CHAPTER 3

CONSISTENT REPRESENTATION OF LANDS

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3.1 INTRODUCTION

Information, in terms of classification, area data, and sampling that represents various land-use categories, is needed to estimate the carbon stocks, and the emission and removal of greenhouse gases associated with Agriculture, Forestry and Other Land Use (AFOLU) activities. This chapter provides guidance on using different types of data to represent land-use categories, and conversions between land-use categories, so that they are applied as appropriately and consistently as possible in inventory calculations.

Countries use various methods to obtain data, including annual census, periodic surveys and remote sensing. Each of these methods of data collection will yield different types of information (e.g., maps or tabulations), at different reporting frequencies, and with different attributes. Guidance is provided on the use of three generic approaches.

Approach 1 identifies the total area for each individual land-use category within a country, but does not provide detailed information on the nature of conversions between land uses. Approach 2 introduces tracking of conversions between land-use categories. Approach 3 extends the information available in Approach 2 by allowing land-use conversions to be tracked on a spatially explicit basis. Countries may use a mix of Approaches for different regions over time.

The guidance presented here is intended to assist countries in making the best use of available data and reducing, as far as practicable, possible overlaps and omissions in reporting. The guidance allows informed decisions on the appropriate use of data of different types by those preparing greenhouse gas inventories, but is not intended to be prescriptive on how data may be collected. Generally, all data should be:

- adequate, i.e., capable of representing land-use categories, and conversions between land-use categories, as needed to estimate carbon stock changes and greenhouse gas emissions and removals;
- consistent, i.e., capable of representing land-use categories consistently over time, without being unduly affected by artificial discontinuities in time-series data;
- complete, which means that all land within a country should be included, with increases in some areas balanced by decreases in others, recognizing the bio-physical stratification of land if needed (and as can be supported by data) for estimating and reporting emissions and removals of greenhouse gases; and
- transparent, i.e., data sources, definitions, methodologies and assumptions should be clearly described.

The descriptions of land use follow the framework of:

- land-use category - is the broad land use (one of the six land-use categories described below) reported as either land remaining in a land-use category (i.e., remaining in the same use throughout the inventory time-series) or land converted to a new land-use category (representing a change in land use).
- sub-category - refers to special circumstances (e.g., areas of grazing within Forest Land) that are estimated and reported separately but do not duplicate land in the broad land-use category.
- Land-use categories and sub-categories may be further *stratified* on the basis of land-use practices and bio-physical characteristics in order to create more homogeneous spatial units as may be used for emissions estimation (see Table 3.1 for examples).

3.2 LAND-USE CATEGORIES

The six broad land-use categories described below form the basis of estimating and reporting greenhouse gas emissions and removals from land use and land-use conversions. The land uses may be considered as top-level categories for representing all land-use areas, with sub-categories describing special circumstances significant to emissions estimation, and where data are available. The categories are broad enough to classify all land areas in most countries and to accommodate differences in national land-use classification systems, and may be readily stratified (e.g., by climate or ecological zones). The categories (and sub-categories) are intended to be identified through use of **Approaches** for representing land-use area data described in subsequent sections.

The definitions of land-use categories may incorporate land cover type, land use based, or a combination of the two. Care needs to be taken in inferring land use from the land cover characteristics and vice versa. For example, in some countries, significant areas of the Forest Land category may be grazed, and firewood may be collected from scattered trees in the Grassland category. These areas with different use may be significant enough for countries to consider them separately as additional sub-categories. Countries should ensure that land is not accounted for in more than one category or sub-category, in order to avoid double-counting of land areas.

For convenience, the categories are referred to as land-use categories. These particular categories have been selected because they are:

- robust as a basis for emissions and removals estimation;
- implementable; and
- complete, in that all land areas in a country may be classified by these categories without duplication.

Countries will use their own definitions of these categories, which may or may not refer to internationally accepted definitions, such as those by FAO, Ramsar[1], etc. Only broad and non-prescriptive definitions are provided for the land-use categories and of managed and unmanaged lands. Countries should describe and apply definitions consistently for the national land area over time.

Countries should describe the methods and definitions used to determine areas of managed and unmanaged lands. Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions. All land definitions and classifications should be specified at the national level, described in a transparent manner, and be applied consistently over time. Emissions/removals of greenhouse gases do not need to be reported for unmanaged land. However, it is *good practice* for countries to quantify, and track over time, the area of unmanaged land so that consistency in area accounting is maintained as land-use change occurs.

As the resolution of the national land use, mapping may be more coarse than the definitions used to describe the land-use categories (e.g., if the forest definition applied by a country includes a minimum area, of say one hectare for example, yet the available land-use mapping minimum unit size is five hectares) it is possible that there will be small (unidentified) areas of one land-use category reported under another. These small areas may be reported under the mapped land use when they remain in the same category. If they are converted to another land-use category (e.g., a small area of Forest Land converted to another use is identified within an area previously mapped as Cropland) and this is identified (e.g., by a permit application for the activity) then they should be reported under the appropriate land-use conversion (i.e., Forest Land converted to another specified land use) and subtracted from the original (previously misclassified) land-use (remaining) area.

The land-use categories for greenhouse gas inventory reporting are:

(i) Forest Land

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

(ii) Cropland

This category includes cropped land, including rice fields, and agro-forestry systems where the vegetation structure falls below the thresholds used for the Forest Land category.

(iii) Grassland

This category includes rangelands and pasture land that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the threshold values used in the Forest Land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, consistent with national definitions.

(iv) Wetlands

This category includes areas of peat extraction and land that is covered or saturated by water for all or part of the year (e.g., peatlands) and that does not fall into the Forest Land, Cropland, Grassland or Settlements categories. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

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[1] Refers to Ramsar Convention on Wetlands. The Convention on Wetlands, signed in Ramsar, Iran, in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

(v) Settlements

This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with national definitions.

(vi) Other Land

This category includes bare soil, rock, ice, and all land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available. If data are available, countries are encouraged to classify unmanaged lands by the above land-use categories (e.g., into Unmanaged Forest Land, Unmanaged Grassland, and Unmanaged Wetlands). This will improve transparency and enhance the ability to track land-use conversions from specific types of unmanaged lands into the categories above.

LAND-USE CONVERSIONS

Full application of the guidance requires estimation of land-use conversions that take place between data collection intervals, particularly when different carbon stock estimates and different emission and removal factors are associated with lands before and after a transition. Applicable land uses and land-use conversions are shown below:

FF	=	Forest Land Remaining Forest Land	LF	=	Land Converted to Forest Land
GG	=	Grassland Remaining Grassland	LG	=	Land Converted to Grassland
CC	=	Cropland Remaining Cropland	LC	=	Land Converted to Cropland
WW	=	Wetlands Remaining Wetlands	LW	=	Land Converted to Wetlands
SS	=	Settlements Remaining Settlements	LS	=	Land Converted to Settlements
OO	=	Other Land Remaining Other Land	LO	=	Land Converted to Other Land

Where detailed data about the origin of land converted to a category are available (which will depend on the Approach available to a country to represent land-use areas), countries can specify the land-use conversion. For example, LC can be sub-divided into Forest Land Converted to Cropland (FC) and Grassland Converted to Cropland (GC). While both land areas end up in the Cropland category, the differences in their emissions and removals of greenhouse gases due to their origin should be represented and reported wherever possible. When applying these land-use category conversions, countries should classify land under only one (end land use) category to prevent double counting. The reporting category is therefore the end-use category, not the category of origin prior to the land-use conversion.

If a country's national land-use classification system does not match categories (i) to (vi) as described above, the land-use classifications should be combined or disaggregated in order to represent the categories presented here. Countries should report on the procedure adopted for the reallocation. The national definitions for all categories used in the inventory and any threshold or parameter values used in the definitions should be specified. Where national land classification systems are being changed or developed for the first time, compatibility with land-use classes (i) to (vi) above should be sought.

The broad land-use categories listed above may be further stratified (as described in Section 3.3.2) by climate or ecological zone, soil and vegetation type, etc., as necessary, to match land areas with the methods for assessing carbon stock changes and greenhouse gas emissions and removals described in Chapters 2 and 4 to 9 of this Volume. Default climate and soil classification schemes are provided in Annex 3A.5. Examples of stratifications that are used for Tier 1 emissions and removals estimation are summarized in Table 3.1. Specific stratification systems vary by land use and carbon pools and are used in the estimation methods later in this Volume. Guidance on stratifying land-use areas to match data needs for estimating emissions and removals is provided in Section 3.3.2 of this chapter.

TABLE 3.1
EXAMPLE STRATIFICATIONS WITH SUPPORTING DATA FOR TIER 1 EMISSIONS ESTIMATION METHODS

Factor	Strata
CLIMATE (see Annex 3A.5)	Boreal Cold temperate dry Cold temperate wet Warm temperate dry Warm temperate moist Tropical dry Tropical moist Tropical wet
SOIL (see Annex 3A.5)	High activity clay Low activity clay Sandy Spodic Volcanic Wetland Organic
BIOMASS (ECOLOGICAL ZONE) (see Figure 4.1, in Chapter 4 Forest Land)	Tropical rainforest Tropical moist deciduous forest Tropical dry forest Tropical shrubland Tropical desert Tropical mountain systems Subtropical humid forest Subtropical dry forest Subtropical steppe Subtropical desert Subtropical mountain systems Temperate oceanic forest Temperate continental forest Temperate steppe Temperate desert Temperate mountain systems Boreal coniferous forest Boreal tundra woodland Boreal mountain systems Polar
MANAGEMENT PRACTICES (more than one may be applied to any land area)	Intensive tillage/Reduced till/No-till Long term cultivated Perennial tree crop Liming High/Low/Medium Input Cropping Systems Improved Grassland Unimproved Grassland

3.3 REPRESENTING LAND-USE AREAS

This section describes three Approaches that may be used to represent areas of land use using the categories defined in the previous section. They are presented below in order of increasing information content. Approach 1 identifies the total change in area for each individual land-use category within a country, but does not provide information on the nature and area of conversions between land uses. Approach 2 introduces tracking of land-use conversions between categories (but is not spatially explicit). Approach 3 extends Approach 2 by allowing land-use conversions to be tracked on a spatially explicit basis.

The Approaches are not presented as hierarchical tiers and do not imply any increase or decrease in accuracy but reflect collection methods and attributes and, therefore, appropriate ways to use the data. Accuracy is affected as much or more by the quality of application of the Approach as by the Approach itself. The Approaches are not mutually exclusive, and the mix of Approaches selected by a country should reflect emissions estimation needs and national circumstances. One Approach may be applied uniformly to all areas and land-use categories within a country, or different Approaches may be applied to different regions or categories or in different time intervals.

In all cases, countries should characterize and account for all relevant land areas in a country consistently and as transparently as possible.

