 48: pp. 1267-1272.

MacKenzie A.F., Fan M.X. and Cadrin F. (1998). Nitrous oxide emission in three years as affected by tillage, corn-soybean-alfalfa rotations, and nitrogen fertilization. *Journal of Environmental Quality* 27: pp. 698-703.

Parton W.J., Schimel D.S., Cole C.V. and Ojima D.S. (1987). Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* 51, 1173-1179.

Paustian K., Andrén O., Janzen H.H., Lal R., Smith P., Tian G., Tiessen H., van Noordwijk M., and Woomer P.L. (1997). Agricultural soils as a sink to mitigate CO_2 emissions. *Soil Use and Management,* 13: pp. 229-244.

Robertson G.P., Paul E.A., Harwood R.R. (2000). Greenhouse gases in intensive agriculture: Contributions of individual gases to the radiative forcing of the atmosphere. *Science,* 289 (5486): pp. 1922-1925.

Smith P., Goulding K.W., Smith K.A., Powlson D.S., Smith J.U., Falloon P.D., Coleman K. (2001). Enhancing the carbon sink in European agricultural soils: Including trace gas fluxes in estimates of carbon mitigation potential. *Nutrient Cycling in Agroecosystems,* 60: pp. 237-252.

Smith P., Powlson D.S., Glendining M.J., and Smith J.U. (1997). Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments. *Global Change Biology,* 3: pp. 67-79.

Smith P., Powlson D.S., Glendining M.J., Smith J.U. (1998). Preliminary estimates of the potential for carbon mitigation in European soils through no-till farming. *Global Change Biology,* 4: pp. 679-685.

Smith P., Powlson D.S., Smith J.U., Falloon P.D. and Coleman K. (2000). Meeting Europe's Climate Change Commitments: Quantitative Estimates of the Potential for Carbon Mitigation by agriculture. *Global Change Biology,* 6: pp. 525-539.

Tian H., Melillo J.M., Kicklighter D.W., McGuire A.D., Helfrich J.V.K. III, Moore B.I., and Vorosmarty C.J. (1998). Effect of interannual climate variability on carbon storage in Amazonian ecosystems. *Nature,* 396: pp. 664-667.

Tate K.R., Scott N.A., Saggar S., Giltrap D.J., Baisden W.T., Newsome P.F., Trotter C.M., Wilde R.H. (2003). Land-use change alters New Zealand's terrestrial carbon budget: uncertainties associated with estimates of soil carbon change between 1990-2000. *Tellus,* 55B: pp. 364-377.

Vinten A.J.A., Ball B.C., O'Sullivan M.F., and Henshall J.K. (2002). The effects of cultivation method, fertilizer input and previous sward type on organic C and N storage and gaseous losses under spring and winter barley following long-term leys. *J. Agric. Sci. Camb.*, 139 (3), pp. 231-243.

Weier K.L., McEwan C.W., Vallis I., Catchpoole V.R., and Myers R.J. (1996). Potential for biological denitrification of fertilizer nitrogen in sugarcane soils. *Aust. J. Agric. Res.*, 47: pp. 67-79.

LULUCF PROJECTS

Araújo T.M., Higuchi N., and de Carvalho Junior J.A. (1999). Comparison of formulae for biomass content determination in a tropical rain forest site in the state of Pará, Brazil. *For. Ecol. Manage,* 117: pp. 43-52.

Avery T.E. and Burkhart H.E. (eds.). (1983). *Forest Measurements*. 3rd edition. McGraw-Hill, New York.

Beets P.N., Robertson K.A., Ford-Robertson J.B., Gordon J., and Maclaren J.P. (1999). Description and validation of C change: a model for simulating carbon content in managed *Pinus radiata* stands. *New Zealand Journal of Forestry Science* 29(3): pp. 409-427.

Bennie A.T.P., Taylor H.M., and Georgen P.G. (1987). An assessment of the core-break method for estimating root density of different crops in the field. *Soil Till. Res.* 9: pp. 347-353.

Blake, G.R. and Hartage K.H. (1986). Bulk density. In Klute A. (ed.) Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. *Agronomy No. 9*. ASA, Madison, WI. pp. 363-375.

Bland W.L. (1989). Estimating root length density by the core-break method. *Soil Sci. Soc. Am. J.* 53: pp. 1595-1597.

Böhm W. (1979). Methods of Studying Root Systems. Springer-Verlag, New York.

Boscolo M., Powell M., Delaney M., Brown S., and Faris R. (2000). The cost of inventorying and monitoring carbon. Lessons from the Noel Kempff Climate Action Project. *Journal of Forestry*, September, pp. 24-27 and 29-31.

