Preparing for Sweden´s reporting of emissions and removals of greenhouse gases in the LULUCF sector under the Kyoto Protocol

A report prepared for the
Swedish Environmental Protection Agency

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Göran Ståhl[1]
Olof Andrén[2]
Leif Klemedtsson[3]
Thomas Kätterer[2]
Mats Nilsson[4]
Håkan Olsson[1]
Hans Petersson[1]

[1]Swedish University of Agricultural Sciences,
Dept of Forest Resource Management and Geomatics

[2]Swedish University of Agricultural Sciences,
Dept of Soil Sciences

[3]University of Gothenburg,
Botanical Institute

[4]Swedish University of Agricultural Sciences,
Dept of Forest Ecology

Orders
Order telephone: +46 (0)8-505 933 40
Order telefax: +46 (0)8-505 933 99
E-mail: natur@cm.se
Address: CM-Gruppen
Box 110 93
SE-161 11 Bromma, Sweden
Internet: www.naturvardsverket.se/bokhandeln

Naturvårdsverket
Telephone: +46 (0)8-698 10 00 (switchboard)
Internet: www.naturvardsverket.se
Address: Naturvårdsverket, SE-106 48 Stockholm, Sweden

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Preface

This report has been written within a project carried out for the Swedish Environmental Protection Agency by SLU. The objective was to propose basic components in a future Swedish system for inventorying and reporting emissions and removals of greenhouse gases from the land-use, land-use change, and forestry (LULUCF) sector under the Kyoto Protocol of the United Nations Framework Convention on Climate Change.

Many people have contributed to the work. Especially we would like to thank the researchers within the LUSTRA project and the members of the project's reference group: Per Eklund, Hillevi Eriksson, Gabriella Hammarskjöld, Jan Karlsson, and Mattias Lundblad. Mattias Lundblad also was the project coordinator at the Swedish Environmental Protection Agency.

Göran Ståhl was responsible for preparing the report. Contributions from specific subject fields were provided by Olof Andrén and Thomas Kätterer (croplands and grasslands), Leif Klemedtsson and Mats Nilsson (non-CO_2-emissions), Håkan Olsson (satellite remote sensing), and Hans Petersson (case study on land-use transfers). Although the propositions by Kätterer & Andrén have been included in the main report, their full contribution also is attached as an appendix.

The authors are responsible for the entire content of the report. The authors are also responsible for opinions and proposals stated in the report. These are not necessarily agreed on by the Swedish Environmental Protection Agency.

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Background

The aim of this report is to interpret what the Kyoto Protocol and Marrakesh accords are likely to imply in terms of components in a Swedish system for reporting of greenhouse gas emissions and removals from the land-use, land-use change, and forestry (LULUCF) sector. Within this sector, it will be mandatory for all Parties to report emissions and removals following Afforestation, Reforestation, and Deforestation (ARD). Further, it will be optional for the Parties to report on changes due to forest management, cropland management, grazing land management, and revegetation. The report is a continuation of the work previously conducted at the Swedish Environmental Protection Agency on this issue (Fink, Hammarskjöld & Forsgren 2002).

This report covers all the above issues except revegetation (which is of negligible importance for Sweden); however, the focus of the report is on ARD and forest management. The latter issue is covered in some depth although no formal decision has yet been made by the Swedish Government about whether or not to include forest management in the reporting under the Kyoto Protocol. Inclusion of this category potentially would have a major impact on Sweden's ability to meet the Kyoto targets, although for the first reporting period, 2008-2012, a "cap" has been agreed upon regarding what maximum values different countries can account for.

The interpretation of the Kyoto Protocol and the Marrakesh accords is expressed in the *Good Practice Guidance* (GPG) reports developed by the IPCC. The LULUCF sector report was, however, only partly approved by the Cooperation of the Parties to the UNFCCC[1] in December 2003. Thus, no formal reference is given here, although the recommendations in this report are based on the text in the draft version of the GPG report.

In the draft GPG report for the LULUCF sector, requirements regarding reporting from the LULUCF sector under both the general UNFCCC agreements and the additional Kyoto Protocol/ Marrakesh Accords are provided. Thus, it is important to note that the already ongoing reporting under the UNFCCC and the additional Kyoto Protocol demands will be integrated in the future reporting. This implies that the UNFCCC reporting also needs to be modified. As a consequence, *the UNFCCC reporting and the additional Kyoto Protocol requirements are treated as one entity* in this proposal for a future Swedish system to meet the Kyoto Protocol requirements.

Although the draft GPG report for the LULUCF sector is very detailed and comprehensive, in many cases the recommendations are that country-specific methods should be developed and used. In addition, it is sometimes difficult to obtain clear-cut recommendations from reading the report, e.g. regarding what minimum requirements must be fulfilled in the reporting. Thus, although the GPG report provides the framework regarding what rules the Parties need to follow, many details are left to the countries to decide on their own. This is the major motivation for the present report; many decisions

[1] United Nation's Framework Convention on Climate Change

regarding Sweden's future LULUCF reporting remain to be made, and need to be made through a process of within-country discussions and decisions. This concerns both methods and definitions.

A base alternative for the future reporting of the LULUCF sector is presented. The components of this alternative are based on a compromise between what data are already available, the cost of acquiring new data, and the likely importance of a specific methodology in relation to estimating the overall emissions/removals of greenhouse gases from the LULUCF sector. In addition, different options to the base alternative are presented and needs for further development activities are discussed.

Due to the level of complexity of reporting emissions and removals for the LULUCF sector - both in terms of ecological/social processes involved and the reporting requirements – it can be foreseen that the national system will continuously need to be up-graded in the future. Thus, the current report is not a proposition for "the final system".

UNFCCC and Kyoto Protocol reporting

General

Under the UNFCCC, every year Sweden must deliver a national inventory report to the UNFCCC secretariat (or formally to the Cooperation of the Parties) regarding emissions and removals of greenhouse gases. This report follows the requirements of the, so called, *Revised 1996 Guidelines* (IPCC 1997), developed by IPCC. The reporting is divided into different sectors: Energy, Industrial Processes, Agriculture, Waste, and Land-use, land-use change, and forestry (LULUCF).

For the LULUCF sector, these guidelines involves reporting from five different categories, namely (i) changes in forest and other biomass stocks, (ii) forest and grassland conversion, (iii) abandonment of managed land, (iv) emissions/removals by soil from land-use change and management, and (v) other sources or sinks.

Within the first category, the implicit emission/ removal of CO_2 due to uptake or release from biomass on managed land is reported. Although all kinds of biomass in principle are included, typically the Parties report only on changes in tree biomass. This category is not restricted to forest areas, but to all areas where trees are managed. Within the second category, emissions from conversion of forests or grasslands to other land-use types are included. Here, not only CO_2 releases but also other greenhouse gases (GHGs) – mainly CH_4 and N_2O - are included. In the third category, the removal of GHGs due to increase of biomass on previously managed land is treated. In the fourth category, emissions/ removals due to both changes in land-use and cultivation of soils are included. Regarding agricultural soils, only emissions/removals of CO_2 are included; the other GHGs are treated within the sector Agriculture.

To date, Sweden's LULUCF sector reporting has concerned changes in forest and other woody biomass stocks and emissions/removals by soils. The GHGs removals within Sweden's LULUCF sector are considerable, and have amounted to 25-50% of the total emissions of GHGs from the other sectors.

The GPG report for the future reporting from the LULUCF sector was developed under the restriction that it should be consistent with the *1996 Revised Guidelines* (IPCC 1997). However, several new concepts are introduced, which imply that the future reporting to UNFCCC most likely will be substantially different from the current reporting. One major difference is that land areas are being more consistently defined, and that emissions/removals of GHGs should be specified for each land-use category and for each transition between categories. The GPG report lists the following land categories:

- Forest
- Cropland
- Grassland
- Settlement
- Wetland

- Other land

Further, land within the different land categories need to be separated on different sub-categories, e.g. on managed and non-managed land; only emissions/removals from managed land should be reported.

Another important difference is that, with regard to CO_2, five different pools of carbon are identified and should be monitored separately. These pools are:

- Above ground biomass
- Below ground biomass
- Litter
- Dead wood (including dead roots)
- Soil organic carbon

In addition to changes in these pools, emissions/removals of N_2O, CH_4, and some other non-CO_2 GHGs, also should be reported in some cases.

Kyoto Protocol requirements

Each year in the period 2008-2012, Parties must submit supplementary information to the UNFCCC reporting to meet the requirements of the Kyoto Protocol and the Marrakesh Accords. This reporting is carried out with some delay, i.e. for year 2008 the report should be submitted to the UNFCCC secretariat in spring 2010 (and similar for the subsequent years). This has some important implications regarding what data and interpolation methods can be used within the LULUCF sector, e.g. it is possible to obtain an average value for 2012 by using data collected in 2011, 2012, and 2013 (although EC also is a Party – besides the individual countries – under the UNFCCC and the Kyoto Protocol, and needs data in advance to compile statistics for the entire community).

The mandatory part of the LULUCF Kyoto Protocol reporting concerns ARD (Afforestation, Reforestation, and Deforestation) lands. Afforestation concerns areas that have not been forested for the past 50 years, while reforestation concerns areas that were previously forested, although not in December 1989 (excluding forest management areas that were only temporarily without forest cover at that time due to clear cutting). Deforestation concerns the conversion of areas from forest to some other land category. For ARD lands, the emissions or removals of GHGs must be reported each year in the period 2008-2012; this concerns all lands subject to these transfers after 1990. For CO_2, this involves reporting on stock changes in the five different carbon pools for each type of land. For non-CO_2 gases other methods must be used.

The following components (or steps) are needed to fulfill the Kyoto requirements on ARD lands:

1) National definitions of the 6 broad land categories must be developed, i.e. national definitions of *forest land*, *cropland*, *grassland*, *wetland*, *settlement*, and *other land* must be decided upon. Regarding *forest land* Parties are only allowed to decide within certain limits according to a decision within the Marrakesh Accords.

2) Determine the state of land areas in 1990 to assess whether or not A, R or D has occurred after that point of time.

3) Identify boundaries of areas with ARD since 1990. This must either be performed by identifying every single unit of ARD land or by identifying areas of lands within which ARD units of land can be found. For Sweden, the second approach is proposed (see below).

4) Develop a system to follow lands area transfers between different land categories after 1990. (This is crucial for the entire reporting under the new GPG).

5) Estimate GHGs emissions and removals on all lands subject to ARD since 1990. These estimates will be specific for each type of land category transfer according to (4).

Regarding afforestation and reforestation, the methods needed for following carbon stocks in forests will be the main components required, while for deforestation methods applicable to grasslands, croplands, settlements, and other lands also need to be applied. Thus, even if Sweden chooses not to report grazing land management and cropland management under the Kyoto Protocol (article 3.4), we still need to develop methods to estimate GHG emissions and removals from such areas in order to fulfill the mandatory requirements regarding ARD lands.

Kyoto Protocol options

In addition to the mandatory parts of the LULUCF sector under the Kyoto Protocol (ARD lands), Parties have the option to report on emissions/removals from Forest Management (FM), Cropland Management (CM), Grazing Land Management (GM), and Revegetation (RV). In case a country chooses to include a specific category, all lands included in the first period must be followed and reported in all subsequent periods as well, regardless of whether or not they remain in the same management category.

FM is of potential major importance for Sweden (although a “cap” has already been decided for the first commitment period). To report FM, Parties must provide clear definitions of what areas are considered FM areas. This may be performed either by identifying and including lands after they have been “managed” according to selected treatments, or by using a more general definition with regard to what areas should be considered FM areas.

Specific rules apply regarding the reporting of CM and GM. For these, so called “net-net” accounting rules should be used, implying that actual emissions/removals in the reporting period must be compared with emissions/removals in 1990, and only the differences be accounted for according to the Kyoto Protocol. These differences may result both due to changes in areas and to changes in management practices.

Country-specific definitions of FM, CM, GM, and RV need to be developed, and a hierarchy needs to be established regarding how lands are allocated to these management types. For example, in case an area is subject to both FM and GM (which may be the case in tree-covered grazing lands) it must be clear what management type the unit of land should be allocated to.

Overview of components in a generic system to meet the reporting requirements

Below, basic components in a system fulfilling both the general requirements of the future UNFCCC reporting and the specific requirements of the Kyoto Protocol are outlined. First, a list of main components is provided as an overview. Secondly, each component is shortly described.

The main components needed are:

- Country-specific definitions for different land-use categories, management types, and carbon pools.
- A system for estimating areas of different land-use categories and land-use transfers.
- A package of methods for estimating changes in the five different carbon pools and for the non-CO_2 gases. Methods must be available for each land-use category and transition, i.e. in principle 36 main methods should be established.
- A system for LULUCF-specific assessment of key categories.
- Methods for uncertainty estimation.
- A LULUCF-module for quality assurance and quality control (QA/QC).
- Methods and procedures for verification.

The final system also needs to be clearly documented.

The GPG report generally outlines many different methodological options in connection with each item to be calculated and reported. These options generally are structured in tiers, implying that the lowest tiers are the simplest and most uncertain options. Higher tier options are judged to be better but also more demanding in terms of efforts and costs. In general, country-specific methodology (clearly documented!) is judged to belong to the highest tiers. Lower tier approaches often make use of default values. In such cases, tier 1 mostly corresponds to default values provided by IPCC while tier 2 corresponds to default values derived at a national level.

Below, the main components outlined above are shortly described.

Country-specific definitions

Each country has to provide definitions on the 6 different land-use categories, and (if Kyoto Protocol 3.4 activities are elected) on definitions of FM, CM, GM, and RV. A country may also choose to define the five carbon pools in a different way as compared to the standard definitions in the GPG report.

A system for estimating areas of different land-use categories

A basic requirement is that a system for consistent and complete estimation of areas of different land use classes and transitions between land-use classes must be established. The entire GPG report is structured around this concept, which introduces many new requirements in comparison to the current reporting under the UNFCCC; this kind of system thus needs to be established.