All data should reflect the historical trends in land-use area, as needed for the inventory methods described in Chapters 2 and 4 to 9 of this Volume. The commencement time for the historical data required is based on the amount of time needed for dead organic matter and soil carbon stocks to reach equilibrium following land-use conversion (20 years is recommended as a default, but can be longer, e.g., for temperate and boreal systems). After the period to reach equilibrium has passed, land that was added to a land-use conversion category needs to be transferred to "land remaining in a land-use category". The time-series data on land-use conversion is therefore also used to determine the annual transfer of area from the category "land converted to category" to "land remaining in a land-use category".

TIME-SERIES

Inventory requires data on land-use area for at least two points in time relevant to the inventory year. For Approach 1 (identifying only the net national change in area of each land-use category, but not the transfers between them), the historical land use may still not be known. In such circumstances countries should either infer the previous land use (see Section 3.3.2.2 below) or assume that the land has remained in the land-use category for all time prior to the land-use conversion. This assumption may underestimate removals where conversions to land uses with higher carbon contents predominate, or underestimate emissions in the opposite case.

It is important that there is a consistent time-series in the preparation of land-use category and conversion data so that artifact from method change is not included as an actual land-use conversion. Care should also be taken to ensure that the areas of managed and unmanaged land are both defined and estimated consistently. The following section details how to deal with changes in managed land areas (and consequent changes in carbon stock) when using stock change methods for emissions estimation.

CONSISTENT USE OF LAND AREA IN CARBON STOCK ESTIMATES

Over the time-series of a national inventory, it is likely that the total area of managed lands will increase as unmanaged lands are converted to managed land. In this case, where the land area is used to estimate the carbon stock (when using a stock-difference method of emissions estimation), it is possible that the entry of additional land into the inventory (by changing from an unmanaged to managed status) will incorrectly appear as a carbon stock increase. This could wrongly be inferred as a removal from the atmosphere, whereas in reality it is only an increase due to the expanded land-use area over the inventory time-series. To separate carbon stock increases arising from changes in area from true carbon stock changes, carbon stock estimates should be recalculated for the complete inventory time-series area whenever the total area of managed land changes in an annual inventory.

The maximum area of land (and associated carbon stock) at any point in the time-series should be used as the basis for emissions and removals estimation throughout the inventory time-series. Carbon stocks on unmanaged lands can be assumed to remain constant (thus, carbon stock changes would be zero) until the year in which land is classified as a managed use. The recalculation will therefore change the initial carbon stock estimate in the year the land entered the inventory, but will not affect the estimation of carbon stock change over the inventory time-series until the relevant land becomes managed.

DATA AVAILABILITY

For many countries, implementing these inventory guidelines may require new data collection. Annex 3A.3 provides general guidance on sampling techniques and Annex 3A.4 on spatially explicit (Approach 3) datasets. Where the data needed to apply these inventory guidelines on land use are not available nationally, data on land categories may be derived from global datasets (examples are provided in Annex 3A.1, but generally report on the basis of land cover only, and not land use). It is preferable that data used should be capable of producing input to uncertainty calculations.

When using land-use data, inventory compilers should:

- Harmonize definitions between the existing independent databases and also with the land-use categories to minimize gaps and overlaps. For example, overlaps might occur if woodland on farms were included both in forestry and agricultural datasets. In order to harmonize data, the woodland should be counted only once for greenhouse gas inventory purposes, taking into account the forest definition adopted nationally. Information on possible overlaps for the purposes of harmonization should be available from agencies responsible for surveys. Harmonization of definitions does not mean that agencies should abandon definitions that are of use to them but should establish the relationship between definitions in use with the aim of eliminating double counting and omissions. This should be done throughout the dataset to maintain time-series consistency.

- Ensure that the land-use categories used can identify all relevant activities. For example, if a country needs to track a managed land-use category such as Forest Land, then the classification system must distinguish managed from unmanaged Forest Land.
- Ensure that data acquisition methods are reliable, well documented methodologically, timely, at an appropriate scale, and from reliable sources.
- Ensure the consistent application of category definitions between time periods. For example, countries should check whether the definition of forest has changed over time in terms of tree crown cover and other parameters. If changes are identified, use the corrected data for recalculation consistently throughout the time-series, and report on actions taken. Guidance on recalculation can be found in Volume 1 Chapter 5.
- Prepare uncertainty estimates for those land-use areas and conversions in area that will be used in the estimation of carbon stock changes, greenhouse gas emissions and removals.
- Ensure that the national land area is consistent across the inventory time-series; otherwise stock changes will reflect false C increases or decreases due to a change in total land area accounted for when using a stock change emissions estimation method.
- Assess whether the sum of the areas in the land classification databases is consistent with the total national area, given the level of data uncertainty. If coverage is complete, then the net sum of all the changes in land area between two time periods should be zero to within the uncertainties involved. In cases where coverage is incomplete, the difference between the area covered and the national area should, in general, be stable or vary slowly with time, again to within the uncertainties expected in the data. If the balancing term varies rapidly, or (in the case of complete coverage) sums are not equal, inventory compilers should investigate, explain, and make any corrections necessary. These checks on the total area should take into account the uncertainties in the annual or periodic surveys or censuses involved. Information on uncertainties should be obtained from the agencies responsible for the surveys. Remaining differences between the sum of areas accounted for by the available data and the national area should be within the expected uncertainty for area estimation.

For some activities reported, such as the application of nitrogen fertilizer, liming and harvested wood products, only national aggregate data may be available. Where emissions and removals estimation methods are applied at a national level, it is appropriate to use such data without categorization by land use.

3.3.1 Three Approaches

APPROACH 1: TOTAL LAND-USE AREA, NO DATA ON CONVERSIONS BETWEEN LAND USES

Approach 1 represents land-use area totals within a defined spatial unit, which is often defined by political boundaries, such as a country, province or municipality. Another characteristic of Approach 1 data is that only the net changes in land-use area can be tracked through time. Consequently, the exact location or pattern of the land uses is not known within the spatial unit, and moreover the exact changes in land-use categories cannot be ascertained. Datasets are likely to have been prepared for other purposes, such as forestry or agricultural statistics. Frequently, several datasets will be combined to cover all national land classifications and regions of a country. In this case the absence of a unified data system can potentially lead to double counting or omission, since the agencies involved may use different definitions of specific land use for assembling their databases. Ways to deal with this are suggested below.

Tables 3.2 and 3.3 show summary land-use area data for a hypothetical country (with a national land area of 140 million ha) using locally relevant land classifications. Table 3.2 is prepared at the level of the broad land-use categories. Table 3.3 depicts the same information with example stratifications to estimate the effect of various activities using the emissions estimation methods described elsewhere in this Volume.

Determination of the area of land-use conversion in each category is based on the difference in area at two points in time, either with partial or full land area coverage. No specification of inter-category conversions (i.e., 'land remaining in a land-use category' and 'land converted to a new land-use category') is possible under Approach 1 unless supplementary data are available (which would then introduce a mix with Approach 2).

The land-use area data may come originally from periodic sample survey data, maps or censuses (such as landowner surveys), but will probably not be spatially explicit. The sum of all land-use category areas may or may not equal the total area of the country or region under consideration, and the net result of land-use conversions may or may not equal zero, depending on the consistency in data collection and application in the inventories for each land-use category. The final result of this Approach is a table of land use at given points in time. Because the total land base that is reported each year for all land-use categories should remain constant, a table similar to Table 3.3 should be generated as a QA/QC measure. If inconsistencies are found, it is *good practice* to identify and correct the problem(s) for future inventories. This may require closer coordination among inventory teams for separate land-use categories (if analyzed separately) or possibly new surveys or other types of data collection.

Other parts of this Volume require information on land area in each land-use category presented in Table 3.3 to be broken down into the categories "land remaining in the same land-use category" and "land converted to a new land-use category". This is dependent on methodological requirements in other chapters of this Volume. If land-use data are not sufficient to support Approach 2 (see below), where the total (gross) land conversion areas can be quantified, the emissions and removals may be reported in the "land remaining in the same land-use category" (as specified in Table 3.2). This is because the data may only be sufficient to identify the net change in area of each land-use category, and not the total effect of all land conversions. However, in general the methods for both soils and biomass related emissions estimation require land area data categorized by "lands remaining" and "converted to" categories and thus it is desirable to do this if possible, even if this is done using expert judgment.

Note that by reporting only in the "land remaining" category, emissions and removals will include, but not explicitly reflect a changing land base within a land-use category (different areas, e.g., by the net transition in areas to and from the Forest Land category) over time. This may overestimate or underestimate emissions for that particular "land remaining" category. However, a complete inventory will tend to counter-balance this with emissions and removals from another "land remaining" category in the inventory.

It is acceptable to report non-CO_2 emission by source category without attribution to land uses if emissions are estimated based on national statistics, without reference to individual land uses (e.g., N_2O emissions from soils). Methods outlined in this Volume frequently estimate emissions using national statistics in this manner.

TABLE 3.2
EXAMPLE OF APPROACH 1: AVAILABLE LAND USE DATA WITH COMPLETE NATIONAL COVERAGE

Time 1			Time 2			Net land-use conversion between Time 1 and Time 2		
F	=	18	F	=	19	Forest Land	=	+1
G	=	84	G	=	82	Grassland	=	-2
C	=	31	C	=	29	Cropland	=	-2
W	=	0	W	=	0	Wetlands	=	0
S	=	5	S	=	8	Settlements	=	+3
O	=	2	O	=	2	Other Land	=	0
Sum	=	140	Sum	=	140	Sum	=	0

Note: F = Forest Land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other Land. Numbers represent area units (Mha in this example).

TABLE 3.3
ILLUSTRATIVE EXAMPLE OF STRATIFICATION OF DATA FOR APPROACH 1

Land-use category/ strata	Initial land area (million ha)	Final land area (million ha)	Net Change in area (million ha)	Status
Forest Land total	**18**	**19**	**1**	
Forest Land (Unmanaged)	5	5	0	Not included in the inventory estimates
Forest Land (temperate continental forest; converted to another land-use category)	7	8	1	Estimates should be prepared on the 8 million ha
Forest Land (boreal coniferous)	6	6	0	No land-use conversion. Could require stratification for different management regimes etc.
Grassland total	**84**	**82**	**-2**	
Grassland (Unimproved)	65	63	-2	Fall in area indicates land-use conversion. Could require stratification for different management regimes etc.
Grassland (Improved)	19	19	0	No land-use conversion. Could require stratification for different management regimes etc.
Cropland total	**31**	**29**	**-2**	Fall in area indicates land-use conversion. Could require stratification for different management regimes etc.
Wetlands total	**0**	**0**	**0**	
Settlements total	**5**	**8**	**3**	
Other Land total	**2**	**2**	**0**	Unmanaged - not in inventory estimates
TOTAL	**140**	**140**	**0**	Note: areas should reconcile

Note: "Initial" is the category at a time previous to the date for which the assessment is made and "Final" is the category at the date of assessment. Activities for which location data are not available should be identified by further sub-categorisation of an appropriate land category.