Brown J.K and Roussopoulos J.K. (1974). Eliminating biases in the planar intercept method for estimating volumes of small fuels. *Forest Science* 20: pp. 350-356.

Brown S. (1997). Estimating biomass and biomass change of tropical forests. A primer. FAO Forestry Paper No.134. Rome, Italy. 55 p.

Brown S. (2002). Measuring, monitoring, and verification of carbon benefits for forest-based projects. *Phil. Trans. R. Soc. Lond*. A 360: pp. 1669-1684.

Brown S., Burnham M., Delaney M., Vaca R., Powell M., and Moreno A. (2000a). Issues and challenges for forest-based carbon-offset projects: a case study of the Noel Kempff Climate Action Project in Bolivia. *Mitigation and Adaptation Strategies for Climate Change* 5: pp. 99-121.

Brown S., Delaney M., and Shoch D. (2001). Carbon monitoring, analysis, and status report for the Rio Bravo Carbon Sequestration Pilot Project. Report to the Programme for Belize, Winrock International, Arlington, VA, USA.

Brown S., Masera O., and Sathaye J. (2000b). Project-based activities. In: Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK. Chapter 5, pp.283-338.

Brown S. and Schroeder P. (1999). Spatial patterns of aboveground production and mortality of woody biomass for eastern US forests. *Ecological Applications,* 9: pp. 968-980.

Cahoon G. A. and Morton E.S. (1961). An apparatus for the quantitative separation of plant roots from soil. *Am. Soc. Hort. Sci*. 78: pp. 593-596.

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

Clark D. A., Brown S., Kicklighter D.W., Chambers J.Q., Thomlinson J.R., and Jian Ni, (2000). Measuring net primary production in forests: concepts and field methods. *Ecological Applications,* 11: pp. 356-370.

Dawkins H.C. (1957). Some results of stratified random sampling of tropical high forest. *Seventh British Commonwealth Forestry Conference,* 7 (iii): pp. 1-12.

Delaney M., Brown S., and Powell M. (1999). 1999 Carbon-Offset Report for the Noel Kempff Climate Action Project, Bolivia. Report to The Nature Conservancy, Winrock International, Arlington, VA, USA.

Delaney M., Brown S., Lugo A.E., Torres-Lezama A., and Bello Quintero N. (1998). The quantity and turnover of dead wood in permanent forest plots in six life zones of Venezuela. *Biotropica,* 30: pp. 2-11.

Drew M.C. and Saker L.R. (1980). Assessment of a rapid method, using soil cores, for estimating the amount and distribution of crop roots in the field. *Plant Soil,* 55: pp. 297-305.

Fang J., Chen A., Peng C., Zhao S., and Ci L. (2001). Changes in forest biomass carbon storage in China between 1949 and 1998. *Science,* 292: pp. 2320-2322.

Fearnside P.M.(1997). Wood density for estimating forest biomass in Brazilian Amazonia. *Forest Ecology and Management,* 90(1): pp. 59-89.

Freese F.(1962). Elementary forest sampling. USDA Forest Service Handbook 232, US Government Printing Office, Washington, DC.

Harmon M.E., Brown S., Gower S.T. (1993). Consequences of tree mortality to the global carbon cycle. In Vinson T.S. and Kolchugina T.P. (eds.). Carbon cycling in boreal and subarctic ecosystems, biospheric response and feedbacks to global climate change. Symposium Proceedings, USEPA, Corvallis, OR, pp. 167-176.

Harmon M. E. and Sexton J. (1996). Guidelines for Measurements of Woody Detritus in Forest Ecosystems. US LTER Publication No. 20. US LTER Network Office, University of Washington, Seattle, WA, USA.Available at http://www.lternet.edu/documents/Publications/woodydetritus/

Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK.

Körner C. (1994). Biomass fractionation in plants: a reconsideration of definitions based on plant functions. In: Roy J and Garnier E. (eds.). A Whole Plant Perspective on Carbon-Nitrogen Interactions. SPB Academic Publishing, The Hague, pp. 173-185.

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

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

Li Z., Kurz W.A., Apps M.J., and Beukama S. (2003). Belowground biomass dynamics in eh carbon budget model of the Canadian forest sector: recent improvements and implications for the estimation of NPP and NEP. *Canadian Journal of Forest Research,* 33: pp. 126-136.

Lund G.H. (ed.). (1998). IUFRO Guidelines for designing multipurpose resource inventories. IUFRO World Service Volume 8, Vienna, Austria.