To meet the requirements of the Kyoto Protocol, the system must be based on either complete mapping of the country or on spatially explicit sample locations. Further, ARD units of land must either be completely mapped, or areas that encompass ARD units must be delineated. In the latter case, it is sufficient to use broad administrative boundaries, if appropriate.

The system for estimating land use categories and land use transfers must be complete, assuring that no land types are either missed or double counted. Thus, there is a need to follow areas of unmanaged land as well, to ascertain that there is always a complete description of a country's land area at all points of time. *Specifically, to meet the requirements of the Kyoto Protocol it is in general not allowed to merge area estimation systems from different sectors to obtain a full system, due to the risk that there will be overlaps or gaps in the representation of areas.*

The six general land use categories also need to be given national definitions and be further subdivided into relevant subcategories.

Every year, a country's total land area needs to be broken down in "matrix form" according to the principle outlined in Figure 1.

From/To	**Forest, managed**	**Forest, unmanaged**	**Cropland**	**Grassland, managed**	**…**
Forest, managed	100	10	0	5	
Forest, unmanaged	0	60	0	1	
Cropland	0	0	20	3	
Grassland, managed	2	0	1	15	
…					

Figure 1. Principle of the kind of land-use transfer matrix that must be estimated each year as a basis for the reporting.

Land areas stay in the "transfer classes" for 20 years following conversion, unless it is decided to use other limits within a country. Moreover, transitions that imply that an area is subject to A, R, or D must be followed separately.

The system needs to be able to estimate the state in 1990 as a basis for the ARD assessments. Moreover the system needs to be able to identify when ARD has occurred. Also, to correctly obtain the "transfer classes" in the matrix, the system must be able to assess – at least 20 years back – when a land use change has occurred.

To simplify integrated reporting, sub-categories should be established that correspond exactly to the Kyoto ARD classes, and to the optional FM, CM, GM or RV classes if they are elected. In case FM is elected, the ARD classes have priority and thus an A or R area should only be reported as such, and not as FM. However, for full visibility it is required that a certain class be specified that corresponds to A, R or D in areas that would otherwise have been reported as FM areas.

In conclusion, the system for area transfers must be rather detailed due to the many different sub-classes that need to be specifically identified.

Methods for assessing changes in carbon pools and emissions/removals of other GHGs

In principle, each cell in (the fully developed!) Figure 1 must be equipped with a set of methods - and their corresponding data acquisition procedures or default values – that enable the estimation of changes in the five different carbon pools as well as the emissions/ removals of other GHGs. This could lead to a very large number of methods, although in practice for Sweden the area estimates in many cells are likely to be insignificant and negligible. Further, the same method can probably be used for a number of cells.

Since there are six different land-use categories there will be 36 main groups of methods, each containing different methods for the different carbon pools and potentially also for the non-CO_2 gases. In determining in which methodological groups emphasis should be put, a key category assessment should be made (see below). For the insignificant categories, default values can be used, while for the key categories country-specific model or measurement-based methods generally need to be developed.

The methods to be developed often must include principles for time series interpolation and extrapolation due to measurements only being carried out at certain intervals.

Harvested wood products (HWPs) may also be reported, although this is not mandatory either under the UNFCCC standard reporting or under the Kyoto Protocol. Due to the current lack of knowledge and lack of systems for following the changes in carbon pools in HWPs in Sweden, no specific suggestions are given in this report.

Key category assessment system

Specific key category assessment is required for the LULUCF sector, according to the Good Practice Guidance (GPG) report. The level at which the “categories” are defined generally corresponds to the level of the cells in Figure 1. That is, each transfer category should be evaluated regarding whether or not it is key.

Although somewhat complicated, LULUCF sector key category assessment needs to be made separately and not fully integrated with the other sectors, according to the GPG.

Uncertainty estimation

According to the GPG report, the uncertainty of each category in the inventory must be assessed, as well as the overall uncertainty of the entire GHG inventory. This should follow the specific guidelines set out in the GPG report.

A Tier 1 uncertainty analysis is always required, although this contains many simplifying assumptions that would generally not be needed for a country like Sweden. Tier 2 uncertainty analysis prescribes that Monte Carlo analyses should be performed, which can be very demanding. Intermediate methods also are allowed.

Methods for quality assurance and quality control

Quality control (QC) refers to principles to be adopted during the compilation of the inventory in order to minimize the risk of errors in the final results. Quality assurance (QA) implies that preliminary figures and calculation principles can be independently reviewed by a second person/organization.

Methods for verification

In addition to QA/QC, verification is a further means to assure that the reported figures are plausible. With verification, data or methods independent to the ones used for the reporting are used to derive estimates of some (or all) or the categories reported in the standard inventory. A large number of different verification methods can be used and it is left to each country to decide on the extent of the verification program.

Proposition for a Swedish system for the LULUCF sector

In this chapter components of a Swedish system are proposed, including definitions to be used in Sweden. The latter issue is treated first.

Defintions

Land-use categories and management

Below, propositions for definitions of the broad land-use categories and different management types are given. These needs to be further discussed and checked during the course of establishing the actual system in practice.

Forest and forest management

The definition of *forest* must be chosen within certain limits according to the Marrakesh Accords. These exclude the use of the traditional Swedish definition. The limits are (at tree maturity): 2-5 m height, 10-30% crown cover, and 0.05-1 ha minimum size. *It is proposed that Sweden uses 5 m height, 10% crown cover, and 0.5 ha size, since this corresponds to the FAO definition*, which is also endorsed in the Swedish National Forest Inventory. Tree-rows narrower than 10 meters are *not* considered forest; roads and power-lines within forests are considered forest if they are narrower than 5 meters.

Forest areas further need to be divided into *managed* and *unmanaged* forests. Deforestation is relevant both for managed and unmanaged forests, while all other reporting only regards managed forests. Specifically this is the case for FM, if elected. *It is proposed that the Swedish definition of managed forest be chosen to correspond to what is considered forest according to the Swedish legislation (excluding unused land without tree cover)*. This asserts that managed forest land should have a production capacity exceeding 1 cubic meter stem wood per hectare and year. It is proposed that reserves be considered unmanaged forest (although the Kyoto Protocol in principle allow reserves to be considered managed forest as well). The distinction between forest and grassland is proposed to be based on dominant land use, implying that tree covered grasslands, if grazed, should be categorized as grasslands, according to the definitions in the National Forest Inventory.

In classifying areas as belonging to AR or D, it is likely that some difficult situations will emerge and require specific consideration, specifically for A. For example, mires that gradually become tree-covered due to natural processes or unknown (climatic?) reasons most likely should not be treated as afforestation, unless some on-site human activities have contributed to the tree-growth. A similar example is when unmanaged agricultural lands gradually be covered by bushes and trees; in this case the area is proposed to be categorized as afforestation land. A general guiding principle could be to classify all previously used lands, which become tree covered when the former land use has ceased, as afforestation lands. Previously non-used lands that become tree-covered due to, e.g., nitrogen deposition or climate change, should not be considered afforestation lands.

Cropland and cropland management

The definition of cropland is proposed to include *all lands where annual or perennial crops are grown, excluding forests*, and where the soil is regularly cultivated. In this category fallow land also is included. Specifically, lands with fast growing bushes or trees grown for energy purposes is proposed to belong to this category, as well as orchards (except seed orchards in forestry). The distinction between cropland and grassland is based on whether or not the area is regularly cultivated. Temporarily grazed lands that regularly are cultivated are categorized as croplands, and thus no short-term land-use transitions between cropland and grassland need to be estimated.

Cropland management is proposed to be all farming and similar activities performed on croplands.

When management ceases on croplands, they may enter any of the other land-use categories. Typically, unless they quickly become tree-covered, they would move to the class unmanaged grasslands.

Grassland and grazing land management

Grasslands generically may be of many different kinds in Sweden. Pastures, including heaths, where cattle graze should be considered a core part of this category. In addition, former croplands or pastures where no trees have yet started to grow also should be included in this category. Open rangelands in mountain areas could be included here as well, but it is argued that these instead be included in the class “Other land”. Although grazing may be ongoing, lands with very shallow soils and low productivity (e.g. “Alvaret”) also are suggested to be “Other land”.

Sometimes it may be difficult to distinguish between forest and grasslands, if grazing is ongoing on tree-covered lands. In this case it is proposed that the predominant land-use be used to classify lands into either forest or grassland (cf. the definitions in the National Forest Inventory). Thus, some grasslands will have a tree cover that exceeds the limits specified under “forest” (see above).

Recreational grasslands (like golf courses and soccer fields) are proposed to be classified as settlements.

Grazing land management is proposed to be the practices connected to animal grazing on grasslands.

Wetland

This category includes all areas regularly covered or saturated by water at least for some part of the year, although temporary flooding is not sufficient for assigning an area to this class. The category includes lakes, marchlands, streams (>2 m wide), reservoirs, and mires that are not covered by trees and thus classified as forests.

Managed wetlands include reservoirs and lands used for peat extraction. Thus, these latter land categories are the only ones that specifically need to be considered in the reporting of wetlands.

Settlement

Settlements include all kinds of developed lands: houses and gardens, villages, and cities. Moreover it includes roads, railroads, and power-lines in forests (power-lines in open areas are classified as croplands, grasslands or other land). Sport arenas like golf courses and soccer fields also are included in this category. In addition, developed areas like airfields, harbours, and industry plants are part of this class.

Other land

Other land includes all kinds of lands that do not belong to the other classes. Major categories are open lands in mountain ranges and low-productive lands with none or shallow soils.

Most parts of the other lands probably can be considered unmanaged.

<u>Carbon pools</u>

It is proposed that the definitions of the five carbon pools in the GPG report be used with only minor changes in the case of Sweden.

Above ground biomass

This pool includes all living above ground biomass. Potentially, only tree biomass will be included for the case of Sweden, at least in many of the land-use categories where the above ground biomass can be assumed to be at steady state. For the case of forests, simple functions for the prediction of non-tree biomass will be available for use.

Below ground biomass

This pool includes all living below ground plant biomass, except fine roots (<2 mm diameter). In Sweden, it is proposed that only tree below ground biomass is included; functional relationships will be available between above and below ground parts of trees.

Dead wood

This pool includes both above and below ground dead wood, larger than 10 cm diameter according to the GPG recommendations. For the above ground part, specific measurements are carried out in the National Forest Inventory and it will be possible to capture this pool. For the below ground part, functional relationships will be used. Since it will be difficult to separate thick and thin dead roots, as a deviation from the GPG definitions it is proposed that all dead roots be included as dead wood. Further, all parts of standing dead trees are proposed to belong to this class, although the GPG report suggests a 10 cm diameter threshold (see discussion under *litter*).

Litter

This pool includes all above ground dead plant parts less than 10 cm diameter (except standing trees). Thus, it includes both fine parts of dead fallen trees and dead leaves and needles on the forest floor. According to the GPG report, this pool also includes the humus layer, which is non-standard for the case of Sweden. In discussions with researchers from the LUSTRA project, it was, however, preliminarily decided that this definition would be acceptable for Sweden.

It remains unclear to which pool fine parts of standing dead trees should be counted. Nothing about this is stated in the GPG report. The most straightforward solution would be to include all parts of standing dead trees in the dead wood pool.

Soil organic matter

This pool comprises all organic matter in mineral and organic soils, including peat lands. Thus, the “humus layer” on peat lands is included in the soil organic matter. It is up to each country to specify down to what depth in the mineral soil the carbon should be included. For mineral soils with a humus layer less than 30 cm, researchers from the LUSTRA project proposed to use a 50 cm limit, starting from the bottom of the humus layer. For peat lands, the suggestion is to include the entire peat layer, ignoring the mineral soil below the peat. Since, over time, peat layers may vary in thickness, it is important to use classification and calculation procedures, so that it is possible to track the carbon pool changes from a 29 cm thick humus layer (to be reported under *litter*) to a 31 cm thick peat layer (to be reported *as soil organic carbon*).

For arable land, topsoil that is affected by ploughing (to 30 cm depth) is the main layer, and the subsoil below this can be included when data exist.

Classes in the reporting tables

In preliminary reporting tables, as well as in other places where the carbon pools are treated in the GPG report, above and below ground biomass is jointly classified as *living biomass*. Dead wood and litter is jointly called *dead organic matter.* Soil organic matter is mentioned as *soils.* However, in the preliminary reporting tables it appears that all five pools should be specifically reported in the Kyoto specific tables. Thus, the aggregated classes mainly appear to be relevant for the basic UNFCCC reporting.

A system for estimating areas of land-use categories and land-use transfers

This system is a core element both for the general UNFCCC requirements and the Kyoto Protocol requirements. As described previously, the system must be able to determine past land use categories, specifically those in 1990, and to be based on spatially explicit assessment in order to meet the Kyoto Protocol requirements.

For Sweden, there are several options available to construct a system of this kind. One rather unique possibility in relation to those of other countries is to use the approximately 40 000 permanent plots of the National Forest Inventory. These plots were established in the period 1983-87 and cover all areas of Sweden, i.e. not only forest. In principle, forests, grasslands, croplands, settlements, wetlands, and other land can be assessed using these data. However, some adjustment procedures will be needed mainly in order to harmonize the previous classification in relation to the definitions of land categories that apply to the Kyoto Protocol reporting.

Using the permanent plots it is possible to estimate the conditions in 1990, and also to assess when – if relevant – ARD has occurred. The plots have been revisited with 5-10 year intervals since they were established and will be revisited again during the first commitment period, this time with a 5 years interval, which is suitable for the reporting requirements.

With the permanent plots, land-use matrices of the kind described in Figure 1 will be possible to establish. The accuracy of the assessments will be high for the common categories (in relative terms) and low for the sparse categories. ARD events are likely to be sparse and thus the relative accuracy can be expected to be relatively low. However, in absolute terms the size of errors will be low. Some examples of what accuracy can be obtained are given further down.

Since ARD will be mandatory to report, a separate case study was conducted based on the permanent plots in order to assess the potential to estimate these activities in the material.

<u>Case study on land use transfers using the permanent plots of the NFI</u>

A case study on land use transfers was conducted based on the permanent plots of the Swedish National Forest Inventory. The results are summarized in Tables 1-3; they are derived from the land use transfers occurring (approximately) during the period 1990-1997.