APPROACH 2: TOTAL LAND-USE AREA, INCLUDING CHANGES BETWEEN CATEGORIES

The essential feature of Approach 2 is that it provides an assessment of both the net losses or gains in the area of specific land-use categories and what these conversions represent (i.e., changes both from and to a category). Thus, Approach 2 differs from Approach 1 in that it includes information on conversions between categories, but is still only tracking those changes without spatially-explicit location data, often based on political boundaries (i.e., locations of specific land use and land-use conversions are not known). Tracking land-use conversions in this manner will normally require estimation of initial and final land-use categories for all conversion types, as well as of total area of unchanged land by category. The final result of this Approach can be presented as a non-spatially-explicit land-use conversion matrix. The matrix form is a compact format for representing the areas that have come under different conversions between all possible land-use categories. Existing land-use databases may have sufficient detail for this Approach, or it may be necessary to obtain data through sampling or other methods. The input data may or may not have originally been spatially-explicit (i.e., mapped or otherwise geographically referenced).

For Approach 2, emission and removal factors can be chosen to reflect differences in the rate of changes in carbon according to the conversions between any two categories, and differences in initial carbon stocks associated with different land uses can be taken into account. For example, the rate of soil organic carbon loss will commonly be much higher from cropping than from pasture.

Approach 2 is illustrated in Table 3.4 using the data from the Approach 1 example (Table 3.3) by adding information on all the conversions taking place. Such data can be written in the more compact form of a matrix and this is presented in Table 3.5. To illustrate the added value of Approach 2 and this land-use conversion matrix format, the data of Table 3.5 is given in Table 3.6 without the stratification of the land-use categories. This can be compared with the more limited information from Approach 1 in Table 3.2. In Table 3.6, the conversions into and out of land categories can be tracked, whereas in Table 3.2 only the net changes in a broad land-use category are detectable.

In Tables 3.5 and 3.6, the area in the diagonal cells represents the area in each land-use category that was not affected by land-use conversion in this inventory year. In preparation for the greenhouse gas emission and removal estimations described elsewhere in this Volume, this area should be further sub-divided into the area that has remained in the land-use category and area that has been affected by a land-use conversion (i.e., the land converted to a different land-use category) in the previous Y years (where Y is the time period during which C pools are expected to reach equilibrium (the IPCC default is 20 years, based on soil C pools typical time to equilibrium after land-use conversion).

Therefore, under the default assumption in every inventory year, the area converted to a land-use category should be added to the category "land converted to" and the same area removed from the land remaining in the land-use category. The area of land that entered that "land converted to" category, 21 years ago (if using the default 20 year period), should be removed and added to the category "land remaining land". For example, in Table 3.5, if data indicated that four of the 56 Mha in the Grassland category had been converted from Forest Land 21 years ago, then four Mha of land should be moved from the category *Land Converted to Grassland* to the category *Grassland Remaining Grassland* in this annual inventory.

APPROACH 3: SPATIALLY-EXPLICIT LAND-USE CONVERSION DATA

Approach 3 is characterized by spatially-explicit observations of land-use categories and land-use conversions, often tracking patterns at specific point locations and/or using gridded map products, such as derived from remote sensing imagery. The data may be obtained by various sampling, wall-to-wall mapping techniques, or combination of the two methods. An overview of potential methods for developing Approach 3 datasets is provided in Annex 3A.4.

Approach 3 data can be summarized in tables similar to Tables 3.5 and 3.6. The main advantage of spatially-explicit data is that analysis tools such as Geographic Information Systems can be used to link multiple spatially-explicit data sets (such as those used for stratification) and describe in detail the conditions on a particular piece of land prior to and after a land-use conversion. This analytical capacity can improve emissions estimates by better aligning land-use categories (and conversions) with strata mapped for classification of carbon stocks and emission factors by soil type, vegetation type. This may be particularly applicable for Tier 3 emission estimation methodologies. However, issues of compatible and comparable spatial resolutions need to be taken into account.

3.3.2 Using the data

Figure 3.1 is a decision tree to assist in describing and/or obtaining the data on land-use areas. All three Approaches can, if implemented appropriately and consistently, be used to produce robust greenhouse gas emission and removal estimates. However, it should be noted that Approach 1 will probably not detect changes in biomass, such as those due to the full extent of deforestation and reforestation on separate areas of land, but only those due to the net conversion of land-use area from a forest to a non-forest use. In general, only Approach 3 will allow for the spatial representation required as an input to spatially-based carbon models.

Different Approaches may be more effective over different time periods, or may be required for different reporting purposes. Methods to carry out matching of the time-series between the different periods or uses should be applied.

TABLE 3.4
ILLUSTRATIVE EXAMPLE OF TABULATING ALL LAND-USE CONVERSION FOR APPROACH 2 INCLUDING NATIONALLY DEFINED STRATA

Initial land use	**Final land use**	**Land area, Mha**	**Inclusions/Exclusions**
Forest Land (Unmanaged)	Forest Land (Unmanaged)	5	Excluded from GHG inventory
Forest Land (Managed, temperate continental)	Forest Land (Managed, temperate continental)	4	Included in GHG inventory
Forest Land (Managed, temperate continental)	Grassland (Unimproved)	2	Included in GHG inventory
Forest Land (Managed, temperate continental)	Settlements	1	Included in GHG inventory
Forest Land (Managed, boreal coniferous)	Forest Land (Managed, boreal coniferous)	6	Included in GHG inventory
Grassland (Unimproved)	Grassland (Unimproved)	61	Included in GHG inventory
Grassland (Unimproved)	Grassland (Improved)	2	Included in GHG inventory
Grassland (Unimproved)	Forest Land (Managed, temperate continental)	1	Included in GHG inventory
Grassland (Unimproved)	Settlements	1	Included in GHG inventory
Grassland (Improved)	Grassland (Improved)	17	Included in GHG inventory
Grassland (Improved)	Forest Land (Managed, temperate continental)	2	Included in GHG inventory
Cropland	Cropland	29	Included in GHG inventory
Cropland	Forest Land (Managed, temperate continental)	1	Included in GHG inventory
Cropland	Settlements	1	Included in GHG inventory
Wetlands	Wetlands	0	Included in GHG inventory
Settlements	Settlements	5	Included in GHG inventory
Other Land	Other Land	2	Excluded from GHG inventory
TOTAL		**140**	

Note: Data are a stratified version of those in Table 3.3. Sub-categories are nationally defined and are illustrative only. "Initial" indicates the category at a time previous to the date for which the assessment is made and "Final" the category at the date of assessment.

TABLE 3.5
ILLUSTRATIVE EXAMPLE OF APPROACH 2 DATA IN A LAND-USE CONVERSION MATRIX WITH CATEGORY STRATIFICATION

Initial / Final	Forest Land (unmanaged)	Forest Land (managed, temperate continental)	Forest Land (managed, boreal coniferous)	Grassland (unimproved)	Grassland (improved)	Cropland	Wetlands	Settlements	Other Land	Final area
Forest Land (unmanaged)	5									**5**
Forest Land (managed, temperate continental)		4		1	2	1				**8**
Forest Land (managed, boreal coniferous)			6							**6**
Grassland (unimproved)		2		61						**63**
Grassland (improved)				2	17					**19**
Cropland						29				**29**
Wetlands							0			**0**
Settlements		1		1		1		5		**8**
Other Land									2	**2**
Initial area	**5**	**7**	**6**	**65**	**19**	**31**	**0**	**5**	**2**	**140**
Net change	0	1	0	-2	0	-2	0	+3	0	**0**

Note: Column and row totals show net conversion of land use as presented in Table 3.3. "Initial" indicates the category at a time previous to the date for which the assessment is made and "Final" the category at the date of assessment. Net changes (bottom row) are the final area minus the initial area for each of the (conversion) categories shown at the head of the corresponding column. Blank entry indicates no land-use conversion for this transition.

TABLE 3.6
SIMPLIFIED LAND-USE CONVERSION MATRIX FOR APPROACH 2 EXAMPLE

Net land-use conversion matrix

Initial / Final	F	G	C	W	S	O	*Final sum*
F	**15**	3	1				***19***
G	2	**80**					***82***
C			**29**				***29***
W				**0**			***0***
S	1	1	1		**5**		***8***
O						**2**	***2***
Initial sum	***18***	***84***	***31***	***0***	***5***	***2***	***140***

Note:
F = Forest Land, G = Grassland, C = Cropland, W = Wetlands,
S = Settlements, O = Other Land
Numbers represent area units (Mha in this example).