MacDicken K.G. (1997). *A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects. Winrock International,* Arlington, VA, USA, 87 pp, available at: http://www.winrock.org/REEP/PDF_Pubs/carbon.pdf; also in Spanish from Fundacion Solar, Guatemala, http://www.winrock.org/REEP/PDF_Pubs/fundacionsolar.pdf

Masera O.R., Garza-Caligaris J.F., Kanninen M., Karjalainen T., Nabuurs G.J., Pussinen A., de Jong B.J., and Mohren F. (2003). Modeling Carbon Sequestration in Afforestation and Forest Management Projects: The CO2fix V.2 Approach. *Ecological Modelling* 3237, pp. 1-23

Page-Dumroese D.S., Jurgensen M.F., Brown R.E., and Mroz G.D. (1999). Comparison of methods for determining bulk densities of rocky forest soils. *Soil Science Society of America Journal,* 63: pp. 379-383.

Paivinen R., Lund G.H., Poso S., and Zawila-Niedzwiecki T. (eds.). (1994). IUFRO international guidelines for forest monitoring. IUFRO World Series Report 5. Vienna, Austria. 102 p.

Parresol B.R. (1999). Assessing tree and stand biomass: a review with examples and critical comparisons. *Forest Science,* 45(4): pp. 573-593.

Parton W.J., Schimel D.S., Cole C.V., and Ojima D.S. (1987). Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* 51: pp. 1173-1179.

Pérez L.D. and Kanninen M. (2002). Wood specific gravity and aboveground biomass of *Bombacopsis quinata* plantations in Costa Rica. *Forest Ecology and Management* 165 (1-3): pp. 1-9.

Pérez L.D. and Kanninen M. (2003). Aboveground biomass of *Tectona grandis* plantations in Costa Rica. *Journal of Tropical Forest Science* 15(1): pp. 199-213.

Pinard M. and Putz F. (1997): Monitoring carbon sequestration benefits associated with a reduced impact logging project in Malaysia. *Mitigation and Adaptation Strategies for Global Change* 2: pp. 203–215.

Phillips D.L., Brown S.L., Schroeder P.E., and Birdsey R.A. (2000). Toward error analysis of large-scale forest carbon budgets. *Global Ecology and Biogeography*, 9(4): pp. 305-313.

Post W.M., Izaurralde R.C., Mann L.K., and Bliss N. (1999): Monitoring and verifying soil carbon sequestration. In: Rosenberg N., Izaurralde R.C., and Malone E.L. (eds.). Carbon Sequestration in Soils. Batelle Press, pp. 41–82.

Ritson P. and Sochacki S. (2003). Measurement and prediction of biomass and carbon content of *Pinus pinaster* trees in farm forestry plantations, south-western Australia. *Forest Ecology and Management* 175: pp. 103-117.

Sampson, R.N. and Scholes R.J. (2000). Additional human-induced activities—Article 3.4. In: Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK. Chapter 4, pp. 181-281.

Schlegel B., Gayoso J., and Guerra J. (2001). Manual de procedimiento para inventarios de carbono en ecosistemas forestales. Medición de la capacidad de captura de carbono en bosques de Chile y promoción en el mercado mundial. Universidad Austral de Chile. 14 pp.

Schroeder P., Brown S., Mo J., Birdsey R., and Cieszewski C. (1997). Biomass estimation for temperate broadleaf forests of the Unites States using inventory data. *Forest Science* 43 (3):pp. 424-434.

Schroth G., D'Angelo S.A., Teixeira W.G., Haag D., and Lieberei R. (2002). Conversion of secondary forest to agroforestry and monoculture plantations in Amazonia: consequences for biomass, litter, and soil carbon stock after 7 years. *Forest Ecology and Management,* 163: pp. 131-150.

Segura M. and Kanninen M. (2002). Inventario para estimar carbono en ecosistemas forestales tropicales. In: Orozco L. and Brumér C. (eds). Inventarios forestales para bosques latifoliados en America Central. CATIE - Centro Agronómico Tropical de Investigación y Enseñanza, pp. 202-216.

Senelwa, K and Sims R.E.H. (1998). Tree biomass equations for short rotation eucalypts grown in New Zealand. *Biomass and Energy* 13(3): pp. 133-140.

Shepherd D. and Montagnini F. (2001). Carbon Sequestration Potential in Mixed and Pure Tree Plantations in the Humid Tropics. *Journal of Tropical Forest Science* 13(3): pp. 450-459.

Smucker A.J.M., McBurney S.L., and Srivastava A.K. (1982). Quantitative separation of roots from compacted soil profiles by the hydropneumatic elutriation system Root and soil separation, root response to adverse soil environment. *Agron. J.*, 74: pp. 499-503.

Sokal R.R. and Rohlf F.J. (1995). Biometry: the principles and practice of statistics in biological research. 3rd Edition. W. H. Freeman and Co., New York.

Zar J.H. (1996). Biostatistical analysis. Prentice Hall, Englewood Cliffs, New Jersey.