Table 1. Land use in 1990 (grey) and 1997 (darker grey), land use conversions (no colour) and non-conversed land (light grey) during the period 1990-1997. Conversions from/to lakes or sea are not presented.

Land Category 1990	[1000 ha]	Land Category 1997, [1000 ha] Forest, Managed	Forest, Unmanaged	Cropland	Grassland	Wetland	Settlements	Other land
Forest, Man.	22856	22352	147	23	52	90	104	84
Forest, Unman.	3963	32	3598	0	1	16	4	275
Cropland	3084	59	3	2948	25	0	44	3
Grassland	480	35	0	38	394	1	11	0
Wetland	4582	64	94	0	2	4399	3	12
Settlements	1590	39	1	16	2	1	1529	0
Other land	4454	25	212	1	2	16	3	4184
Total	41009	22609	4082	3030	478	4534	1698	4566

Table 2. Annual land use conversions in the period 1990-1997 Conversions from/to lakes or sea are not presented.

Land Category 1990	[1000 ha]	Land Category, Annual Conversions 1990-1997, [1000 ha] Forest, Managed	Forest, Unmanaged	Cropland	Grassland	Wetland	Settlements	Other land
Forest, Man.	22856	-	20	3	7	12	14	11
Forest, Unman.	3963	4	-	0	0	2	0	37
Cropland	3084	8	0	-	3	0	6	0
Grassland	480	5	0	5	-	0	1	0
Wetland	4582	8	12	0	0	-	0	2
Settlements	1590	5	0	2	0	0	-	0
Other land	4454	3	28	0	0	2	0	-
Total	41009	-33	16	-7	0	-6	14	15

Table 3. Annual converted managed forest area and loss of biomass (averages for the period 1990-1997). The reduced biomass refers to biomass removed by harvest, including branches, needles, tips, stumps and roots. (The average biomass of trees in Swedish managed forests is about 94 ton/ha).

		Annual Conversions from Managed Forests to:				
	Unit	Cropland	Grassland	Wetland	Settlements	Other land
Converted area	1000 ha	3.1	6.9	12	14	11
Reduced living biomass	Mton	0.05	0.27	0.26	1.03	0.17
Reduced living biomass	ton/ha	16	39	22	74	15
Uncertain classifications*	%	66	52	30	3	39

*) In the NFI material, land use classes may have been changed although no actual changes have taken place on plots. This row provides a rough estimate of the percentage of such cases, assessed based on the number of plots where no harvesting of trees was part of the conversion.

In Tables 1-2, the following definitions were used regarding the land use categories in relation to those of the Swedish NFI (see Anon 2003):

- Forest, managed:	”Skogsmark” according to the NFI
- Forest, unmanaged:	”Fjällbarrskog” and ”Fridlyst område” that was previously classified as ”Skogsmark”
- Cropland	”Åkermark”
- Grassland	”Naturbete”
- Wetland	”Myr”
- Settlements	”Väg och järnväg”, ”Bebyggd mark”, and ”Annan mark”
- Other land	”Berg och vissa andra impediment”, ”Fjäll”, ”Annat klimatimpediment”, ”Kraftledning inom skogsmark”, and ”Militärt impediment”

The definitions used in the case study do not fully correspond to the definitions according to the GPG. Thus, the results should only be considered indicative. Moreover, two other problems were observed during the case study:

1) It is technically difficult to handle permanent plots that have undergone changes between periods regarding how they are divided into different land use classes, i.e. this problem may occur for plots that are located on boundaries between different land use classes.

2) Plots may have been assigned to different classes at different time points although no real change has occurred. This is due to the fact that different surveyors may have had different opinions regarding how the land-use on a plot should be classified.

A possible solution to the first issue would be to only consider plot centers in the calculations, and disregard changes in plot divisions over time unless they imply a change for the plot center. This would probably be rather straightforward and the reduced precision in the estimates would be minimal. Other solutions to this problem also are available, although they are more complicated and require more work in setting up a calculation system.

A possible solution to the second problem would be that the permanent plots next time they are visited are reviewed regarding whether previously assigned land-use changes have been due to actual changes or only changes in how the surveyor has perceived the land use category. This would be possible at relatively low cost.

A preliminary conclusion from the case study is, however, that changes in carbon pools due to deforestation cannot be entirely disregarded as insignificant for the case of Sweden. In Table 3, it can be seen that the annual reduction of living biomass on deforested plots may amount to as much as 2 Mton (corresponding to almost 1 Mton C).

On the precision of area estimates

About 40 000 permanent plots are available from the NFI. These will be revisited during the period 2008-2012. Estimates for the specific period are likely to be made based on data obtained as three years averages, and thus about 24 000 plots would be part of the calculations.

With this number of plots, the precision of the estimates (in relative terms) will be high for the common land use classes. Although the NFI is carried out as systematic sampling of plot clusters, the formulas for simple random sampling can be used to provide approximate values for the precision of the area estimates. The standard error of an area estimate with simple random sampling is:

$$Std(\hat{A}_C) = A\sqrt{\frac{p(1-p)}{n}}$$

Here, A_c is the area of a specific land use category (or transfer class), A is the total area of Sweden (about 45 Mha), p is the proportion of the land use class, and n the number of sample plots.

In Table 4, some examples of standard errors are given for various cases, differentiated on proportion of the land-use category and the number of sample plots used.

Table 4. Examples of standard errors of area estimates, using a certain number (n) of sample plots in the calculations. The first figure is the standard error expressed in hectares, the second is the relative standard error (%).

Proportion and Corresponding area	n = 10 000	n = 24 000	n = 40 000
p = 0.001 (45000 ha)	14000 – 32%	9000 – 20%	7000 – 16%
p = 0.01 (450 000 ha)	45000 – 10%	29000 – 6%	22000 – 5%
p = 0.1 (4 500 000 ha)	135000 – 3%	87000 – 2%	67000 – 2%
p = 0.5 22 500 000 ha)	225000 – 1%	145000 – 1%	112000 – <1%

From the table it can be seen that the relative errors of the uncommon categories will be rather high. On the other hand, once a certain category becomes common the relative precision of its assessment will be higher. Thus, by using the permanent plots of the NFI as a basis for the area estimation the uncommon (usually non-important) classes will be assessed with low accuracy. However, the system will be “self-adjusting” in the sense that once a category becomes common it will be assessed with higher accuracy.

<u>Satellite image based options to enhance the estimation of land use transfers</u>
According to the GPG, there are no requirements on what precision needs to be achieved in the reported emissions and removals due to ARD. It is left to the Parties to choose methods that reduce uncertainties as far as practicable, and thus implicitly to choose methods that represent a good balance between cost and precision. Due to the relatively limited importance of ARD lands for Sweden’s GHG balance, it can be argued that it would not be advisable to develop expensive methods in order to estimate small numbers with high accuracy. This is the foundation for the proposed base alternative for following land-use transfers using the permanent plots of the NFI. Furthermore, it is not yet 100 % certain that suitable satellite data will be available in the future. The existence of a base method that not is dependent on satellite data is therefore advisable, even if the inclusion of satellite should be a preferred option for enhancing the estimates.

In particular, the emissions of GHGs due to deforestation may be rather significant (Table 3), which may motivate increased efforts for obtaining better figures. Either of the following two different satellite remote sensing based methods might be worthwhile to develop in order to obtain higher certainty in the deforestation estimates:

1) Medium resolution satellite images (such as for example images from the current SPOT HRG or Landsat ETM+ sensors with 5-30 m pixel size) could be used together with existing NFI plots in a post-stratification approach.

2) Like (1), but using the satellite images for (pre-) stratification, allocating a separate set of field plots (or quick visits) to those areas identified as changed since 1990.

In general, major changes in forests can be easily found by comparing satellite images from different time points. However, it is more difficult to classify the detected changed areas into the correct change categories (e.g. temporarily clear-cut areas, deforested areas, non-deforested areas with damages, etc.). Thus, there is a need for field sampling to classify at least a small proportion of the areas identified as changed in the images. With post-stratification, the field sampling will be rather limited, using only the NFI plots already available, while with a complementary field sampling effort the sample sizes can be large.

With alternative (1) there will be possibilities to link the activities required due to the UNFCCC/Kyoto reporting to the methods foreseen to be used within the Swedish National Forest Inventory in the future. Thus, the costs need not be very much increased. In this case, the poststratification could preferably be based on a difference image; thus areas with major changes due to tree-reduction could form a specific stratum.

With alternative (2) it would be possible to establish cooperation with, e.g., the Swedish Forest Administration, which every year uses a countrywide set of satellite images for follow-up of landowners' reports of new clear-cut areas. In alternative (2) additional field visits would be required to areas identified as changed using the remote sensing methods, but where the nature of the change is unknown. This procedure could be limited to a sample of map sheets. The labeling of the amount of biomass on the changed areas, before and potentially also after the change, could be performed with the so called kNN-method, where NFI field plot data and satellite image data are combined into a raster data base with pixelwise information about estimated forest variables.

The above discussion about use of satellite imagery focuses on Deforestation. Afforestation and Reforestation areas generally are more difficult to timely detect in satellite images. It can be judged that at least 5-15 years after plantation of a forest need to pass before afforestation/reforestation can be tracked in the satellite images with reasonable accuracy. Moreover, the need for increased precision in relation to ARD mainly is motivated for D, since the yearly GHG removals due to A and R are likely to be very small.

Additional databases of potential interest for area estimation

Above, the plots from the Swedish NFI are proposed to form the basis for the main area estimation alternative. Remote sensing is proposed as a potential complement.

However, there are additional data sources for area estimation of potential major value. The IACS databases ("Blockdatabaserna") of the Swedish Board of Agriculture provides important data when it comes to separating the broad land-use categories (croplands and grasslands) listed above on sub-categories, of importance for the modeling of GHG emissions with the ICBM system (see appendix to this report, by Kätterer & Andrén).

Moreover, the soil survey of agricultural soils carried out as part of the Swedish Environmental Monitoring program provides data that can also be used for modeling purposes, as well as – probably – for verification purposes once repeated measurements of soil carbon are carried out. The latter program comprises some 2000-3000 permanent plots on agricultural soils.

To have a complete system for area estimation, it is proposed that the NFI permanent plots are used for estimating the areas of the broad land use categories. Then, the complementary datasets for croplands and grasslands can be used to estimate proportions of relevant sub-categories, given the overall area estimates from the NFI.

Another dataset of potential value is the LUCAS dataset. LUCAS is a system for land-use monitoring on the European scale, currently being run on a pilot basis by Eurostat. It covers the entire EC with a rather dense network of plots that are revisited in the field with short (1-2 yrs) intervals. Broad land-cover and land-use categories are registered on the LUCAS plots. Today, it is unknown whether or not LUCAS will remain and become operational on a permanent basis. In case LUCAS is made permanent, data from this inventory could be used at least in order to verify the estimates obtained from the NFI system. A drawback with LUCAS is that the inventory is unable to establish the state in 1990, and thus it is not possible to estimate areas of ARD lands.

<u>Area identification</u>
Both for ARD and for FM (and CM, GM and RV) according to the Kyoto Protocol/ Marrakesh Accords it is required that the actual areas either be individually identified or that areas that encompass units of these kinds of lands be identified. That is, it is not sufficient to correctly estimate areas and emissions/removals from these kinds of lands, but they must also be geographically identified.

It is proposed that individual areas of ARD and FM lands *not* be identified in Sweden, due to the high costs that would be incurred. Instead, the second methodological option is proposed to be used, i.e. identification of areas that encompass ARD and FM units of land. In the case of Sweden, it is proposed that straightforward administrative boundaries be used, either counties, or – better, if allowed – an even coarser delineation into N. Norrland, S. Norrland, Svealand, and Götaland. Within the broadly defined areas, the methods above will be used separately to estimate areas and area transfers.

To some extent the area identification issue will complicate the reporting without leading to any increased precision of the estimates. However, it is mandatory according to the Kyoto/Marrakesh agreements.

<u>Division into climatic regions</u>
The GPG suggests that reporting be broken down on different climatic regions. For the case of Sweden a map in the GPG report indicates that Sweden might be divided into three different climatic types. Since the reporting will contain a large number of sub-categories as it is, and since a break-down on different climatic types, according to the classes suggested in the GPG report, is unlikely to improve(?) the precision of the

estimates it is suggested not to make a division of Sweden into different climatic regions. However, in the underlying work, e.g., modeling of carbon balances in a given area, high-resolution climate data will sometimes be used.

Methods to estimate changes in carbon pools and non-CO_2 emissions

Methods to estimate changes in carbon pools

Specific methodologies for assessing changes in the five carbon pools apply to each land-use category and each type of land-use transfer. For practical reasons, though, as far as possible the same basic approaches for the assessments should be applied.

In Table 5 the 36 main land-use and land-use transfer categories are listed and a classification is made regarding what methodological approach may be most appropriate for estimating changes in the specific carbon pool. The basic idea is to use simple default values (derived using models in some cases?) for insignificant categories, while emphasis should be put on using solid national methods for the important pools. This is in line with the recommendations in the GPG report. The recommendations of the table should only be considered as preliminary. As part of the next step of the development work a key category assessment will be performed as an additional basis for prioritizing what methods should be emphasized.

Three broad methodological approaches can be identified:

1) Assessments based on repeated measurements
2) Assessments based on modeling; many different kinds of models may be applied
3) Assessments based on default values that apply to a certain land-use category

Compared to many other countries, Sweden is relatively well equipped with monitoring programs that repeatedly measure some of the carbon pools of interest. In case such measurements are ongoing, it is proposed that methods based on repeated measurements be applied (if they are judged to result in better estimates than alternative approaches). Several models also are available, or can be derived at limited effort.

Some matrix cells in Table 5 are pointed out specifically in the GPG report due to the very limited knowledge regarding GHGs emissions and removals. For these, it is left to the countries to decide on their own whether or not a category should be reported. This concerns, e.g., wetlands remaining wetlands, settlements remaining settlements, and non-CO_2 emissions from drained areas within forests. However, it is not always clear exactly what is recommended in the GPG report. For example, for countries where data are available the recommendation is that these should be reported. Thus, it obviously remains as a decision for the individual country to decide whether or not data are judged to be good enough to be reported.