3.3.2.1 STRATIFICATION OF LAND-USE DATA

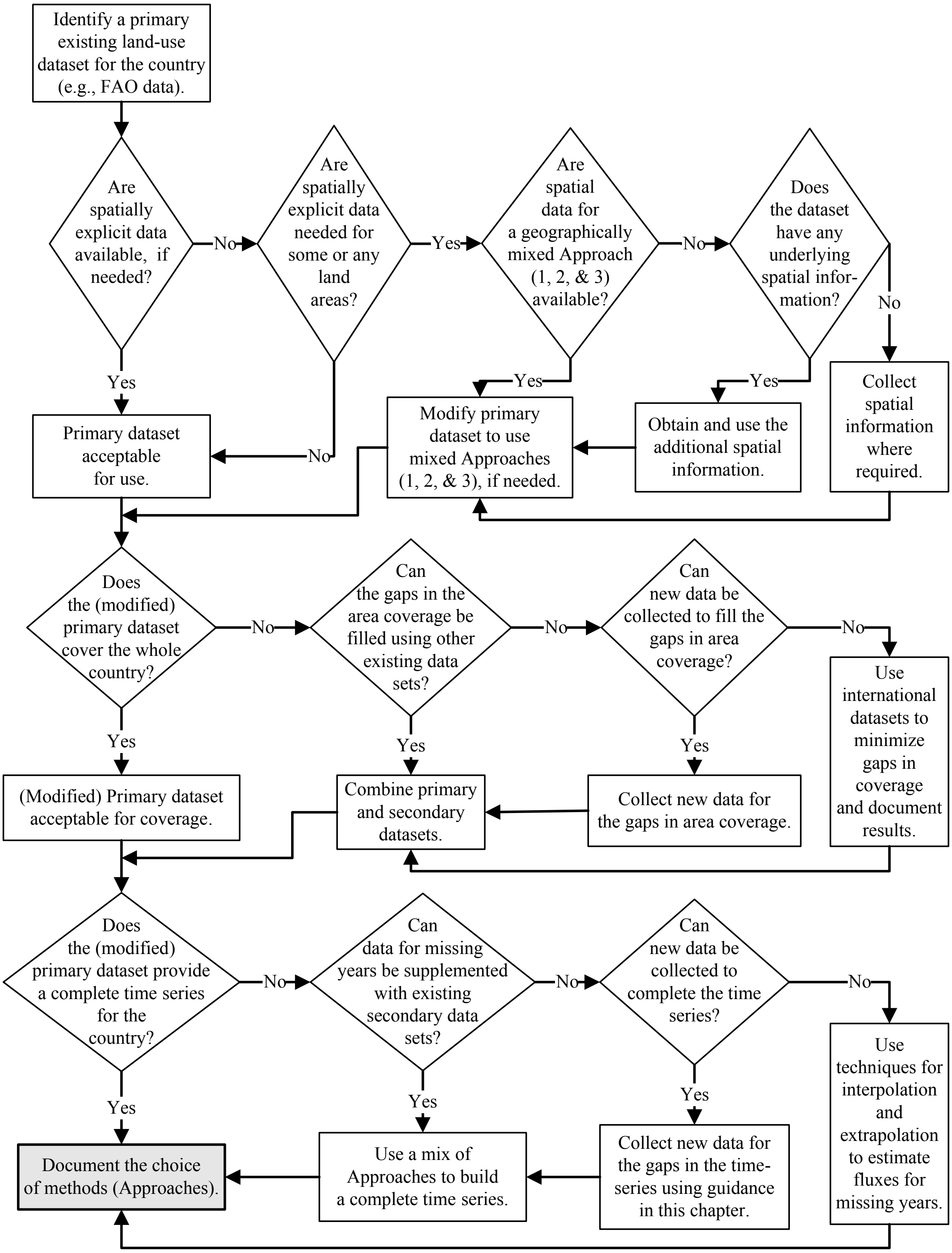
Once land use and land-use conversion areas have been established, it is necessary to consider the capacity and need for further stratification. This may be needed to locate relevant data from subsequent chapters for emissions factors, carbon stocks, etc. Table 3.1 shows the typical stratifications for which data are available for the application of Tier 1 emissions and removals estimation. Throughout the default tables used to populate equations to calculate a Tier 1 inventory, specific data cells are highlighted that represented the pre-defined stratifications applied to Tier 1 inventories. That is, Tier 1 default data (tables) conform to a consistent stratification so that there is no further calculation or ambiguity in the appropriate selection of default data to populate equations. Where countries are preparing Tiers 2 and 3 inventories, it is likely that stratification schemes may differ based on country-specific information and selection, manipulation or supplementation of default data may be required.

Unless all land-use area and stratification data are spatially-explicit (Approach 3), the development of rules for allocations to strata may be required. For example, Approach 1 land-use data are stratified by climate and soil type to estimate soil C stock changes. Optimally, the land-use data can be down-scaled to capture the proportion of land uses in each climate or soil type, with ancillary information and expert knowledge. If re-scaling is not possible, inventory estimation can still proceed, but the emissions and removals estimates should reflect uncertainties in the assignment of emission/stock change factors (and associated parameters) that vary by climate and/or soil.

Management data may only be available in an Approach 1 format (e.g., expert knowledge or periodic surveys of different sets of land owners) even if Approach 2 or 3 data are available for land-use categories. In this case, management can be summarized as a proportion of the management practice (e.g., % no till, intensive tillage and reduced tillage) in each "lands remaining" and "lands converted" land-use category. This will be a limiting assumption if the management classes are not evenly distributed as the impact of management on the emission or removal depends on land-use category.

Tiers 2 and 3 methods may also evaluate interactions between management practices that affect emission/stock change factors. Determining the appropriate combinations of management is another issue that needs careful consideration. Tier 1 methods typically do not address the temporal trends in emissions/stock change factors (assuming a linear change) or capture interactions among management practices on a specific land use, but rather represent an average effect. Consequently, assignment of emission/stock change factors may become more complicated with higher Tier methods and require careful explanation of the scaling processes that were used to delineate the appropriate combinations of the climate, soil, ecological zones, and/or management systems.

Figure 3.1 Decision tree for preparation of land-use area data



3.3.2.2 PREPARING AREA DATA FOR EMISSIONS AND REMOVALS ESTIMATION

Preparing a greenhouse gas inventory for AFOLU requires the integration of land-use area with data of land management and biomass, dead organic matter and soil carbon stock pools, in order to estimate carbon stock changes and CO_2 and non-CO_2 emissions and removals associated with land use. Depending on the type of data available (Approach 1, 2 or 3), there are implications for the subsequent use of the data in the preparation of estimates of emissions and removals according to the land-use conversion framework represented in the reporting tables.

Countries that only have access to Approach 1 data have two options for reporting land-use category conversions. Total areas for categories of "land remaining in a land use" may include some portion of land that was converted to that land use since the last inventory. Countries should wherever possible apportion change in land-use areas over time to inferred land-use conversion categories for the purposes of determining appropriate carbon stock and emission factor estimates. For example, a country with 1 Mha of forest, 1,000 ha deforestation and 1,000 ha afforestation has a zero net change in Forest Land area (presuming these changes occurred on managed land), but will have a reduction in forest biomass C stocks, at least until sufficient regrowth occurs. Subsequent decisions will be needed to relate these inferred area conversions between land-use categories to appropriate land management, biomass and soil C stocks and emission factors. Where this is done, countries should report the basis for these decisions, and any methods of verification or cross-checking of estimates that have been applied, and the effects on inventory uncertainty. If this apportioning is not done, then countries should state this, and report the effect on uncertainties associated with doing so.

For countries with Approach 2 data, where information on the areas of each land-use conversion is known but is not spatially-explicit, these area estimates still need to be linked to appropriate initial carbon stocks, emissions factors, etc. In some cases, this may require the assignment of the land-use conversion data to climate, and/or vegetation type, soil and management strata. Again, this can be done by some form of sampling, scaling or expert judgement. Countries should report the basis for these decisions, and any methods of verification or cross-checking of estimates that have been applied.

For countries using Approach 3 data, it is possible to apportion areas of land-use conversion by spatially intersecting the data with other spatial datasets, such as those on climate, and/or vegetation type, soil and management strata. However, it is likely that inference, for example, based on survey data and expert judgement, will be needed to apportion the land-use conversion and biophysical data by management practices as data on management practices are rarely available in spatially explicit formats.

3.4 MATCHING LAND AREAS WITH FACTORS FOR ESTIMATING GREENHOUSE GAS EMISSIONS AND REMOVALS

This section provides brief guidance on matching the land-use area data with carbon stocks, emissions factors and other relevant data (e.g., forest biomass stocks, average annual net increment) to estimate greenhouse gas emissions and removals. An initial step in preparing national inventory estimates is to assemble the required activity data (i.e., land-use areas) and match them with appropriate carbon stock, emissions and removal factors and other relevant data.

This Volume provides default data (specifically marked) needed to make Tier 1 estimates for all AFOLU categories according to specified climate and ecological zone stratifications. In addition, countries may develop country-specific carbon stock, emission and removal factors and other relevant data (Tiers 2 and 3 inventory methods). The following summarizes the principles to be followed when matching activity data with carbon stock, emission and removal factors and other relevant data:

- match national land-use area classifications to as many land-use categories as possible;
- when national land-use classifications do not conform to the land-use categories of these guidelines, document the relationship between classification systems;
- use classifications consistently through time and, when necessary, document any modifications made to classification system;
- document definitions of land categories, land-use area estimates, and how they correspond to emission and removal factors; and,

- match each land-use category or sub-category to the most suitable carbon stock estimates, emission and removal factors and other relevant data.

Following are the recommended steps for matching land areas with emission and removal factors:

1. Start with the most disaggregated land-use area stratification as well as the most detailed available emission and removal factors needed to make an estimate. For example, the Forest Land methodologies, described in Chapter 4 of this Volume, provide a default factor for above-ground biomass stocks in forest plantations that is disaggregated at the most detailed stratification, relative to other factors (i.e., forest type, region, species group, age class, and climate). These strata would be used as an initial base stratification.
2. Include only those strata applicable in your country and use this as a base stratification.
3. Match land-use area estimates to the base stratification at the most disaggregated level possible. Countries may need to use expert judgment to align the best available land-use area estimates with the base stratification.
4. Map emission and removal factors onto the base stratification by matching them as closely as possible to the stratification categories. Note that many of the default stock change and emissions factors and other parameters in Tier 1 (default) equations were statistically derived for specifically defined strata (e.g., climate type, soil type) so that countries wishing to use Tier 1 methods for these emissions and removals should stratify land-use categories using the definitions as specified for Tier 1 change factors and parameters.

If a national land-use classification is fitted to the land-use categories (and sub-categories) this facilitates matching of emission and removal factors that follow the same classification. For example, default soil carbon factors for Forest Land, Cropland, and Grassland are disaggregated by the same climate regions (see Annex 3A.5). Therefore, the same land area classification can be used to estimate soil carbon changes in each of the land-use categories, enabling consistent tracking of lands and carbon fluxes on lands resulting from land-use category conversions.

Countries may find that national land classifications change over time as national circumstances change and more detailed activity data and emission/removal factors become available. In some cases, the stratification will be elaborated with the addition of more detailed emission and removal factors. In other cases, new stratifications systems will be established when countries implement new forest inventories or remote sensing sampling designs. When changes to the stratification system occur, countries should recalculate the entire time-series of estimates using the new stratification if possible.

3.5 UNCERTAINTIES ASSOCIATED WITH THE APPROACHES

Uncertainties should be quantified and reduced as far as practicable. Land-use area uncertainty estimates are required as an input to overall uncertainty analysis. Although the uncertainty associated with the Approaches (1 to 3) obviously depends on how well they are implemented, it is possible to give an indication of what can be achieved in practice. Table 3.7 sets out the *sources* of uncertainty (not the significance) for different Approaches. This provides a guide to sources of uncertainties, indicative levels of uncertainty under certain conditions that might be encountered, and a basis for reducing uncertainties.

The number of potential sources of uncertainty in area estimates will tend to increase from Approach 1 to Approach 3, because successively more data are brought into the assessment. This does not imply that uncertainty increases, however, because of the additional cross-checks that are made possible by the new data, and because of the general reduction in uncertainties due to cancellation of errors. The main difference between Approach 1, and Approaches 2 and 3 is that percentage uncertainties on conversion between land uses are likely to be greater in Approach 1 (if known at all). This is because in Approach 1 land-use conversions are derived from differences (net change) in total areas. The effect of this Approach 1 uncertainty on emissions and removals from conversions will depend on the relative amount of land conversion in the country as a fraction of total land area. Approach 3 produces detailed spatially-explicit information; which may be required e.g., for some spatial modelling approaches to emissions estimation.

TABLE 3.7 SUMMARY OF UNCERTAINTIES UNDER APPROACHES 1 TO 3			
	Sources of uncertainty	**Ways to reduce uncertainty**	**Indicative uncertainty following checks**
Approach 1	Sources of uncertainty may include some or all of the following, depending on the nature of the source of data: • Error in census returns • Differences in definition between agencies • Sampling design • Sampling error • Interpretation of samples • Only net change in area is known In addition: Cross-checks on area changes between categories cannot be conducted under Approach 1 and this will tend to increase uncertainties.	• Check for consistent relationship with national area • Correct for differences in definitions • Consult statistical agencies on likely uncertainties involved • Compare with international datasets	Order of a few % to order of 10% for total land area in each category. Greater % uncertainty for changes in area derived from successive surveys. Systematic errors may be significant when data prepared for other purposes is used.
Approach 2	As Approach 1, but gross changes in area are known, and with ability to carry out cross-checks	As above, plus consistency checks between inter-category changes within the matrix	Order of a few % to order of 10% for total land area in each category, and greater for changes in area, since these are derived directly
Approach 3	As Approach 2 plus uncertainties linked to interpretation of remote sensing data where used, and minus any sampling uncertainty	As Approach 2 plus formal analysis of uncertainties using principles set out in Volume 1 Chapter 3	As Approach 2, but areas involved can be identified geographically. However, for Approach 3, the amount of uncertainty can be estimated more accurately than for Approach 2 because errors are mapped and can be tested against independent data/field checked.

Annex 3A.1 Examples of international land cover dataset [2]

TABLE 3A.1.1
EXAMPLES OF INTERNATIONAL LAND COVER DATASET

	(A)	(B)	(C)	(D)
Dataset name	Asian Association on Remote Sensing (AARS) Global 4-Minute Land Cover	International Geosphere-Biosphere Program – Data & Information Services (IGBP-DIS) Global 1km Land Cover Data Set	Global Land Cover Dataset	Global Land Cover Dataset
Author	Center for Environmental Remote Sensing, Chiba University	IGBP/DIS	United States Geological Survey (USGS), USA	GLCF (Global Land Cover Facility)
Brief description of contents	Land cover classes are identified through clustering National Oceanic & Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) monthly data.	This classification is derived from AVHRR 1km data and ancillary data.	The data set is derived from a flexible data base structure and seasonal land cover regions concepts	Metrics describing the temporal dynamics of vegetation were applied to 1984 PAL data at 8km resolution to derive a global land cover classification product using a decision tree classifier.
Classification scheme	Original classification scheme is applied. Compatible with IGBP/DIS classification scheme.	It consists of 17 classes.	A convergence of evidence approach is used to determine the land cover type for each seasonal land cover class.	The classification was derived by testing several metrics that describe the temporal dynamics of vegetation over an annual cycle.
Data format (vector/raster)	Raster	Raster	Raster	Raster
Spatial coverage	Global	Global	Global	Global
Data acquisition year	1990	1992-1993	April 1992-March 1993	1987

[2] These datasets are primarily about land cover and/or land cover change. Few refer to actual land use.

TABLE 3A.1.1 (CONTINUED) EXAMPLES OF INTERNATIONAL LAND COVER DATASET				
	(A)	**(B)**	**(C)**	**(D)**
Spatial resolution or	4min x 4min.	1km x 1km	1km x 1km	8km x 8km
Revision interval (for time-series	Not applicable	Not applicable	Not applicable	Not applicable
Quality description	Ground truth data are compared against the dataset.	High-resolution satellite imagery used to statistically validate the dataset.	Sample point accuracy: 59.4% Area-weighted accuracy: 66.9% (Scepan, 1999).	No description
Contact address and reference URL	http://ceres.cr.chiba-u.ac.jp:8080/usr-dir/	http://www.ngdc.noaa.gov/paleo/	http://edcdaac.usgs.gov/glcc/	http://glcf.umiacs.umd.edu/

TABLE 3A.1.1 (CONTINUED)
EXAMPLES OF INTERNATIONAL LAND COVER DATASETS

	(E)	(F)	(G)	(H)	(I)
Dataset name	Geocover	1º Land Cover Map from AVHRR	CORINE land cover (CLC2000) database	Digital Chart of the World	Global Map
Author	MacDonald Dettwiler & Associates	Dr. Ruth De Fries University of Maryland at College Park, USA	European Environmental Agency	ESRI Products	Produced by National Mapping Organizations, and Compiled by ISCGM.
Brief description of contents	A medium resolution land cover database from orthorectified Landsat Thematic Mapper imagery	The data set describes the geographical distributions of eleven major cover types based on inter-annual variations in NDVI.	It provides a pan-European inventory of biophysical land cover. CORINE land cover is a key database for integrated environmental assessment.	It is a worldwide base map of coastlines, boundaries, land cover, etc. Contains more than 200 attributes arranged into 17 thematic layers with text annotations for geographical features.	Digital geographic information in 1 km resolution covering the whole land with standardized specifications and available to everyone at marginal cost.
Classification scheme	13 class map	It consists of the digital 13 class map	Uses a 44 class nomenclature.	8 Agriculture/ Extraction features and 7 surface cover features.	Refer to http://www.iscgm.org/
Data format (vector/raster)	Raster & vector	Raster	Raster	Vector Polygons	Raster and Vector
Spatial coverage	Global	Global	Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland , Portugal, Romania, Slovakia, Spain, United Kingdom, Parts of Morocco and Tunisia.	Global coverage	Participating countries (90 in number)

TABLE 3A.1.1 (CONTINUED)
EXAMPLES OF INTERNATIONAL LAND COVER DATASETS

	(E)	(F)	(G)	(H)	(I)
Data acquisition year	Various	1987	Depends on the country (overall time span is around 1985-95)	Based on ONCs of US Defence Mapping Agency. Period 1970-80. Refer to the Compilation date layer.	Depends on the participating nations.
Spatial resolution or grid size	30m x 30m grid	1 x 1 degree	250m by 250m grid database which has been aggregated from the original vector data at 1:100,000.	1:1,000,000 scale	1km x 1km grids
Revision interval (for time-series datasets)	Not applicable	Not applicable	CLC Update Project of 2000 for updating it to the 1990's data	Not applicable	Approximately five-year intervals
Quality description	No description	No description	No specific information available. Refer to http://dataservice.eea.eu.int/ dataservice/; for country wise information.	Data quality information exists at three levels within the database: feature, layer and source.	Refer to http://www.iscgm.org/
Contact address and reference URL	http://www.mdafederal.com/geocover/project	landcov@geog.umd.edu http://www.geog.umd.edu/landcover/	dataservice@eea.eu.int http://www.terrestrial.eionet.eu.int/	http://www.esri.com/data/	sec@iscgm.org http://www.iscgm.org/

Annex 3A.2 Development of land-use databases

There are three broad sources of data for the land-use databases needed for greenhouse gas inventories:

- databases prepared for other purposes;
- collection by sampling; and
- complete land inventory.

The following subsections provide general advice on the use of these types of data. Greenhouse gas inventory preparers might not be involved in the detailed collection of remote sensing data or ground survey data, but can use the guidance provided here to help plan inventory improvements and communicate with experts in these areas.

3A.2.1 USE OF DATA PREPARED FOR OTHER PURPOSES

Two types of available databases may be used to classify land. In many countries, national datasets of the type discussed below will be available. Otherwise, inventory compilers may use international datasets. Both types of databases are described below.

NATIONAL DATABASES

These will usually be based on existing data, updated annually or periodically. Typical sources of data include forest inventories, agricultural census and other surveys, censuses for urban and natural land, land registry data and maps.

INTERNATIONAL DATABASES

Several projects have been undertaken to develop international land-use and land cover datasets at regional to global scales (Annex 3A.1 lists some of these datasets). Almost all of these datasets are stored as raster data generated using different kinds of satellite remote sensing imagery, complemented by ground reference data obtained by field survey or comparison with existing statistics/maps. These datasets can be used for:

- Estimating spatial distribution of land-use categories. Conventional inventories usually provide only the total sum of land-use area by classes. Spatial distribution can be reconstructed using international land-use and land cover data as auxiliary data where national data are not available.
- Reliability assessment of the existing land-use datasets. Comparison between independent national and international datasets can indicate apparent discrepancies, and understanding these may increase confidence in national data and/or improve the usability of the international data, if required for purposes such as extrapolation.
- When using an international dataset, inventory compilers should consider the following:
  (i) The classification scheme (e.g., definition of land-use classes and their relations) may differ from that in the national system. The equivalence between the classification systems used by the country and the systems described in Section 3.2 (Land-use categories) therefore needs to be established by contacting the international agency and comparing their definitions with those used nationally.
  (ii) Spatial resolution (typically 1km nominally but sometimes an order of magnitude more in practice) may be coarse, so national data may need aggregating to improve comparability.
  (iii) Classification accuracy and errors in geo-referencing may exist, though several accuracy tests are usually conducted at sample sites. The agencies responsible should have details on classification issues and tests undertaken.
  (iv) As with national data, interpolation or extrapolation will probably be needed to develop estimates for the time periods to match the dates required for reporting.

3A.2.2 COLLECTION OF NEW DATA BY SAMPLING METHODS

Sampling techniques for estimating areas and area changes are applied in situations where total tallies by direct measurements in the field or assessments by remote sensing techniques are not feasible or would provide inaccurate results. Sampling concepts that allow for estimation procedures that are consistent and unbiased, and result in estimates that are precise, should be used.

Sampling usually involves a set of sampling units that are located on a regular grid within the inventory area. A land-use class is then assigned to each sampling unit. Sampling units can be used to derive the proportions of land-use categories within the inventory area. Multiplying the proportions by the total area provides estimates of the area of each land-use category. Where the total area is not known it is assumed that each sampling unit represents a specific area. The area of the land-use category can then be estimated via the number of sampling units that fall into this category.

Where sampling for areas is repeated at successive occasions, area changes over time can be derived to construct land-use conversion matrices.

Applying a sample-based type for area assessment enables the calculation of sampling errors and confidence intervals that quantify the reliability of the area estimates in each category. Confidence intervals can be used to verify if observed category area changes are statistically significant and reflect meaningful changes.

Annex 3A.3 provides more information on sampling.

3A.2.3 COLLECTION OF NEW DATA IN COMPLETE INVENTORIES

A complete inventory of land use of all areas in a country will entail obtaining maps of land use throughout the country at regular intervals. This can be achieved by using remote sensing techniques. As outlined under Approach 3, the data will be most easily used in a GIS based on a set of grid cells or polygons supported by ground truth data needed to achieve unbiased interpretation. Coarser scale data can be used to build data for the whole country or appropriate regions.

A complete inventory can also be achieved by surveying all landowners and each would need to provide suitable data where they own many different blocks of land. Inherent problems in the method include obtaining data at scales smaller than the size of the owner’s land as well as difficulties with ensuring complete coverage with no overlaps.