Table 5. Proposed methods for quantifying the different carbon pools (Me=Measurement, Mo=Modeling, De= Default value) and the likely importance of the different pools for the overall carbon budget within the LULUCF sector (*=not important, **=important, and ***=very important).

From class	To class	Above ground biomass	Below ground biomass	Dead wood	Litter[2]	Soil organic matter
Forest	Forest	Me ***	Me/Mo ***	Me/Mo **	Me/Mo ***	Me ***
Forest	Cropland	Me *	Me/Mo *	Me/Mo *	De *	Mo *
Forest	Grassland	Me *	Me/Mo *	Me/Mo *	De *	Mo *
Forest	Settlement	Me **	Me/Mo **	Me/Mo *	De **	De *
Forest	Wetland	Me *	Me/Mo *	Me/Mo *	De *	De *
Forest	Other	Me *	Me/Mo *	Me/Mo *	De *	De *
Cropland	Cropland	De *	De *	De *	De *	Mo ***
Cropland	Forest	Me *	Me/Mo *	Me *	Me/Mo *	Mo *
Cropland	Grassland	De *	De *	De *	Mo *	Mo *
Cropland	Settlement	De *	De *	De *	De *	De *
Cropland	Wetland	De *	De *	De *	De *	De *
Cropland	Other	De *	De *	De *	De *	De *
Grassland	Grassland	De *	De *	De *	De *	Mo **
Grassland	Forest	Me *	Me/Mo *	Me *	Me/Mo *	Mo *
Grassland	Cropland	De *	De *	De *	De *	Mo *
Grassland	Settlement	De *	De *	De *	De *	De *
Grassland	Wetland	De *	De *	De *	De *	De *
Grassland	Other	De *	De *	De *	De *	De *
Settlement	Settlement	De *	De *	De *	De *	De *
Settlement	Forest	Me *	Me/Mo *	Me *	De *	De *
Settlement	Cropland	De *	De *	De *	De *	De *
Settlement	Grassland	De *	De *	De *	De *	De *
Settlement	Wetland	De *	De *	De *	De *	De *
Settlement	Other	De *	De *	De *	De *	De *
Wetland	Wetland	De *	De *	De *	De *	De *
Wetland	Forest	Me *	Me/Mo *	Me *	De *	De *
Wetland	Cropland	De *	De *	De *	De *	De *
Wetland	Grassland	De *	De *	De *	De *	De *
Wetland	Settlement	De *	De *	De *	De *	De *
Wetland	Other	De *	De *	De *	De *	De *
Other	Other	De *	De *	De *	De *	De *
Other	Forest	Me *	Me/Mo *	De *	De *	De *
Other	Cropland	De *	De *	De *	De *	De *
Other	Grassland	De *	De *	De *	De *	De *
Other	Settlement	De *	De *	De *	De *	De *
Other	Wetland	De *	De *	De *	De *	De *

[2] Note that according to the GPG definition the humus layer of soils is included in the litter pool

From the table, it is clear that many of the classes are likely to be very insignificant. In a large number of cases, very crude default values thus are proposed to be established, merely to obtain a complete system that can run regardless of what land-use transfers are obtained. Moreover, in some cases a combination of methods is needed for monitoring a specific pool (e.g. forest on mineral soils and forest on peat lands).

In the following, comments on the main methodological classes are given

<u>Forest remaining forest</u>
Forest remaining forest is a very important category for Sweden; currently the net removal of CO_2-C by growing trees amounts to 5-10 Mton annually. In this case the plots from the National Forest Inventory and the Survey of Forest Soils (which is carried out in connection with the NFI) will form the basis for the assessment of changes per area unit in the different carbon pools, that can then be multiplied with the area estimates.

The most straightforward estimates will be for entire five years evaluation periods, e.g. 2008-2012. In this case, the average of changes observed on permanent plots (e.g. 2007/2009 – 2011/2013) can be used in straightforward change estimates. This concerns above ground biomass, below ground biomass, and dead wood. Re-measurements of the litter pool and soils will – according to the plans – be carried out with a 10 yrs interval, and thus procedures for averaging will be needed. These may be as straightforward as simply estimating the 5 yrs change by taking 50% of the measured 10 yrs change.

Using permanent plots for estimating changes is very powerful, and has been shown to produce estimates with relatively high precision for the case of Sweden (Ståhl et al. 2003). The temporary plots of the NFI can be used in addition to the permanent plots, although this will not increase the precision very much.

For the *above ground biomass*, specific biomass functions (e.g. Marklund 1987) for trees will be applied to the measurements of trees on permanent NFI plots. By using the permanent plots, no separate estimates of cuttings will be needed. In addition, simple functions estimating the biomass of other vegetation than trees will be applied based on the assessments made on the NFI plots.

For *below ground biomass*, biomass functions developed for the purpose also will be used. These use measurements of basic tree characteristics as diameter as input variables. These functions are available for fewer species, and in the long run it might be advisable to enhance the accuracy of these functions by collecting additional data on root biomass.

For the *dead wood pool*, volume estimates are obtained from the NFI at all measurement occasions. New functions are currently being established whereby volume can be converted to biomass and carbon, taking into account the decomposition class of the dead wood. Also, dead roots are included in the dead wood pool. In principle these will be possible to follow by using a new set of function that are currently being established (at SLU) that predict the biomass of dead roots given the time since cutting. However, this involves elaboration of additional details in the estimation, since stumps and their ages on the permanent plots needs to be kept track of. Procedures for this need to be worked out in connection with the NFI.

The *litter pool* comprises both the humus layer and coarse and fine only slightly decomposed vegetation parts. Changes in the humus layer are followed through the Survey of Forest Soils through re-measurements on permanent plots. For the remaining fine litter, new simple models need to be established. The same holds for the coarse litter on dead trees.

The *soil organic carbon pool* (mineral soils) is followed through repeated measurements within the Survey of Forest Soils. These measurements are carried out with 10 yrs intervals. Currently, methods are not available to quantify the amount of carbon from the measurements of carbon concentration that are made in soil samples. However, methods for this are currently being developed within the LUSTRA project. Key issues regard the scaling up from samples in specific layers to totals for the specific plot, considering the distribution of soil carbon in different layers and the amounts of stones and boulders in the soil.

Managed forests that grow on thick peat layers pose a specific problem, since the current measurement procedures are insufficient for estimating the changes in these carbon stocks. In this case, in the short run crude model assumptions need to be developed and inserted in the national reporting system.

As an alternative to repeated measurements of soils, soil carbon models may be applied. At least such models could be used as tools for verification.

Annual estimates

It is required that annual figures be reported, although these may be recalculated once better data become available. This kind of recalculation is proposed to be conducted based on the actual change estimates for the first evaluation period 2008-2012, based on repeated measurements of the permanent plots (2007/2009 – 2011/2013). However, annual estimates also need to be derived according to some straightforward principle.

The traditional method of obtaining annual biomass change estimates for forests remaining forest (used for a long time within the Swedish UNFCCC reporting) is to calculate the biomass growth of the forest and deduct the biomass harvests. This method remains as an options also with the new GPG report. However, due to the increased complexity of the pools to be reported and an ambition to keep calculation procedures as common as possible for all the different pools, it is proposed that annual values in all cases be calculated as average figures from repeated measurements of plots, based on the last remeasurement period (which is 5 years, or ca 10 years for soils and litter). This also simplifies the problem of distributing the figure for total fellings (obtained from Board of Forestry Statistics) on different land categories that would otherwise have to be solved.

However, a compromise that could be worthwhile to explore would be to compare each year's implicit harvesting figures (from the repeated measurements) with the actual harvesting statistics from the Board of Forestry. In case of major differences, the actual harvesting figure could be used to calibrate the figures obtained for the different land and land transfer categories.

Forest converted to other land-use classes

In the GPG report it is proposed that units of land stay within a transfer class for 20 years before they are moved to another class (e.g. grassland remaining grassland). Although the time required to reach steady state in, e.g., soil conditions probably is much longer, it is proposed that the transfer categories always be specified as 20 years long and that the information that a certain plot was, e.g., deforested 30 years ago instead be used when the emissions or removals are calculated for that specific plot within its new land category.

Forest converted to other land categories implies deforestation. In the calculations, a distinction must be made between the immediate effects of deforestation (biomass removed, etc.) and the longer-term effects following deforestation (e.g. the need to apply techniques developed for croplands and grasslands). The immediate effects due to removal of biomass generally are large. These effects can be estimated using the last NFI measurements made on the deforested plots, i.e. the actual removals of biomass from a plot can be assessed, which is an advantage with using the permanent plots.

Once the first phase of the deforestation is completed, the ICBM model (see the Appendix to this report, by Kätterer & Andrén) – or its development into ICBMregion – can be applied on grasslands and croplands to estimate changes in the soil carbon pool. Regarding conversions to wetlands, settlements and other lands, once the first phase of deforestation is completed it is proposed that simple default values be used regarding the changes in different carbon pools.

Forest converted to settlement can be expected to be a rather significant class. In this case, biomass removals can be assessed using previous values from the NFI plots. In case satellite remote sensing becomes part of the system, estimates based on the kNN-principle also might enhance the estimates.

Cropland remaining cropland and Grassland remaining grassland

In these cases, it is proposed that the ICBM model be used for estimating annual emissions/removals of CO_2. For further discussions on this topic, see the Appendix. Total areas of these classes are proposed to be provided using the NFI-based system. Then, areas of relevant sub-classes for the ICBM model can be derived using data from the IACS databases (from the Board of Agriculture) and from the agricultural soils monitoring program.

The issue of estimating the conditions in 1990 must be specifically treated here, since this will be an issue in case CM and GM are elected under article 3.4 of the Kyoto Protocol. Estimates of this kind will also be obtained using the ICBM model.

Cropland or Grassland converted to Forest

These are the major afforestation or reforestation classes. In this case, increases in biomass, dead wood, and litter can be obtained from the measurements on the permanent plots of the NFI. Since, in principle, both croplands and grasslands are included in the measurements made within the NFI if there are trees on a plot, data from repeated measurements will be the basis for the assessments.

Regarding the soils, the ICBM model can be used for estimating the changes in the soil carbon pool following this land use conversion (see the Appendix).

Cropland or Grassland converted to other land use classes

Carbon pool changes for these transfer classes are proposed to be handled mainly by default figures, to some extent established using the ICBM model (see the Appendix).

Settlements, Wetlands, and Other lands

Lands remaining within these categories, as well as transfers from these categories to other categories are proposed to be handled mainly by default values. Another option is to leave them out entirely, which is allowed according to the GPG report due to the very limited knowledge from these areas.

Default values for these classes (and some others) are proposed to be derived through a workshop with invited national experts.

Non-CO_2 emissions and removals

For the non-CO_2 gases, the estimates generally will be based on emission factors multiplied with relevant area estimates. Thus, an important task will be to obtain accurate emission factors for different types of land. This issue is discussed in the following sections.

Methane exchange on forest soils

Upland mineral soils represent a net sink for CH_4. The annual oxidation rate has been found to be between 0.1 to 9.1 Kg CH_4 ha^{-1} y^{-1}, with a mean of about 1.6 Kg CH_4 ha^{-1} y^{-1} (Smith et al., 2000). These numbers are in the same range as the default figures used by the GPG for LULUCF.

An annual mean rate of 1.6 Kg CH_4 ha^{-1} y^{-1} is equal a C-uptake of 10 kg ha^{-1} y^{-1} using the Global Warming Potential (GWP) for methane of 23 from IPCC (2001). These relatively low uptake rates might be negligible to te estimated soil carbon pool changes.

The rate of methane oxidation is negatively influenced by the amount of ammonium in the soil. Nitrogen deposition and nitrogen fertilization might therefore be incorporated to model a variation in CH_4 uptake on mineral forest soils. The same effect has been found for a decrease in pH or gas diffusion. Lower gas diffusion in the litter layer has been shown in deciduous compared to coniferous forest stands on the same soil. Thus the tree species influence the methane oxidation.

Croplands and grasslands act as a sink for methane. The sink strength is influenced by both farming practice and nitrogen fertilization regimes. A simple classification into classes of farming practice and fertilization regimes is probably required to achieve accurate estimates of the methane emission from these land classes.

The largest change in methane oxidation rates have been found after land use changes. The methane oxidation rates are reduced to 1/3, when changing a forest ecosystem into agriculture. However, it takes more than 100 years to recover the original forest methane oxidations rates, when changing back from agriculture to forest.

Drained peat soils contain the potential for both production and consumption of methane and will therefore vary between being a small source or a small sink, mainly depending on drainage efficiency. Therefore, a simple classification of drained and forested peat soils into different humidity classes will probably be enough to estimate the rate of exchange of methane with the atmosphere. The current NFI database is probably sufficient. The most important uncertainty is whether the current humidity classes are accurate enough or if a more detailed description on the ground water table level and the humidity of the unsaturated zoon is needed.

Emissions of soil CO_2 from drained and forested peat soils

Any changes in the peat soil carbon pool results from the balance between input of dead organic material either from above ground plant material or from below ground, i.e. roots, plant material and the rate of carbon mineralization. The emission of CO_2, however, originates from both mineralization of organic material, i.e. heterotrophic respiration, and from plant root respiration, i.e. autotroph respiration. Drainage of peat soils normally increases the input of new dead organic material from dead plant litter to the soil. The aeration however also increases the mineralization of the old peat. The change in the peat soil carbon pool after drainage and afforestation is therefore to a large extent controlled by the potential for tree growth, i.e. the fertility of the peat soil is one of the main determinants. Some information exists, mainly based on studies from Finland, the former Soviet Union and from Sweden, the current knowledge, however, do not allow for an accurate assessment of any changes in the peat soil carbon pool.

Any attempt to assess changes in the peat soil carbon pool needs to be based on a model fed with data on the most important controlling factors both for plant growth after drainage and of peat mineralization after drainage. Estimation of the release of carbon from old peat can probably be based on a simple model, based on data on the botanical composition, degree of humification and the degree of aeration after drainage. A number of potential decomposition models exist, but especially Sphagnum peat has not so far been successfully modeled. Any model therefore needs to be developed to successfully describe decomposition of old peat, especially Sphagnum peat.