3A.2.4 TOOLS FOR DATA COLLECTION

REMOTE SENSING (RS) TECHNIQUES

Remotely sensed data, as discussed here, are those acquired by sensors (optical, radar or lidar) onboard satellites, or by cameras equipped with optical or infrared films, installed in aircraft. These data are usually classified to provide estimates of the land cover and its corresponding area, and usually require ground survey data to provide an estimate of the classification accuracy. Classification can be done either by visual analysis of the imagery or photographs, or by digital (computer-based) methods. The strengths of remote sensing come from its ability to provide spatially-explicit information and repeated coverage, including the possibility of covering large and/or remote areas that are difficult to access otherwise. Archives of past remote sensing data also span several decades and can therefore be used to reconstruct past time-series of land cover and land use. The challenge of remote sensing is related to the problem of interpretation: the images need to be translated into meaningful information on land cover and land use. Depending on the satellite sensor, the acquisition of data may be impaired by the presence of atmospheric clouds and haze. Another concern, particularly when comparing data over long time periods, is that remote sensing systems may change. Remote sensing is particularly useful for obtaining area estimates of land cover and land-use categories and for assisting in the identification of relatively homogeneous areas that can guide the selection of sampling schemes and the number of samples to be collected.

Types of remote sensing (RS) data

The most commonly used types of RS data are: 1) aerial photographs, 2) satellite imagery using visible and/or near-infrared bands, 3) satellite or airborne radar imagery and, 4) lidar. Combinations of different types of remote sensing data (e.g., visible/infrared and radar; different spatial or spectral resolutions) might very well be used for assessing different land-use categories or regions. A complete remote sensing system for tracking land-use conversions can include many sensor and data type combinations at a variety of resolutions.

Important criteria for selecting remote sensing data and products are:

- Adequate land-use categorisation scheme;
- Appropriate spatial resolution;
- Appropriate temporal resolution for estimating of land-use conversion;
- Availability of accuracy assessment;
- Transparent methods applied in data acquisition and processing; and
- Consistency and availability over time.

1. Aerial photographs

Analysis of aerial photographs can reveal forest tree species and forest structure from which relative age distribution and tree health (e.g., needle loss in coniferous forests, leaf loss and stress in deciduous forests) may be inferred. In agriculture, analysis can show crop species, crop stress, and tree cover in agro-forestry systems. The smallest spatial unit possible to assess depends on the type of aerial photos used, but for standard products it is often as small as 1 square metre.

2. Satellite images in visible and near infrared wavelengths

Complete land use or land cover of large areas (national or regional) may be facilitated by the use of satellite images. The possibility exists of obtaining long time-series of data from the desired area since the satellite continuously and regularly passes over it. The images usually generate a detailed mosaic of distinct categories, but the labelling into proper land cover and land-use categories commonly requires ground reference data from maps or field surveys. The smallest unit to be identified depends on the spatial resolution of the sensor and the scale of work. The most common sensor systems have a spatial resolution of 20 – 30 metres. At a spatial resolution of 30 metres, for example, units as small as 1ha can be identified. Data from higher resolution satellites are also available.

3. Radar imagery

The most common type of radar data are from the so-called Synthetic Aperture Radar (SAR) systems that operate at microwave frequencies. A major advantage of such systems is that they can penetrate clouds and haze, and acquire data during night-time. They may therefore be the only reliable source of remote sensing data in many areas of the world with quasi-permanent cloud cover. By using different wavelengths and different polarisations, SAR systems may be able to distinguish land cover categories (e.g., forest/non-forest), or the biomass content of vegetation, although there are at present some limitations at high biomass due to signal saturation.

4. Lidar

Light detection and ranging (lidar) uses the same principles as radar. The lidar instrument transmits light out to a target. The transmitted light interacts with and is changed by the target. Some of this light is reflected/scattered back to the instrument where it is analysed. The change in the properties of the light enables some property of the target to be determined. The time for the light to travel out to the target and back to the lidar is used to determine the range to the target. There are three basic types of lidar: range finders, differential absorption lidar, and doppler.

Ground reference data

In order to make use of remote sensing data for inventories, and in particular to relate land cover to land use it is *good practice* to complement the remotely sensed data with ground reference data (often called ground truth data). Ground reference data can either be collected independently, or be obtained from forest or agricultural inventories. Land uses that are rapidly changing over the estimation period or that have vegetation cover known to be easily misclassified should be more intensively ground-truthed than other areas. This can only be done by using ground reference data, preferably from actual ground surveys collected independently. High-resolution photographs may also be useful.

Integration of remote sensing and GIS

Visual interpretation of images is often used for identifying sampling sites for forestry inventories. The method is simple, and reliable. However, it is labour intensive and therefore restricted to limited areas, and may be affected by subjective interpretations by different operators.

Full use of remote sensing generally requires integration of the extensive coverage that remote sensing can provide with ground-based point measurements or map data to represent areas associated with particular land uses in space and time. This is generally achieved most cost effectively using a geographical information system (GIS).

Land cover classification using remotely sensed data

Classification of land cover using remotely sensed data may be done by visual or digital (computer based) analysis. Each one presents advantages and disadvantages. Visual analysis of imagery allows for human inference through the evaluation of overall characteristics of the scene (analysis of the contextual aspects in the image). Digital classification, on the other hand, allows several manipulations to be performed with the data, such as merging of different spectral data, which can help to improve modelling of the biophysical ground data (such as tree diameter, height, basal area, biomass) using the remotely sensed data. In addition, digital analysis allows for the immediate computation of areas associated with the different land categories. It has developed rapidly over the past decade, along with the associated technical computer development, making hardware, software and also the satellite data readily available at low cost in most countries, although capacity to use these data and facilities may have to be outsourced, particularly in mapping at national level.

Detection of land-use conversion using RS

Remote sensing can be used to detect locations of change. Methods for change detection can be divided into two categories (Singh, 1989):

Post-classification change detection: This refers to techniques where two or more predefined land cover/use classifications exist from different points in time, and where the changes are detected, usually by subtraction of the datasets. The techniques are straightforward but are also sensitive to inconsistencies in interpretation and classification of the land-use categories.

Pre-classification change detection: This refers to more sophisticated and biophysical approaches to change detection. Differences between spectral response data from two or more points in time are compared by statistical methods and these differences are used to provide information on land cover/use changes. This type is less sensitive to interpretation inconsistencies and can detect much more subtle changes than the post-classification approaches, but is less straightforward and requires access to the original remotely sensed data.

There are also other viable methods. For example, one can use change enhancements and visual interpretation. Areas of change are highlighted through display of different band combinations, band differences or derived indices (e.g., vegetation indices). This focuses attention on potential land-use conversions sites that can then be delineated and attributed through manual or automated techniques. These methods are subject to human interpreter inconsistencies, but are capable of detecting subtle changes and better detecting and mapping land-use conversion where land cover, context and ancillary information is needed to determine land-use conversion.

Evaluation of mapping accuracy

Whenever a map of land cover or land use is being used, inventory compilers should acquire information about the reliability of the map. When such maps are generated from classification of remote sensing data, it should be recognised that the reliability of the map is likely to vary between the different land categories. Some categories may be uniquely distinguished while others may be confounded with others. For example, coniferous forest is often more accurately classified than deciduous forest because its reflectance characteristics are more distinct, while deciduous forest may easily be confounded with, for example, Grassland or Cropland. Similarly, it is often difficult to ascertain changes in land management practices through remote sensing. For example, it may be difficult to detect a change from intensive to reduced tillage on a specific land area.

Inventory compilers should estimate the accuracy of land-use/land cover maps on a category-by-category basis. A number of sample points on the map and their corresponding real world categories are used to create a confusion matrix (see footnote 5 in Annex 3A.4) with the diagonal showing the proportion of correct identification and the off-diagonal elements showing the relative proportion of misclassification of a land category into one of the other possible categories. The confusion matrix expresses not only the accuracy of the map but it is also possible to assess which categories are easily confounded with each other. Based on the confusion matrix, a number of accuracy indices can be derived (Congalton, 1991). Multi-temporal analysis (analysis of images taken at different times to determine the stability of land-use classification) can also be used to improve classification accuracy, particularly in cases where ground truth data are limited.

GROUND-BASED SURVEYS

Ground-based surveys may be used to gather and record information on land use, and for use as independent ground-truth data for remote sensing classification. Prior to the advent of remote sensing techniques such as aerial photography and satellite imagery, ground-based surveys were the only means of generating maps. The process is essentially one of visiting the area under study and recording visible and/or other physical attributes of the landscape for mapping purposes. Digitisation of boundaries and symbolising attributes are used to make hard copy field notes and historical maps useful in Geographical Information Systems (GIS). This is done via protocols on minimum land area delineation and attribute categorization that are linked to the scale of the resultant map and its intended use.

Very precise measurements of area and location can be made using a combination of survey equipment such as theodolites, tape measures, distance wheels and electronic distance measuring devices. Development of Global Positioning Systems (GPS) means that location information can be recorded in the field directly into electronic format using portable computer devices. Data are downloaded to an office computer for registration and coordination with other layers of information for spatial analysis.

Landowner interviews and questionnaires are used to collect socio-economic and land management information, but may also provide data on land use and land-use conversion. With this census type, the data collection agency depends on the knowledge and records of landowners (or users) to provide reliable data. Typically, the resident is visited and interviewed by a representative of the collection agency and data are recorded in a predetermined format, or a questionnaire is issued to the land user for completion. The respondent is usually encouraged to use any relevant records or maps they may have, but questions may also be used to elicit information directly (Swanson *et al.*, 1997).

Census surveys are probably the oldest form of data collection methods (Darby, 1970). Land user surveys can be conducted on the entire population or a sample of suitable size. Modern applications employ a full range of validation and accuracy assessment techniques. The survey may be undertaken through personal visits, telephone interviews (often with computer-assisted prompts) or mail-out questionnaires. Land user surveys start with the formulation of data and information needs into a series of simple and clear questions soliciting concise and unequivocal responses. The questions are tested on a sample of the population in order to ensure that they are understandable and to identify any local technical terminology variations. For sample applications, the entire study area is spatially stratified by appropriate ecological and/or administrative land units, and by significant categorical differences within the population (e.g., private versus corporate, large versus small, pulp versus lumber, etc.). For responses dealing with land areas and management practices, some geographic location, whether precise coordinates, cadastral description or at least ecological or administrative units should be required of the respondent. Post-survey validation of results is conducted by searching for statistical anomalies, comparing with independent data sources, conducting a sample of follow-up verification questionnaires or conducting a sample of on-site verification surveys. Finally, presentation of results must follow the initial stratification parameters.

Annex 3A.3 Sampling

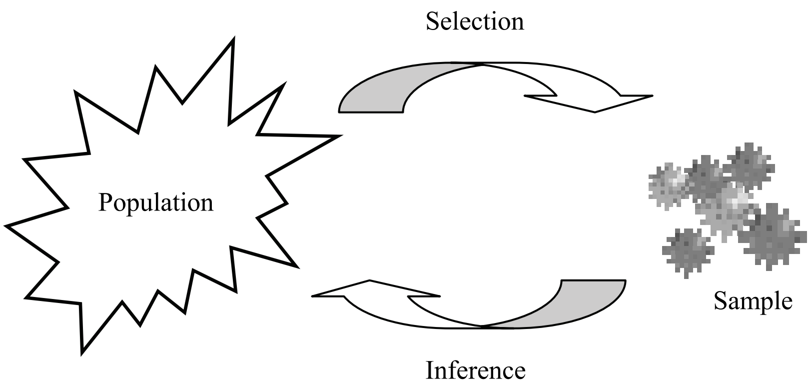
3A.3.1 INTRODUCTION

Data on land use are often obtained from sample surveys and typically are used for estimating changes in land use or in carbon stocks. National forest inventories are important examples of the type of surveys used. This section provides guidance for the use of data from sample surveys for the reporting of emissions and removals of greenhouse gases, and for the planning of sample surveys in order to acquire data for this purpose.

3A.3.2 OVERVIEW ON SAMPLING PRINCIPLES

Sampling infers information about an entire population by observing a fraction of it: the sample (see Figure 3A.3.1). For example, changes of carbon in tree biomass at regional or national levels can be estimated from the growth, mortality and cuttings of trees on a limited number of sample plots. Sampling theory then provides the means for scaling up the information from the sample plots to the selected geographical level. Properly designed sampling can greatly increase efficiency in the use of inventory resources. Furthermore, field sampling is generally needed in developing inventories because, even if remote sensing data provide complete territorial coverage, there will be a need for ground-based data from sample sites for interpretation and verification.

Figure 3A.3.1 Principle of sampling



Standard sampling theory relies on random selection of a sample from the population; each unit in the population has a specific probability of being included in the sample. This is the case when sample plots have been distributed entirely at random within an area, or when plots have been distributed in a systematic grid system as long as the positioning of the grid is random. Random sampling reduces the risk of bias and allows for an objective assessment of the uncertainty of the estimates. Therefore, randomly sampled data generally should be used where available, or when setting up new surveys.

Samples may also be taken at subjectively chosen locations, which are assumed to be representative for the population. This is called subjective (or purposive) sampling and data from such surveys are often used in greenhouse gas inventories (i.e., when observations from survey sites that were not selected randomly are used to represent an entire land category or strata). Under these conditions, observations about, for example, forest type might be extrapolated to areas for which they are not representative. However, due to limited resources greenhouse gas inventories may need to make use of data also from subjectively selected sites or research plots. In this case, it is *good practice* to identify, in consultation with the agencies responsible for the sites or plots, the land areas for which the subjective samples can be regarded as representative.

3A.3.3 SAMPLING DESIGN

Sampling design determines how the sampling units (the sites or plots) are selected from the population and thus what statistical estimation procedures should be applied to make inferences from the sample. Random sampling designs can be divided into two main groups, depending on whether or not the population is *stratified* (i.e., sub-divided before sampling) using auxiliary information. Stratified surveys will generally be more efficient in terms of what accuracy can be achieved at a certain cost. On the other hand, they tend to be slightly more complex, which increases the risk of non-sampling errors due to incorrect use of the collected data. Sampling designs should aim for a good compromise between simplicity and efficiency, and this can be promoted by following three aspects as set out below:

- Use of auxiliary data and stratification;
- Systematic sampling;
- Permanent sample plots and time-series data.

Use of auxiliary data and stratification

One of the most important sampling designs which incorporate auxiliary information is *stratification*, whereby the population is divided into subpopulations on the basis of *auxiliary data*. These data may consist of knowledge of legal, administrative boundaries or boundaries of forest administrations which will be efficient to sample separately, or maps or remote sensing data distinguishing between upland and lowland areas or between different ecosystem types. Since stratification is intended to increase efficiency, it is *good practice* to use auxiliary data when such data are available or can be made available at low additional cost.

Stratification increases efficiency in two main ways: (i) by improving the accuracy of the estimate for the entire population; and (ii) by ensuring that adequate results are obtained for certain subpopulations, e.g., for certain administrative regions.

On the first issue, stratification increases sampling efficiency if a sub-division of the population is made so that the variability between units within a stratum is reduced as compared to the variability within the entire population. For example, a country may be divided into a lowland region (with certain features of the land-use categories of interest) and an upland region (with different features of the corresponding categories). If each stratum is homogeneous a precise overall estimate can be obtained using only a limited sample from each stratum. The second issue is important for purposes of providing results at a specific degree of accuracy for all administrative regions of interest, but also in case sampled data are to be used together with other existing datasets, which have been collected using different protocols with the same administrative or legal boundaries.

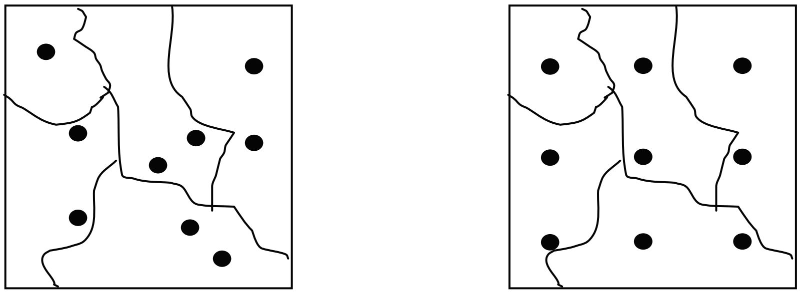
Use of remote sensing or map data for identifying the boundaries of the strata (the land-use class sub-divisions to be included in a sample survey) can introduce errors where some areas may be incorrectly classified as belonging to the stratum whilst other areas that do belong to the specific class are missed. Errors of this kind can lead to substantial bias in the final estimates, since the area identified for sampling will then not correspond to the target population. Whenever there is an obvious risk that errors of this kind may occur, it is *good practice* to make an assessment of the potential impact of such errors using ground truth data.

When data for the reporting of greenhouse gas emissions or removals are taken from existing large-scale inventories, such as national forest inventories, it is convenient to apply the standard estimation procedures of that inventory, as long as they are based on sound statistical principles. In addition, *post-stratification* (i.e., defining strata based on remote sensing or map auxiliary data after the field survey has been conducted) means that it may be possible to use new auxiliary data to increase efficiency without changing the basic field design (Dees *et al.,* 1998). Using this estimation principle, the risk for bias pointed out in the previous paragraph also can be reduced.

Systematic sampling

Sample based forest or land-use surveys generally make use of sample points or plots on which the characteristics of interest are recorded. One important issue here regards the layout of these points or plots. It is often appropriate to allocate the plots in small clusters in order to minimise travel costs when covering large areas with a sample based survey. With cluster sampling, the distance between plots should be large enough to avoid major between-plot correlation, taking (for forest sampling) stand size into account. An important issue is whether plots (or clusters of plots) should be laid out entirely at random or systematically using a regular grid, which is randomly located over the area of interest (see Figure 3A.3.2). In general, it is efficient to use systematic sampling, since in most cases this will increase the precision of the estimates. Systematic sampling also simplifies the fieldwork.

Figure 3A.3.2 Simple random layout of plots (left) and systematic layout (right)



Somewhat simplified, the reason why systematic random sampling generally is superior to simple random sampling is that sample plots will be distributed evenly to all parts of the target area.[3] With simple random sampling, some parts of an area may have many plots while other parts will not have any plots at all.

Permanent sample plots and time-series data

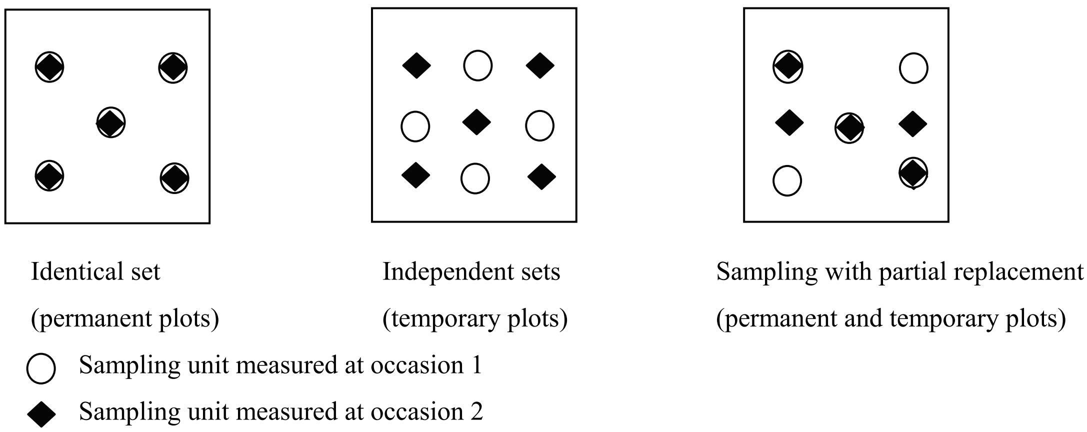
Greenhouse gas inventories must assess both current state and changes over time (e.g., in areas of land-use categories and carbon stocks). Assessment of changes is most important and it involves repeated sampling over time. The time interval between measurements should be determined based on the frequency of the events that cause changes, and also on the reporting requirements. Generally, sampling intervals of 5-10 years are adequate, and in many countries data from well designed surveys are already available for many decades, especially in the forest sector. Nevertheless, since estimates for the reporting are required on an annual basis, interpolation and extrapolation methods will need to be applied. Where sufficiently long time-series are not available, it may be necessary to extrapolate backwards in time to capture the dynamics of carbon stock changes.

When undertaking repeated sampling, the required data regarding the current state of areas or carbon stocks are assessed on each occasion. Changes are then estimated by calculating the difference between the state at time $(t + 1)$ from the state at time t. Three common sampling designs can be used for change estimation:

- The same sampling units are used on both occasions (permanent sampling units);
- Different, independent sets of sampling units are used on both occasions (temporary sampling units);
- Some sampling units can be replaced between occasions while others remain the same (sampling with partial replacement).

Figure 3A.3.3 shows these three Approaches.

Figure 3A.3.3 Use of different configurations of permanent and temporary sampling units for estimating changes



[3] In unusual cases when there is a regular pattern in the terrain that may coincide with the systematic grid system, systematic sampling may lead to less precise estimates than simple random sampling. However, such potential problems generally can be handled by orienting the grid system in another direction.