When estimating the gas emission from drained forest ecosystems special attention has to be taken to drained mineral soils (peat layer less than 30 cm) and forest on former agricultural land on organic soils.

Wet forests on mineral soils may have a botanical composition of the forest floor vegetation, as an effect of inflow of nutrient to the areas from surrounding mineral areas, than on peat soils. When drained, the more easily decomposable soil organic matter may result in higher soil fluxes. Special emphasis ought to be taken for the drained forests on nutrient rich ecosystems in the south of Sweden. Furthermore, the annual pattern in aeration may differ between a well-drained mineral soils compared to peat soils, due to different hydrology, which has to be addressed by models.

The former drained and farmed organic soils converted into forest, has to be treated separately both for the decomposition rates (C-losses) and nitrous oxide emissions (see below). The degradation rate of organic matter of these soils are most likely higher than from the ones drained for direct forest production; due to fertilization and soil perturbation during the farm management period. These soils may represent a relatively large portion of the drained forest soils. The drained organic agriculture land was in the 1930 about twice as large as present. This means that about 0.3 Mha of the total about 1.2- 1.3 Mha of drained forestland may have been farmed land. The current NFI database is probably sufficient for the area estimates. There is an urgent need of both decomposition studies as well as field measurements for to generate data to improve models and estimates.

Nitrous oxide emissions from forestland

The emissions of nitrous oxide can vary significantly between different forest ecosystems and is compared to the methane oxidation rates of importance, as the GWP conversion factor to CO_2 is 296 compared to 23 for methane.

The forests can be classified into three categories in terms of their nitrous oxide emission pattern; i) base emissions, ii) event emissions and iii) seasonal emission type.

The emissions from the "base emission" soil types are low, this due to oxygen inhibition, and are so low that the importance of these soils in terms of C-budgets are negligible. This type of emissions is hard, if not impossible to model.

The emissions from soils of the "event emission" type can both be or not to be important for the GPG evaluations. These soils have anaerobic or oxygen limited micro sites during periods of the year and the rate at the events are mainly regulated by the nitrate content in the micro sites. These emissions can be modeled (by "Forest-DNDC, COUP etc) and will be enhanced by climate change, N-deposition and N-fertilization. The important soils are the ones in the south of Sweden. How to separate between low and high event emission types, in relation to the NFI database, is still unclear.

The emission of the "seasonal emission" type is driven by the seasonal changes of the temperature. These emissions can be higher than 20 kg N_2O ha^{-1} y^{-1}, which is equal to about 1700 kg C ha^{-1} y^{-1}, using IPCC values for GWP conversion between N_2O and CO_2. Well-drained and fertile drained forest soil, especially the ones used for agriculture, are examples of these soils. The emissions from these soils ought to be able to model, but more data from both laboratory as well as field studies are needed in order to create and verify the models.

It is unclear to what category the forest on former mineral agriculture soils belongs. The emissions ought however in a long time perspective to be lower than under farm management.

Emissions from burning

Both CO_2 and non-CO_2 emissions from burning also should be reported. The GPG report provides many details regarding these computations. The main issues that remain to be determined for the case of Sweden are the areas of different types of burning and the biomass in these areas before burning. Currently, no databases appear to be available regarding the extent of forest fires in Sweden. Thus, some kind of expert judgment would be needed in order to assess the extent of the emissions due to forest fires.

A system for key category assessment

In the future reporting, it is mandatory to perform an assessment of key categories. This calculation is performed in order to identify which are the major components of the entire GHG inventory. Regarding LULUCF, the key category assessment is somewhat complicated, since key categories first should be established in a separate action involving all sectors except LULUCF. Then, the activity is repeated, this time including LULUCF as well. When added accumulatively according to size of emissions/removals, the key categories are the ones that occur up to the 95^{th} percentile of the accumulated GHG emissions/removals (including all sectors). Removals in the LULUCF sector are entered in this analysis with their absolute values.

When inventory estimates are available for several years (as will be the case) key category assessment must be performed according to two different methods, i.e. both regarding *level* and *trend*. Both these analyses can be performed once the emissions/ removals of GHGs from each category in the inventory have been estimated.

All categories identified as key in either the level analysis or the trend analysis should be considered as key categories. In addition, qualitative criteria may apply, meaning that categories that did not appear as key in the formal analyses but that may carry large uncertainty into the overall estimates should be considered key as well.

Key category assessment may be applied according to either of two tiers. Tier 1 only requires that the levels of emissions/removals each year are known. Tier 2 also requires that the uncertainties of the estimates are known. For the case of Sweden, it is proposed – at least to start with – to perform the simplest form of key category analysis, which fulfils the requirements of both the UNFCCC and the Kyoto Protocol.

The key category assessment is a tool both for national agencies in prioritizing efforts between different categories, and for reviewers in scrutinizing the figures provided by Parties.

Methods for uncertainty estimation

It is mandatory for all Parties to undertake an uncertainty analysis according to the lowest tier, implying that uncertainties for emission factors be combined with those of activity data. Error propagation formulas for this kind of analysis are provided in the GPG report. Although rather straightforward in principle, it is likely to be rather time consuming due to the very large number of categories in the analysis. Specific consideration must be given to each methodological package (see Table 5) and thus the number of individually considered inputs to the uncertainty analysis will be large. In some cases, e.g. following sampling of forest resources, uncertainties can be directly estimated following standard sampling theory. In other cases, uncertainty figures must be guessed. Specifically, this is the case when default data are applied. Thus, in the process of determining default data, one should remember also to assess the likely size of errors of the default data. This can be done by pure subjective judgment.

For some methods, there will be a need to clearly document the national methods applied for the uncertainty analysis, since these will deviate slightly from the standard Tier 1 approach.

In this context it may also be pointed out that the methods provided for the other sectors in a previous GPG report were found to be erroneous during the course of the work with the GPG report for the LULUCF sector. This indicates that calculation of uncertainties is not a trivial undertaking, and requires sound knowledge of statistics.

It is optional for Parties to use a Tier 2 Monte Carlo uncertainty analysis. For the case of Sweden it is recommended *not* to do this, due to the complexity of such analyses, and due to the fact that it can be very much argued if – for the LULUCF sector – a Monte Carlo analysis will provide better uncertainty estimates than the simpler Tier 1 method.

A LULUCF module for quality assurance and quality control

Quality control is a system of technical recommendations given in order to enhance the quality of the inventory. The system provides principles for checking data and for documentation and archiving data. Quality assurance includes procedures for independent review of calculation principles and results.

In Sweden, a QA/QC system for all sectors but LULUCF currently is being developed. The working hypothesis is that LULUCF QA/QC rather easily can be integrated in this system. Incorporating LULUCF into the system requires the description of principles for checking data and calculations in connection with all methods used. This may be time consuming due to the mere number of methods involved.

One specific QC issue is to enhance the control procedures of the data capture within the NFI. Currently a very low proportion of the plots are revisited and checked by an independent control team. This proportion would need to be increased.

Regarding quality assurance, today the LULUCF figures within the UNFCCC reporting are checked by people from the Swedish Board of Forestry. It is proposed that this procedure should continue.

Methods for verification

Verification is related to QA/QC. However, technically QA/QC focuses on procedures for continuous control and checking during the preparation of the GHG inventory report, while verification focuses on the use of independent data sources and techniques for checking the plausibility of the estimates.

One major decision that needs to be made is what the ambition should be regarding verification in Sweden. We could either use the independent data sources and methods that are already available or introduce new programs for the purpose of verification. According to the GPG report, the minimum requirements appear to be very low; i.e., as long as something is done regarding verification it appears that the requirements are fulfilled.

In the following, some potential verification options based on what is currently ongoing are proposed.

<u>Verifying changes in the biomass pool</u>
If a system based on estimation using the permanent plots of the NFI (for entire 5 yrs periods) is selected, a means for verification would be to predict the tree growth using models (e.g. by applying the Hugin system, or its successor, the Heureka system). Cuttings would then be estimated using the figures provided by the Board of Forestry.

In addition, standard growth minus cuttings calculations could be used for verifying the calculations based on repeated measurements.

<u>Verifying changes in the soil pool</u>
The basic alternative proposed is to estimate the changes in the forest soil carbon pools be repeated measurements. It is known that there are many potential problems in connection with this approach.

A procedure for verifying the plausibility of the estimates would be to apply soil carbon models, e.g. the ones that are likely to be applied in Finland.

Regarding the agricultural soils, the basic approach is proposed to be modeling using the ICBM model. In this case, a verification procedure might be built around the repeated measurements of agricultural soils that are likely to continue and be repeated at 10 yrs intervals within the framework of the Swedish Environmental Monitoring.

<u>Micro-meteorological measurements</u>

Carbon fluxes are continuously being measured at some sites by means of micro-meteorological techniques (Eddy covariance). At these sites, the standard techniques for measuring/modeling the five carbon pools could be applied to obtain estimates to be compared with the flux estimates. With this kind of verification, it is important to obtain large enough sample sizes around the micro-meteorological sites for the comparisons to be meaningful.

Modifications of our data capture systems

The base alternatives outlined above all make use of data that are currently (more or less) available from ongoing monitoring programs. The major data providers would be:

- The Swedish National Forest Inventory
- The Swedish Survey of Forest Soils
- The IACS databases of the Board of Agriculture
- The Swedish Survey of Agricultural Soils
- The Harvesting Statistics of the Board of Forestry
- Annual Agricultural Yield Statistics

In the following, these systems are briefly described, and it is discussed what modifications of the monitoring programs potentially are needed.

In addition to the data sets/data providers listed, other sources might be of interest as well. The LUCAS datasets have already been mentioned. Another potential data source of interest would be the landscape level inventory (NILS) carried out by SLU on commission from the Swedish Environmental Protection Agency. Also, satellite imagery might be needed in order to improve the deforestation estimates.

The Swedish National Forest Inventory

The Swedish NFI is run by SLU as part of the Swedish official statistics. It is scheduled to continue in the foreseeable future. For many reasons the proportion of permanent plots within the NFI has increased from 2003 onwards. The reason is the general trend in many subject fields that change data become increasingly important. This suits the needs related to the Kyoto reporting. Thus, no major changes in the NFI in relation to what is discussed in this report be required. Some issues need to be pointed out, however:

- There is a need for slightly increased efforts in the control inventory, in order to fulfill the needs related to quality assurance.

- There is a need for future additional assessments related to the nature of previously registered land-use transfers on the permanent plots.

- The system is sensible to the number of permanent plots. For sparse categories, like Deforestation, the current number of plots may be considered being close to a minimum.

Potentially, an additional incorporation of remote sensing in the NFI would be advisable in order to obtain higher precision in many of the estimates.

The Swedish Survey of Forest Soils

The Survey of Forest Soils is carried out by SLU on commission of the Swedish Environmental Protection Agency, as part of the Swedish national environmental monitoring program. In 2003 a number of new procedures have been incorporated in the program, partly due to the foreseeable needs to meet the Kyoto reporting requirements. Even after these modifications, lands with thick peat layers continue to pose substantial problems regarding how to assess carbon pool changes and emissions of other GHGs. Thus, there is a potential need to enhance this inventory with regard to its capability to assess changes on thick peat lands. Potentially, some additional measurements might also be needed in order to establish more reliable values on CH_4 and N_2O fluxes from forest soils.

The IACS databases ("Blockdatabaserna")

The IACS databases are the responsibility of the Board of Agriculture. The current contents are likely to remain in the foreseeable future, and thus information from the databases will mainly be available for areas where agricultural subsidies are granted. Since the main use of the IACS databases would be to distribute the NFI based estimates of croplands on different categories, no change in the contents of these databases appear to be needed from the point of view of what is treated in this report.

The Swedish Survey of Agricultural Soils

This survey is part of the Swedish Environmental Protection Agency's national level monitoring. It is carried out, on commission, by SLU. It is foreseen that the approximately 2000 permanent plots on agricultural soils will remain in the foreseeable future. The re-measurement interval currently is 10 years.

Regarding this program, it might be discussed whether or not more emphasis should be put on quantifying changes of soil carbon. Currently this is not a main issue within the inventory.

The Harvesting Statistics of the Board of Forestry

The harvesting statistics are part of the Swedish official statistics. They are produced mainly by assessing the consumption of roundwood at industrial sites. However, a number of other modules are attached in order to obtain a complete system.

From the point of view of Kyoto reporting, there might be a need to develop a system to decompose the total harvests on different types (Deforestation, Forest Management, etc.). Moreover, there might be a need to document what organizations participate in the data provision for the harvest statistics, in order to obtain a complete description of the national Kyoto reporting system.

Annual Agricultural Yield Statistics

Agricultural yield data are published annually at high resolution. Eight agricultural production regions can represent a feasible level of resolution for the calculations.

Concluding discussion

In this report, components of a Swedish system for reporting of GHG emissions/removals from the LULUCF sector have been proposed. The system should fulfill the requirements of both the future reporting to the UNFCCC and the Kyoto Protocol/Marrakesh Accords.

The proposed system is rather basic. Still, due to the structure of the GPG report, many details needs to be filled in, in order to set up a complete system. In many cases, it is proposed that the components of the system should be rather crude default values; later on these can be substituted by more elaborated methods.

Thus, it is probably relevant to consider the establishment of a Swedish system for LULUCF reporting as a process that will continue for some time. In the short run, however, it must be ascertained that the system be complete, and thus some shortcut methodologies need to be applied that can later on be substituted by better alternatives.

One specific issue that need to be resolved later on is the question of “factoring out” natural and indirect human-induced GHG emissions/removals from those that are direct human-induced. The principles for this work have not yet been decided upon by IPCC.

Notes from a Nordic meeting

A meeting with participants from Finland, Norway and Sweden was held in Helsinki beginning of November, 2003, to discuss the development of national systems for the new LULUCF reporting. Some conclusions from that meeting were:

- The same general principles based on sample based assessment of areas and area changes were aimed at in all three countries.
- The issue of area identification was discussed. It was argued that the area identification will not improve the quality of the reported figures and thus only broad administrative boundaries would be aimed at.
- Soil carbon changes most likely will be handled by models in Finland and Norway.
- The definition of Forest Management should, if possible, be the same both for the general UNFCCC reporting and for the Kyoto Reporting, although it is allowed to use different definitions.
- The problem of proper area identification of Deforestation was discussed. At least in Norway there will be a specific project aimed at improving the estimate that can be obtained by using the permanent sample plots only in the area estimation. This project at least to some extent will investigate the use of satellite imagery for the purpose.

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APPENDIX – The report by Thomas Kätterer & Olof Andrén

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Report on net emissions/carbon sequestration by land use change (forest, arable, grassland) and suggestions regarding a system for reporting soil C changes 1990 – in arable and grassland.

Thomas Kätterer & Olof Andrén

Department of Soil Sciences, SLU, P.O. Box 7014, 75007 Uppsala

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Commission/Uppdraget:

Förslag om lämpliga systemkomponenter och fortsatta utvecklingsbehov inom följande områden sammanställs (på engelska):

- *Nettoemissioner från marken vid övergångar mellan skogsbruk, åkermark och betesmark (gärna i samråd med LUSTRA/Lars Rosenqvist som studerar effekter på kollagren vid beskogning av jordbruksmark). Alla typer av övergångar mellan dessa markanvändningsformer är aktuella*
- *Översiktig beskrivning av komponenter i tänkbart system för rapportering av koldioxidemission/inbindning till följd av (förändrat) åkerbruk och bruk av betesmark. Här gäller särskilt att ge förslag om hur emissionerna 1990 ska fastställas inom dessa marktyper, eftersom dessa emissioner utgör referens vid rapporteringen. Inom denna del bör samtliga relevanta kolpooler beaktas.*

I uppdraget ingår ej att utreda metoder för att skatta arealer av olika markanvändningsklasser och övergångar mellan olika markanvändningsklasser.

Important points:

- Our basic understanding of the processes determining soil C pools is quite solid
- Swedish agricultural soil C data are quite limited, but land use and management data are available at least at regional resolution
- Estimates of management effects on agricultural soil C stocks are more certain than estimates due to land use change (between arable and forest)
- An IPCC Tier 2-3 method is suggested for reporting management effects on agricultural mineral topsoils and a Tier 1-2 approach for organic agricultural soils.
- A Tier 2 approach is suggested for soils affected by land use changes, from arable or meadow/pasture to forest or vice versa

Introduction

Globally, 1.7 billion (10^9) hectares can be classified as agricultural land with at C stock of approximately 170 Pg (Paustian et al., 2000). The C amount lost in the past due to agricultural activity has been estimated to approximately 50 Pg C (Lal et al., 1998). Thus, a full regeneration of natural vegetation would finally (hundreds of years) result in a similar amount of sequestered C. A more realistic estimate of the capacity for C sequestration in agricultural soils globally, without major changes in land use, are in the order of 20-30 Pg C over the next 50-100 years (Paustian et al., 1997). However, if more drastic changes are allowed, e.g., addition of charcoal to soils (Glaser et al., 2000) more than 50 Pg can be sequestered, and with a high long-term stability (Andrén and Kätterer, 2002a).

Changes in soil carbon pools and their relation to atmospheric greenhouse gases have been extensively discussed, investigated and reported during the last two decades, and soil C reporting is mandatory at a national level according to the Kyoto protocol. This has resulted in high number of primary scientific reports, and an increased understanding of the principles behind soil C balances. However, this interest and funding has also resulted in an almost infinite number of plans, meetings, conference reports and protocols. All organisational levels, from global (UN, IPCC...), via regional (EU, OECD...) to national (Miljödepartement, Jordbruksdepartement, Jordbruksverk, Naturvårdsverk...) contribute to the paper mountain.

Naturally, the wisdom contained in these documents is useful, but the sieving out and compilation of facts from this ever increasing mass of 'grey' literature becomes more and more difficult, even if we limit ourselves to Swedish literature. There is a lot of overlapping work being done, and more coordination and concentration of resources would be of value.

Changes in net soil C emissions/sequestration affected by land use

For quantifying net soil C fluxes due to land use change, we first need to understand the basics of soil carbon dynamics. Second, we need to find the existing data. Third, we need to know how to use the theory and data for calculating soil C dynamics backwards and forwards in time.

Basic theory

Soil carbon pool sizes are the result of input – output. For simplicity, we assume here that carbon input to the soil is constant at a rate of i kg year^{-1}, and that a certain fraction ($k_1 = 0.01$ year^{-1}) of the soil carbon is respired as CO_2-C each year. Thus 1 ton of soil C will lose 10 kg C to the atmosphere each year, and 2 tons will lose 20 kg, i.e., the fraction but not the amount is constant. Written as a differential equation:

$$dC/dt = i - k_1 C \qquad \text{Eq. 1}$$

In words: For each infinitesimally small time step (t) the change in soil carbon (C) is the input (i) minus the fraction parameter (k_1) times the carbon mass present in the soil (C).

At equilibrium (steady state of soil carbon mass) $dC/dt = 0$. The conditions for equilibrium are thus:

$$i = k_1 C \qquad \text{Eq. 2}$$

In words: When the input (i) is equal to the respiration output (k_1C) there is no change in the amount of soil carbon, even if the inputs and outputs are large. The amount of C present in the soil at steady state thus becomes $C_{SS} = i/k_1$. For example, to maintain 1 ton of soil C with $k_1 = 0.01$ year^{-1} we need an annual input (i) of 10kg.

When C is large, i must be large to maintain C, unless k_1 is very small. In other words, if we have increased C, we must maintain a high i to maintain the high C mass. If on the other hand we reduce i to zero, soil carbon will decrease to zero at a rate of 1% year^{-1}, but at a decreasing rate if expressed as kg year^{-1}. If C is plotted against time, we get the familiar “exponential decay curve” which becomes less and less steep with time. Perhaps less familiar is the fact that if we start at steady state and then double the annual input, the rate of increase will gradually decrease towards the new, twice as high, steady state (Fig. 1). Note that the additional 1000 kg of input (100 x 10) only has increased soil C by 630 kg after 100 years. See Andrén and Kätterer (2001) for further discussion of basic principles.

To make the carbon mass increase linear, we have to add carbon in a form that is not subject to decomposition, e.g., as charcoal. If we add 10kg charcoal year^{-1}, we would actually have 100 x 10=1000kg charcoal in the soil after 100 years. Further, after 200 years we will have 2000kg of charcoal, and a steady state will never be reached (or rather after an extremely long time, since even charcoal will decompose, but at a very low rate).

One should note that even this quite extreme change – twice the input every year – gives a fairly linear response in a 10-50 yr perspective. This is the case, because most soils have a large pool of humus, and the relative change is small. Therefore the IPCC linear calculations work well in practice, even though the assumptions used in linear calculations are inherently wrong. On the other hand, non-linear thinking is absolutely crucial for calculations of steady-state values, and for understanding how we should sequester soil carbon.

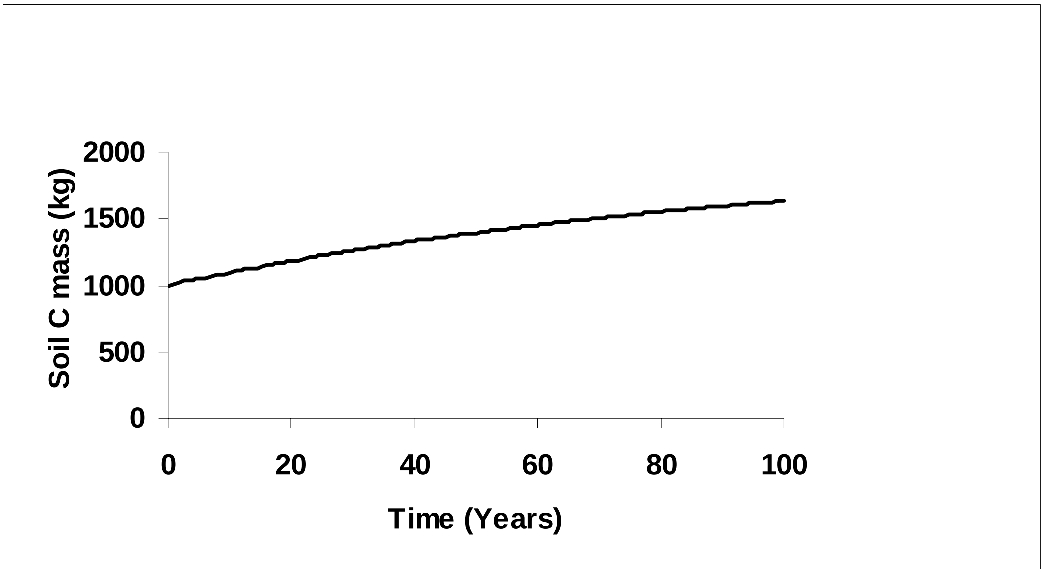

Figure 1. Soil carbon mass dynamics in a hypothetical soil. The initial mass (1000 kg soil C) is in balance when i =10 kg year^{-1} and k_1C = 0.01 year^{-1} (Eq. 2). The graph shows what will happen if we double this annual input (i =20 kg year^{-1}) and maintain this for 100 years. Note the decreasing rate of increase, and that after 100 years the new steady-state mass (2000 kg) still is distant. Source: Andrén and Kätterer (2002b)

Soil carbon itself is not homogeneous, and most soil carbon models take this into account by handling a number of pools of various decomposability. Further, the varying quality of the input has to be managed, and some factor has to be included to account for differences in soil climate; e.g., a dry soil will show lower decomposition rates than a moist soil.

ICBM, Introductory Carbon Balance Model, was developed as a minimum approach for calculating soil carbon balances in a 30-year perspective (Andrén and Kätterer, 1997). The model is based on widely accepted concepts (See, e.g., Hénin and Dupuis, 1945), and it has two state variables or pools, "Young" (*Y*) and "Old" (*O*) soil carbon, and five parameters: i, k_Y, h, k_O, and r_e. (Table 1). Two pools were considered a minimum, since the model has to follow the fate of fairly large instantaneous inputs of litter, e.g., ploughing of grassland (this will give a rapid decrease during the initial years, when roots etc are decomposed). The "humification coefficient" (*h*) controls the fraction of *Y* that enters *O* and (*1-h*) then represents the fraction of the outflow from *Y* that immediately becomes CO_2–C. The parameter r_e summarizes all external influence on the decomposition rates of *Y* and *O*.

The model is analytically solved, i.e., simulation techniques are not necessary, model properties can be mathematically analysed and the model can be run and optimised in an ordinary spreadsheet program (Excel etc.). There are also, in analogy with the one-compartment model above, equations for steady-state conditions, i.e., when the pools are constant and the inputs and outputs balance out. The steady-state equation for *Y* is:

$$Y_{ss}=i/k_Y r_e \qquad \text{Eq. 3}$$

The corresponding equation for O (when Y is in steady-state) is:

$$O_{ss}=ih/k_O r_e \qquad \text{Eq. 4.}$$

Table 1. The parameters of the ICBM model, their typical dimensions and the effect on total soil carbon mass of an increase in value

Parameter	Symbol	Typical unit	Effect on soil C mass of increase
Input	i	kg $year^{-1}$	Positive
Decomp. rate constant for *Y*	k_Y	$year^{-1}$	Negative
"Humification coeff."	h	dimensionless	Positive
Decomp. rate constant for *O*	k_O	$year^{-1}$	Negative
External influence on k_Y and k_O	r_e	dimensionless	Negative

Arable to forest

Most studies from temperate regions indicate increases in soil C stores following afforestation or development of natural succession forest on former arable land.

However, the variation in reported sequestration between different studies is substantial and is probably attributed to variability in climate, soil type, tree species, forest management, differences in pre-afforestation agricultural management, and finally to methodological differences between studies (Table 2, adapted from a literature review conducted by Vesterdal et al. 2002a).

The C dynamics following afforestation are described in a LUSTRA progress report (http://www-lustra.slu.se/rapportermm/pdf/utv1.pdf). Here we only briefly describe changes in soil and forest floor. While the forest floor accumulates carbon following afforestation, the mineral soil may not initially function as a C sink (Rosenqvist et al., 2002). Many studies show C increases in the upper part of the previously ploughed layer (topsoil) and decreasing or unchanged C contents in the lower parts of the topsoil (Richter et al., 1999; Jug et al., 1999; Alriksson, 1998; Vesterdal et al., 2002b).

Immediately after afforestation, model analyses show that there is a transient period (about 10 – 15 years) of decreasing C stores (Rosenqvist et al., 2002). This may be explained by reduced inputs of C to the lower parts of the topsoil layer due to ceased tilling and also by rapid decay of easily decomposing crop residues from agriculture. Furthermore, input of forest litter to the top soil layers is small in the earliest stage of afforestation. However, some longer-term studies have shown significant C accumulation in the topsoil and deeper mineral soil layers (Jenkinson, 1971; Robertson and Vitousek, 1981; Leth and Breunig-Madsen, 1992). The differences may be related to the production and wilting of remaining grass and weeds between the newly planted saplings. A substantial and not exported grass production can be mixed into the topsoil by earthworms.

Model analysis with data from long term agricultural field experiments in Northern Europe has demonstrated that initial C stocks and soil management are the major determinants for soil C balances in agricultural soils (Kätterer and Andrén, 1999). Since parent material and management history is highly variable even within the same farm, fields that have been heavily amended with organic inputs such as manure or sludge, may lose carbon upon afforestation and others that have not received these inputs may increase their C stock. Results from model analyses suggest that, despite of significant medium-term (15-200 years) accumulation of C in the soil, afforestation of former arable land may in the long-term lead to losses of C from the soil (Rosenqvist et al., 2002). Losses would be highest where previous land use and management have resulted in a high C stock.

In conclusion, the length of the studied time interval is very important when interpreting the effects of afforestation on soil C stocks. Furthermore, to predict the consequences of implemented afforestation and management strategies on the soil C stock, former land use and management must be assessed. As a minimum effort, the effects of previous land use must be measured with high precision, i.e., the amount and quality of soil organic matter initially present. A high precision is needed, since the pools are large, often around 100 t C ha^{-1} in 30 cm deep topsoil.

Forest to arable

The dynamics in soil C stocks described above for afforestation are different from those that will occur due to their reversion. Upon the conversion of forest into agricultural land, stumps and coarse roots will be removed and the litter layer will be mixed into the A-horizon. Tillage activity will stimulate the decomposition of litter which will result in a rapid decrease of the C stock in the new Ap-horizon. Tile-draining of the field will increase oxygen levels in the soil, adding to this stimulation. However, this conversion will only take place on very minor areas in the foreseeable future.

<u>Permanent pastures and meadows to forest or vice versa</u>

Agricultural land as well as permanent pastures and meadows have decreased in area by about 20% during the last 50 years. Unfortunately, we know very little about the C stocks in Swedish pasture and meadow soils. These areas were not included in any national surveys. The character of these areas is not uniform and consists mainly of stony and shallow soils with low fertility and hydromorphic soils in lowland areas. The corresponding C stocks in the former are probably much lower than in the latter. The initial decline in soil C upon conversion to forest as discussed above for agricultural soils is probably even more pronounced upon the conversion of these grasslands, since a greater portion of total C is bound in roots and plant litter, which will decompose rapidly, since forest can rarely be established on grassland without soil preparation and/or herbicide treatment. A conservative guess for a medium and long-term effect is that C stocks in the mineral will decline more than upon change from arable to forest, but the build-up of a litter/humus layer would compensate for this decline. C dynamics in lowland areas are probably more affected by drainage than vegetation. At least in coastal areas, the land-rise due to the last glaciation can contribute to carbon losses.

<u>Arable to permanent pasture/meadow or vice versa</u>

Conversion of arable land to temporary and permanent pasture is generally considered to be an efficient means of increasing soil C stocks. According to ECCP (2003) this is the most effective carbon mitigation option of agricultural land. We are only aware of one Swedish investigation where the effects of the conversion from permanent pasture that has never been ploughed to arable and the regeneration of C stocks after the conversion from arable to permanent pasture were quantified (Kätterer et al., 2003). In that investigation, C concentrations were monitored in 1937, 1970 and 2002 in a regular sample grid on the farm Kungsängen, Uppsala (Table 3).

Table 3. Effects of land use change on soil C concentration (0-20 cm depth) in 3 fields on a Swedish farm (Kätterer et al., 2003)

Sampling year	Permanent pasture	Pasture until 1920 Arable 1920-1970 Pasture since 1971	Arable since 1850
1937	3.67	2.60	2.60

1970	3.83	2.44	2.33
2002	3.81	3.02	2.50

The two main conclusions that can be drawn from that investigation are:

1) Carbon concentrations in the topsoil at assumed steady-state are about 1.3% units higher under permanent pasture than under arable conditions. In terms of C stocks, this corresponds to about 25 ton C ha^{-1} at 0-20 cm depth assuming that soil bulk density is about 10% higher under arable conditions than under permanent pasture.

2) Carbon stock changes are more rapid when going from pasture to arable land than vice versa, which is easily explainable by a simple two-pool soil C model.

The results presented above represent relatively moist lowland conditions, fairly recently in geological terms (<500 years) risen from lake bottom. We do not know how representative these figures are for Sweden. However, the results from several Swedish long-term field experiments also outline the positive effect of short-term pastures/meadows within the crop rotation on C stocks of ‘normal’ arable soils (e.g. Ericsson and Mattsson, 2000). These results agree well with those from long-term experiments conducted at Rothamsted in England (e.g. Johnston, 1973; Johnston, 1991), and many other investigations (e.g. Post and Kwon, 2000; Romkens et al, 1999; Vleeshouwers and Verhagen, 2002). Conversion of upland stony pastures to arable land is hardly an option in Sweden today, so these results may be fairly representative overall.

Management is important for C sequestration not only in arable land but also in pastures (Table 4). For example, grazing will probably lead to higher C stocks than mowing (Vandasselaar and Lantinga, 1995) whereas overgrazing will probably decrease C stocks (e.g. Conant and Paustian, 2002; Fuhlendorf et al., 2002). However, our empirical knowledge regarding the effects of cutting method and frequency, and livestock management on soil C is limited (ECCP, 2003).

<u>Management changes within arable land</u>

Changes in management policies affect soil C stocks also within the arable land category (Table 4). In the following we present some examples:

Energy crops

An increase in the production of energy-crops on agricultural land would save fossil fuels and thus, result in a direct C mitigation effect. If perennials are used, reduced tillage would also result in positive soil C balances. Instead of growing specific energy-crops it is also possible to imagine the use of conventional agricultural crops or their harvest residues for extracting combustible gases (biogas generation, pyrolysis) for fossil fuel replacement. The remaining solids will be fairly refractory (biogas rests) or even very refractory (charcoal/char from pyrolysis) and could be added to soil for a high and long-term sequestering effect per kg carbon added.

Altered crop rotations and ecological agriculture

Recently, the Swedish government has set up the target that 20% of the total arable land in Swedish should be managed according to the principles of ecological agriculture. This will have implications on long-term soil carbon stocks. To maintain agricultural production at the present level, an increase in ecological farming practices will probably result in an increased area used for perennial leys. In most cases, this will probably lead to increased carbon stocks in these soils. On the other hand, lower production in cereals will increase the demand of arable land used for grain production, and thus, the area that potentially is available for energy and/or fibre production will decrease. Increased cultivation due to the ban of herbicides will also reduce soil C. The total effect of the 20% target on soil carbon stocks has to be elucidated. About 50% of the area used for ecological agriculture is based on crop production without animal husbandry. Since these farms rely on nitrogen-fixing green manuring crops as their main nitrogen source, this will also increase the demand for arable land.

Catch crops and reduced tillage

The use of catch crops is subsidized and reduced tillage is recommended for reducing nitrate leaching from arable land. These management changes will result in C sequestration due to increased C inputs and lower decomposition rates.

Organic soils

Whereas the C balance for Swedish mineral soils probably is close to zero, organic soils used for agriculture lose a considerable amount of carbon (Andrén and Kätterer, 1999). Management changes on organic soils could therefore result in C mitigation, particularly a reduction of soil cultivation.

Reporting changes in agricultural soil carbon 1990-2010 and onwards

Swedish arable land covers 3 Mha and its topsoil contains about 300 Mton C (Andrén and Kätterer, 1999; Lilliesköld and Nilsson, 1997). We are fairly confident that these values are correct – given with one significant figure. The challenge is to estimate the changes from 1990 to present, and to predict what will happen in the future with and without climate and land use change. This should be made with high precision (note that 1% change corresponds to 3 Mton), an exact measure of the uncertainty of the estimates (for ‘accountability’) and with separate estimates of the effects of, e.g., change from arable to grassland or arable to spruce forest, higher summer temperatures and increased atmospheric CO_2 concentrations.

<u>Building blocks</u>

The assets we have for solving this task can be summarized in the following points:

1. The theoretical background is reasonably solid. We know how to calculate soil C balances if we have enough data of sufficient quality. The theories and models have been developed and tested, based on long-term field and laboratory experiments since early 20th century and are solid. However, if they are exact enough for high-precision estimates remains an open question.
2. There are annual reports of agricultural statistics available. Crop type and yield etc are reported for each year and region. Again, the precision or possible bias of these data sets are not entirely clear. Small farms are not included.
3. Weather statistics on a daily basis are available from a number of measuring stations.
4. One nation-wide agricultural soil C sampling (3000 grid points) has been performed in 1995, and another is in the pipeline
5. Databases are available containing basic soil properties (texture, hydraulic properties etc) for different regions.

Using the building blocks

First, what we do not have is a high-resolution (10x10m) grid of Swedish agricultural land, where each grid point is repeatedly measured for crop and soil properties. When data of this type are available, albeit at a slightly lower resolution, it is possible to calculate changes in this grid and the sum up the results (e.g. Sleutel et al., 2003).

After surveying available data and the amount, resolution and quality of these we recommend the following approach, named ICBMregion (Andrén, Kätterer & Karlsson, in press):

ICBMregion consists of the following modules, W2re, C2hi, and ICBMr (Fig 2). W2re calculates annual soil climate (r_e) from daily weather station data, C2hi calculates annual input of C to the soil (i) and its quality (h) from crop yield and manuring data, and these parameter values are delivered to the actual soil carbon model, ICBMr. ICBMr is a version of ICBM that is adapted to using annual data classified according to production region, soil type and crop type. In the following, all sets of annual inputs are classified according to these. For example, if we run the model for 10 years, we will have 10 (years) x 8 (regions) x 14 (soil types) x 9 (crop types) = 10080 input lines.

The data sets (2-5) thus are used to calculate parameter values for a model, and the measured carbon content in 1995 (Eriksson et al., 1997a,b) gives us an anchoring point, from which we can project carbon pools forwards in time or even backwards. We can use the available information to calculate the carbon pools in the IPCC baseline year (1990) to present time and all years in between, individually for each production region.

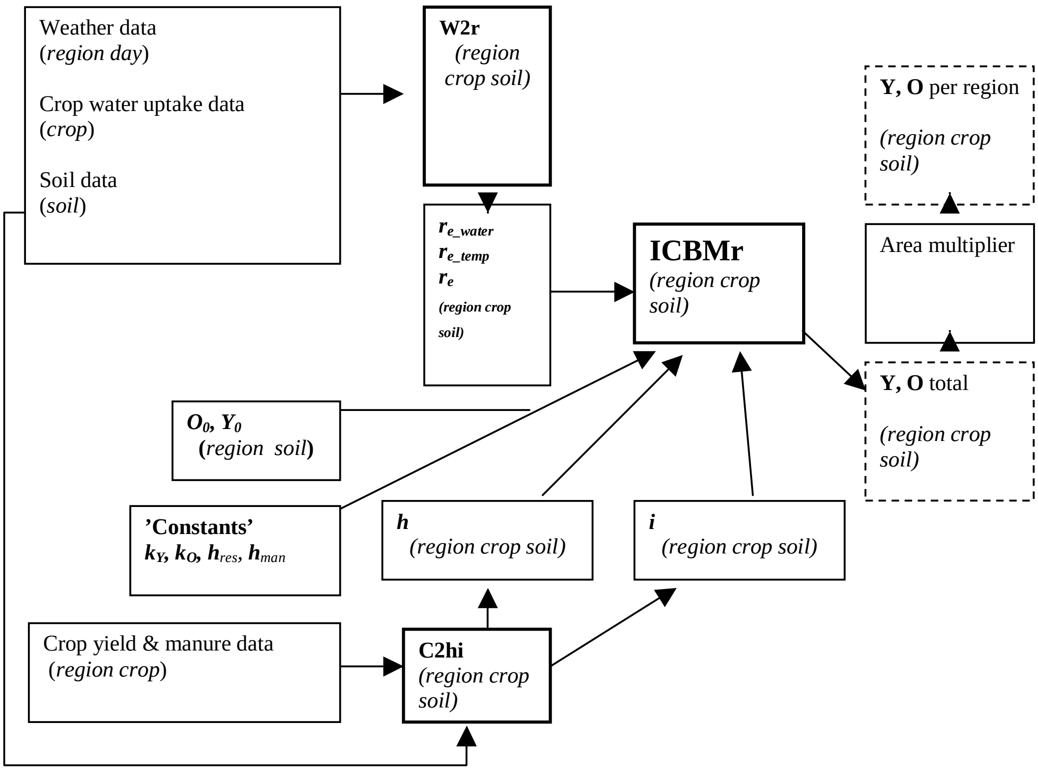

Figure 2. The ICBMregion concept. Crop, weather, and soil data for each region are used in the weather-to-r_e module (**W2r$_e$**), calculating soil climate, r_e, for each region, crop and soil (Y and O (kg ha^{-1}). These are then multiplied by the actual area to obtain totals for, e.g. region. The initial carbon mass values (O_0, Y_0) are taken from the literature. Parameters k_Y, k_O, h_{res}, h_{man} are regarded as constants (Table 1), and the indices *res* and *man* indicate crop residues and manure, respectively. Crop yield and manure input data are used to calculate C input to soil (i), as well as a weighted h, by the allometric functions in the **C2hi** module. The two initial values (O_0, Y_0) and the five parameters (r_e, k_Y, k_O, h, i) are then used for calculating annual soil C dynamics. From Andén et al. (in press).

The annual crop yield statistics are reported for different crops, for each of the eight production regions (Anonymous 1990ab, etc.). We use weather station data for each region together with crop type (bulked from individual crop data) and soil type to calculate annual soil climate for each crop/soil type permutation in each region. For each year, region, crop and soil type, ICBMr calculates the annual change in young and old soil carbon per hectare, and sums up the changes to, e.g., national changes. What-if scenarios as well as comparisons between benchmark years are readily made.

When projections of regional climate change are available, we can quite easily make projections of soil C dynamics under different climate (or land use/management)

scenarios. We can follow the dynamic effects of carbon sequestration efforts – and estimate their efficiency.

<u>Precision and simplifications – where to go</u>

The ICBMregion concept as described above is fairly complex, and one may ask whether this is necessary and if the effort really is worth the results. In other words, is this the best approach to IPCC reporting – or should we just use the Tier 1 default values and agricultural land use statistics? Further, how do we estimate the uncertainty of the forward and backward projections?

ICBMregion is already programmed and the data sets are available in digital form, so the extra effort needed for the modelling itself is limited. A time-consuming part is quality check of the data sets, which is necessary regardless of approach. However, improving the functions calculating soil climate from weather data, the allometric functions used for calculating soil C input from yield data etc are major research tasks. This is not an argument against this approach – we simply use today's state-of-the-art functions and can easily refine them when new knowledge emerges. It is also very valuable to have a mathematical description of the whole problem complex – as a template for further reasoning.

We think that the results from this comprehensive approach applied to, e.g., a 10-year period, can be condensed (using table functions for generating parameter values) into a simple spreadsheet model that easily can be used to test ideas on C sequestration. In other words, we need the experience of a more comprehensive approach to create a simplified version.

To increase the precision of the estimates it is most urgent to have as much high-quality field measurements of soil carbon pools as possible. If we know starting points, what has been done, some intermediate points and the endpoints, we can test our assumptions. The field data need to be of high quality (no bias, high precision, low variance) to critically test the model assumptions – low-precision data will fit any model. Planned and future soil samplings (monitoring) of Swedish arable land are very valuable, but we also need controlled long-term experiments of very high standard, where factor by factor can be revealed (black fallow with no vegetation, also irrigated, ploughed/not ploughed etc). It is simply so that without high-quality data sets we can neither calibrate models nor estimate the precision of their projections.

An excellent but somewhat chilling example of the precision expected in whole-country estimates of agricultural soil carbon is presented by Ogle et al. (2003). They calculated the 95% confidence estimates of agricultural soil carbon changes in the US 1990-1997, using the IPCC Tier 1 methodology. They used different combinations from the range of factors listed and calculated the outputs of 50 000 combinations. With 95% confidence they could conclude that 6Mt C had been lost – or 6Mt C had been gained – or something in between. Clearly, the Tier 1 approach is not satisfactory for exact 'accountability', but at least the result supports the overall feeling that today's US agricultural soils are not far from balance.

A more exact approach (Tier 2-3) will probably give more exact projections, but it will be impossible to objectively calculate confidence intervals, because nobody will know the inherent variance in the parameter values used. However, if we look at individual measures, e.g., reduced cultivation, we can calculate the average effects of these with a much higher precision, if we have good long-term field trial data and a reasonably realistic model.

For reporting changes in Swedish arable mineral topsoils, we suggest a Tier 2 approach which is based on modelling. A dynamic modelling approach is necessary for separating management-induced impacts on C stocks from natural variation or climatic trends. The contributions from subsoils is still very uncertain. However, the same principles will hold, but we need more data.

Our empirical knowledge concerning the impact of management on C balances of organic soils is poor. Tier 1 default values could be used but these ought to be adjusted for realistic management schemes. The impact of row crops like potatoes or sugar beets contra perennial crops like grass leys on C balances differ probably considerably.

Reporting changes in soil carbon due to land use change 1990-2010 and onwards

The effect of land use changes between arable, pasture/meadow and forest on soil C stocks is dependent on the time scale of interest. For transitions between land use types and eventually even for all land, we propose an accounting system based on the approach proposed by Kirschbaum et al. (2001), which is based on the following principles:

The land is divided into different land use types, with each one having a characteristic average carbon density determined by land use and environmental factors (Fig 3). Each transition from one land use type to another or a change in average C density within a specified type due to changed management would be defined as anthropogenic. To calculate annual credits and debits, the change in average C stocks is divided by a time constant which would be a characteristic of each possible land-use conversion.

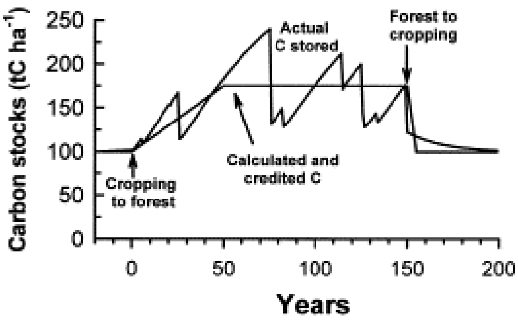

Fig. 3. Example of a production forest established on former agricultural land, subject to a series of disturbances, and then converted back to agriculture after 150 years. Shown are actual and credited carbon stocks assuming a linear accumulation over 50 years following the cessation of agriculture, and a 5-year linear decline associated with the subsequent re-conversion to agriculture. Source: Kirschbaum et al. (2001).

It has to be further evaluated weather the transitions in C stocks can be approximated by linear functions as proposed by Kirschbaum et al. (2001) or if non-linear transition periods have to be assumed. The number of land use types, management types and their possible subdivision regarding soil type and climatic region also has to be further discussed.

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Table 2(Source: Table 15, Vesterdal et al., 2002a). Studies reporting carbon sequestration in soil of afforestation stands on former arable land.

Country	**Mean temp./prec. (ºC/mm)**	**Soil type**	**Land-use change**	**Time (years)**	**Type of study and Soil compartment**	**Change in soil C (Mg ha^{-1})**	**Rate of C accretion (g m^{-2} yr^{-1})**	**Reference**
Sweden	7.8/700	Cambisols (Loam)	Plantations of *Alnus*, *Betula*, *Populus*, *Salix*	0-6	Resampling Forest floor	+0.2-1.7	+3.3-28.0	Alriksson (1998)
Germany Abbachhof Canstein	 8.0/650 7.5/675	Cambisols (sandy loam-loamy sand)	Plantations of *Populus spp.*, *Salix sp.*	0-9	Resampling 0-30 cm	 +7.0 0	 +77.8 0	Jug et al. (1999) Makeschin (1994)
North central USA	Cool temperate	Former prairie soils (Mollisols?)	Plantations of *Populus sp.*	0-15	Chronosequence 0-100 cm	 +24.4*	 +163	 Hansen (1993)
N Spain	14.8/802	Cambisols	Plantations of *Pinus radiate*	0-17	Chronosequence Forest floor 0-5 cm	 +7.0 +1.7	 +41.2 +10.2	Romanya et al. (2000)
SE USA	16/1170	Kanhapludults (sandy loam to clay)	Plantations of *Pinus taeda*	0-40	Resampling Forest floor 0-15 cm 15-60	 +37.8 +1.45 0	 +94 +3.6 0	Richter et al. (1999)
North central USA	Cool temperate	Sand and sandy loam	Plantations of *Pinus resinosa*	10-50	Chronosequence 0-15 cm	 +26.3	 +65.7	Wilde (1964) (from Post & Kwon, 2000)
SE USA	12.8-15.6/1020	Ultisols (clay)	Plantations of *Pinus taeda*	0-50	Chronosequence 0-10 cm	 +10 †	 +20.0	Schiffman & Johnson (1989)
Sweden Karlsborg Värnamo Grillby	 6.2/510 5.9/695 5.8/529	 Sandy loam Sandy loam Clay	Plantations of *Picea abies*	 0-60 0-45 0-45	Chronosequences Forest floors + A horizons	 +10 0 +30	 +16.7 0 +66.7	Alriksson (1998)
SE USA	Warm temperate	Sandy loam	Plantations of *Pinus virginiana*	0-50/70	Chronosequence 0-17.8 cm	 +7.1	 +11.8	Hosner & Graney (1970) from Post & Kwon, 2000)
NE USA	Temperate	Haplorthods (sandy loam)	Succession to mixed deciduous and coniferous forest	2-65	Chronosequence Forest floor Ap horizon B horizon	 +30 -14 +15	 +47.0 -21.0 +22.0	Hamburg (1984)

Table 2. Cont.

Denmark	7.8/800	Spodosols (Sand)	Plantations of *Picea abies*	0-76	Chronosequence Forest floor 0-100 cm	 +38 +114	 +49 +150	Leth & Breuning-Madsen (1992)
England Geescroft Broadbalk	9.0/700	Leached brown soil (loam)	Succession to mixed deciduous forest	0-83	Resampling 0-23 cm	 +21 +43	 +25.3 +51.8	Jenkinson (1971, 1991)
NE USA	Temperate	Sandy loam	Succession to *Quercus-Carya* forest	12-100+	Chronosequence 0-20 cm	 +10.3	 +10.3	Robertson & Tiedje (1984)
SE USA	16.0/1300	Spodosols and Ultisols (loam and sandy clay loam	Succession to *Quercus-Carya-Pinus* forest	25-200	Chronosequence Forest floor 0-3 cm	 +7.6 Mg ha^{-1} +12.7 Mg ha^{-1}	 +4.3 +7.3	Switzer et al. (1979)
NE USA	11.7/1000	Silty Loam	Succession to *Quercus spp.*	0-250+	Chronosequence 0-15 cm	 +23.4	 +9.4	Robertson & Vitousek (1981)

*includes tree roots

†weak relationship, only one stand younger than 30 years.

Table 4. Measures for increasing soil carbon stocks in agricultural soils and potential yearly soil carbon sequestration rates (t CO_2 ha^{-1} y^{-1}). Source: Nortcliff et al. working paper, soil organic matter working group; EU Soil Thematic Strategy.

Measure	**Potential soil carbon sequestration rate (t CO_2 ha^{-1} y^{-1})**	**Estimated uncertainty (%)**	**Reference / notes**
Crop-land			
Zero-tillage	1.42 but see reference	> 50%	1, 2
Reduced-tillage	< 1.42	>> 50%	3
Set-aside	< 1.42	>>50%	4
Perennial grasses and permanent crops	2.27	>50%	5
Deep-rooting crops	2.27	>50%	5
Animal manure	1.38	> 50%	1
Crop residues	2.54	> 50%	1
Sewage sludge	0.95	>50%	1, 15
Composting	1.38 or higher	>>50%	6, 15
Improved rotations	>0	Very high	7
Fertilisation	0	Very high	8
Irrigation	0	Very high	8
Bioenergy crops	2.27	>>50%	1
Extensification	1.98	>>50%	1
Organic farming	0-1.98	>>50%	9
Convert arable to woodland	2.27	>>50%	1
Convert arable to grassland	7.03 ± 2.08	110% (2.3 to 11.2)	10
Convert grassland to arable	-3.66	>>50%	11
Convert permanent crops to arable	-3.66	>>50%	11
Convert woodland to arable	-?	?	?
Grassland			
Increase in the duration of grass leys	0.4-1.8	?	14
Change from short duration to permanent grasslands	1.1-1.5	?	14
Increase of fertiliser on nutrient poor permanent grassland	0.7	?	14
Intensification of organic soils with permanent grassland	-3.3-4.0	?	14
Livestock management	??	??	?
Cutting method and frequency	?	?	?
Fire protection	??	-	?
Revegetation			
Abandoned arable land	2.27	>>50%	12
Farmed organic soils			
Protection and restoration	Up to 17	Range 0–17. Spatial variability high	13
Avoid row crops and tubers	0	>50%	13
Avoid deep ploughing	5	>50%	13
More shallow water table	5-15	>50%	13
Convert arable to grassland	5	>50%	13
Convert arable to woodland	2-5	>>50%	13

New crops on restored wetlands from arable	8-17	>50%	13
New crops on restored wetlands from grassland	3-12	>50%	13
Sheep grazing on undrained peatland	>8	>50%	13
Abandon for conservation	>8	>50%	13

References / notes:

1. Smith et al. (2000); per hectare values calculated using the average C content of arable top soils (to 30cm) of 53 t C ha^{-1}; Vleeshouwers and Verhagen (2002). According to some experts, C accumulation resulting from no-tillage is over-estimated in the literature, some figures given by case studies appear not reliable – thus strong sequestration doubtful.
2. Uncertainty estimated from 95% confidence interval about the mean – statistical uncertainty of the mean only; actual uncertainty is higher.
3. Estimated from papers reviewed in Smith et al. (2000)
4. Assumed to be the same as zero tillage figure of Smith et al. (2000)
5. Assumed to be the same as for bioenergy crops figure of Smith et al. (2000)
6. Assumed to be the same as animal manure figure of Smith et al. (2000).
7. Minimal impact of arable rotations in papers reviewed in Smith et al. (2000) but perennial crops in rotations may increase soil carbon levels
8. Net carbon impact of irrigation and fertilisation is minimal or negative when carbon costs of producing fertiliser and pumping irrigation water are considered (Schlesinger, 1999)
9. Organic farming is increasing in Europe, but is not a single management practice. Within an organic farm, a combination of practices may be used including extensification, improved rotations, residue incorporation and manure use. These will contribute to carbon sequestration positively, but in different proportions depending of the degree of implementation of a given practice. Zero and reduced tillage are generally incompatible with organic farming since increased tillage is frequently used to control weeds. It is, therefore, impossible to assign an exact figure for the carbon sequestration potential of organic farming, but a range between the lowest and highest potential sequestration rate can be given.
10. From Vleeshouwers & Verhagen (2002). Also based on figures from Rothamsted grass to arable conversions
11. From figures of Jenkinson (1988) used by Smith et al. (1996)
12. Per hectare value assumed to be the same as Rothamsted Geescroft natural regeneration (Poulton, 1996)
13. From Freibauer (in press). Carbon sequestration is from avoiding carbon loss from peats. Further benefit through reduced emission of N_2O, which is not compensated by increased CH_4 emissions.
14. Average net annual fluxes over a 20-yr. period (Loiseau, in: Arrouays et al., 2002).

The sequestration values are based on a loading rate of 1 t ha^{-1} y^{-1}, which was the lowest safe limit in place (in Sweden) at the time of analysis for this figure (1997). A higher loading rate would give a higher sequestration rate per area. As the limiting factor for the application of compost is the amount of producible compost, a higher loading rate on a certain area would imply that a more limited area could be treated.

Report 5337

Preparing for Sweden´s reporting of emissions and removals of greenhouse gases in the LULUCF sector under the Kyoto Protocol

The aim of this report is to interpret what the Kyoto Protocol and Marrakesh accords are likely to imply in terms of components in a Swedish system for reporting of greenhouse gas emissions and removals from the land-use, land-use change, and forestry (LULUCF) sector.

Within this sector, it will be mandatory for all Parties to report emissions and removals following Afforestation, Reforestation, and Deforestation (ARD). Further, it will be optional for the Parties to report on changes due to forest management, cropland management, grazing land management, and revegetation.

A base alternative for the future reporting of the LULUCF sector is presented. The components of this alternative are based on a compromise between what data are already available, the cost of acquiring new data, and the likely importance of a specific methodology in relation to estimating the overall emissions/removals of greenhouse gases from the LULUCF sector. In addition, different options to the base alternative are presented and needs for further development activities are discussed.

Due to the level of complexity of reporting emissions and removals for the LULUCF sector, both in terms of ecological/social processes involved and the reporting requirements, it can be foreseen that the national system will continuously need to be upgraded in the future. Thus, the current report is not a proposition for “the final system”.

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