Permanent sample plots generally are more efficient in estimating changes than temporary plots because it is easier to distinguish actual trends from differences that are only due to changed plot selection. However, there are also some risks in the use of permanent sample plots. If the locations of permanent sample plots become known to land managers (e.g., by visibly marking the plots), there is a risk that management of the permanent plots will differ from the management of other areas. If this occurs, the plots will no longer be representative and there is an obvious risk that the results will be biased. If it is perceived that there might be a risk of the above kind, it is *good practice* to assess some temporary plots as a control sample in order to determine if the conditions on these plots deviate from the conditions on the permanent plots.

The use of sampling with partial replacement can address some of the potential problems with relying on permanent plots, because it is possible to replace sites that are believed to have been treated differently. Sampling with partial replacement may be used, although the estimation procedures are complicated (Scott and Köhl, 1994; Köhl *et al.,* 1995).

When only temporary plots are used, overall changes still can be estimated but it will no longer be possible to study land-use conversions between different categories unless a time dimension can be introduced into the sample. This can be done by drawing on auxiliary data, for example maps, remote sensing or administrative records about the state of land in the past. This will introduce additional uncertainty into the assessment which it may be difficult to quantify other than by expert judgement.

3A.3.4 SAMPLING METHODS FOR AREA ESTIMATION

Many approaches for assessing land-use areas or conversions in areas of land use rely on sampling. Areas and changes in areas can be estimated in two different ways using sampling:

- Estimation via proportions;
- Direct estimation of area.

The first approach requires that the total area of the survey region is known, and that the sample survey provides only the proportions of different land-use category. The second approach does not require the total area to be known.

Both approaches require assessment of a given number of sampling units located in the inventory area. Selection of sampling units may be performed using simple random sampling or systematic sampling (see Figure 3A.3.2). Systematic sampling generally improves the precision of the area estimates, especially when the different land-use classes occur in large patches. Stratification also may be applied to improve the efficiency of the area estimates; in this case it is *good practice* to perform the procedures described below independently in each stratum.

In estimating proportions it is assumed that the sampling units are dimensionless points, although a small area around each point must be considered when the land-use category is determined. Sample plots may also be used for area estimation, although this principle is not further elaborated here.

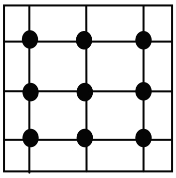
3A.3.5 ESTIMATION OF AREAS VIA PROPORTIONS

The total area of an inventory region is generally known. In this case the estimation of the areas of different land-use categories can be based on assessments of area proportions. When applying this approach, the inventory area is covered by a certain number of sample points, and land use is determined for each point. The proportion of each land-use category then is calculated by dividing the number of points located in the specific category by the total number of points. Area estimates for each land-use category are obtained by multiplying the proportion of each category by the total area.

Table 3A.3.1 provides an example of this procedure. The standard error of an area estimate is obtained as $A\sqrt{(p_i \bullet (1-p_i))/(n-1)}$, where p_i is the proportion of points in the particular land-use category *i*; A the known total area, and *n* the total number of sample points.[4] The 95% confidence interval for A_i, the estimated area of land-use category *i*, will be given approximately by ±2 times the standard error.

[4] Note that this formula is only approximate when systematic sampling is applied.

TABLE 3A.3.1
EXAMPLE OF AREA ESTIMATION VIA PROPORTIONS

Sampling procedure	Estimation of proportions	Estimated areas of land-use category	Standard error
	$p_i = n_i / n$	$A_i = p_i \cdot A$	$s(A_i)$
	$p_1 = 3/9 \cong 0.333$	$A_1 = 300$ ha	$s(A_1) = 150.0$ ha
	$p_2 = 2/9 \cong 0.222$	$A_2 = 200$ ha	$s(A_2) = 132.2$ ha
	$p_3 = 4/9 \cong 0.444$	$A_3 = 400$ ha	$s(A_3) = 158.1$ ha
	Sum = 1.0	Total = 900 ha	

Where:

A = total area (= 900 ha in the example)

A_i = estimated area of land-use category i

n_i = number of points located in land-use category i

n = total number of points

Estimates of land-use conversion areas can be made by introducing categories of the type A_{ij} where land use is converted from category *i* to category *j* between successive surveys.

3A.3.6 DIRECT ESTIMATION OF AREA

Whenever the total inventory area is known, it is efficient to estimate areas, and area changes, via assessment of proportions, since that procedure will result in the highest accuracy. In cases where the total inventory area is not known or is subject to unacceptable uncertainty, an alternative procedure that involves a direct assessment of areas under different land-use classes can be applied. This approach can only be used when systematic sampling is applied; each sample point will represent an area corresponding to the size of the grid cell of the sample layout.

For example, when sample points are selected from a square systematic grid with 1000 metres distance between the points, each sample point will represent an area of 1 km ● 1 km = 100 ha. Thus, if 15 plots fall within a specific land-use class of interest the area estimate will be 15 ● 100 ha = 1500 ha.

Annex 3A.4 Overview of potential methods for developing Approach 3 datasets

Figure 3A.4.1 Overview of Approach 3: Direct and repeated assessments of land use from full spatial coverage

Description

Under Approach 3 the country is sub-divided into spatial units such as grid cells or small polygons. In this example grid cells are used for sub-division of the area. The grid cells may be sampled by remote sensing and/or ground survey, in order to establish the areas of the land use whose estimated extent is shown by the grey lines below the grid. Remote sensing can also enable complete coverage of all grid cells (Figure 3A.4.1A) in the interpretation of land use. Ground surveys can be carried out in a sample of grid cells and can be used to establish land use directly, as well as to help interpret remotely sensed data. The sample of grid cells can be distributed regularly (Figure 3A.4.1B) or irregularly (Figure 3A.4.1C), for example, to give greater coverage where land-use conversion is more likely. Generalised maps can be prepared using the grid cells, which can also be aggregated into polygons (Figure 3A.4.1D). The final result of the Approach can result in either a tabular or spatially-explicit land-use conversion matrix.

Time 1 **Time 2**

Figure 3A.4.1A Remote sensing can also enable complete coverage of all grid cells.

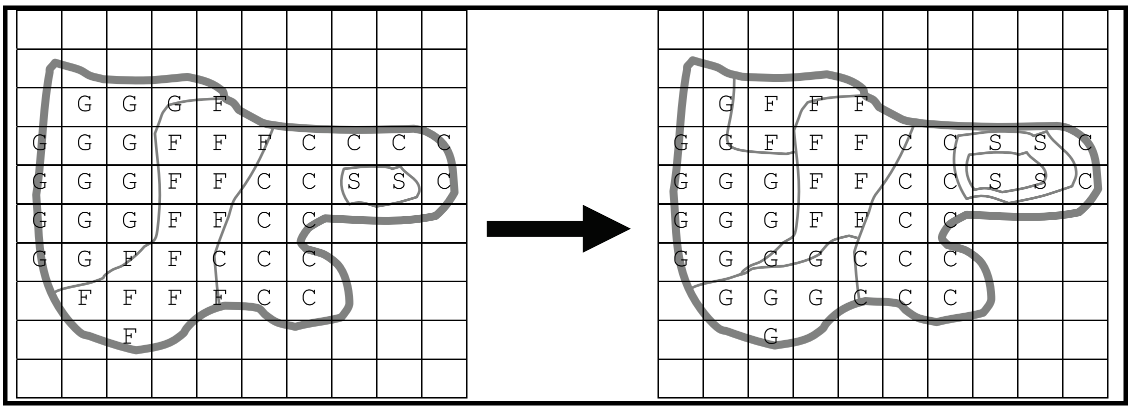
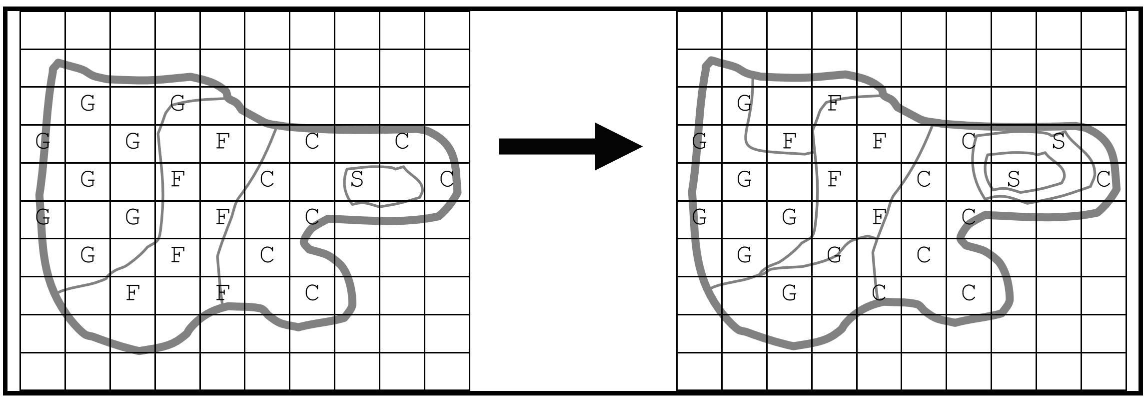


Figure 3A.4.1B The sample of grid cells can be distributed regularly



Time 1 **Time 2**

Figure 3A.4.1C The sample of grid cells can be distributed irregularly

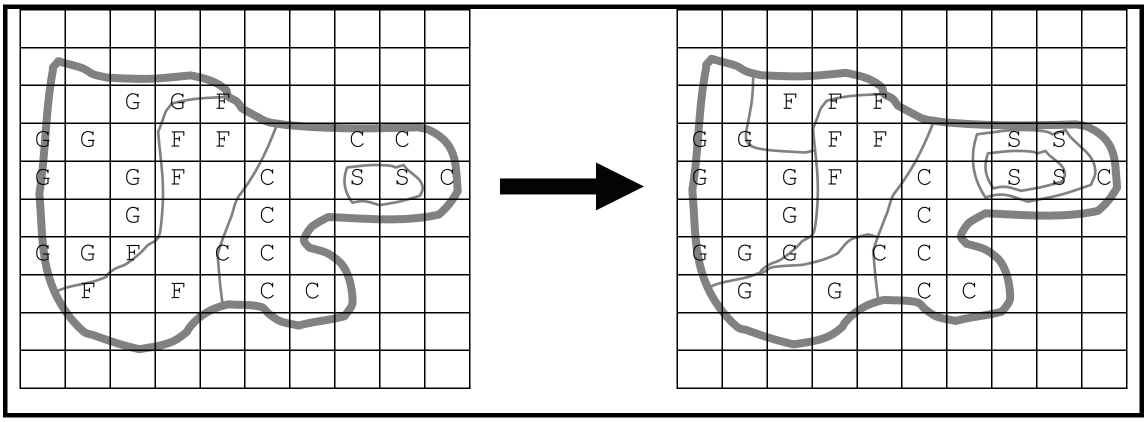
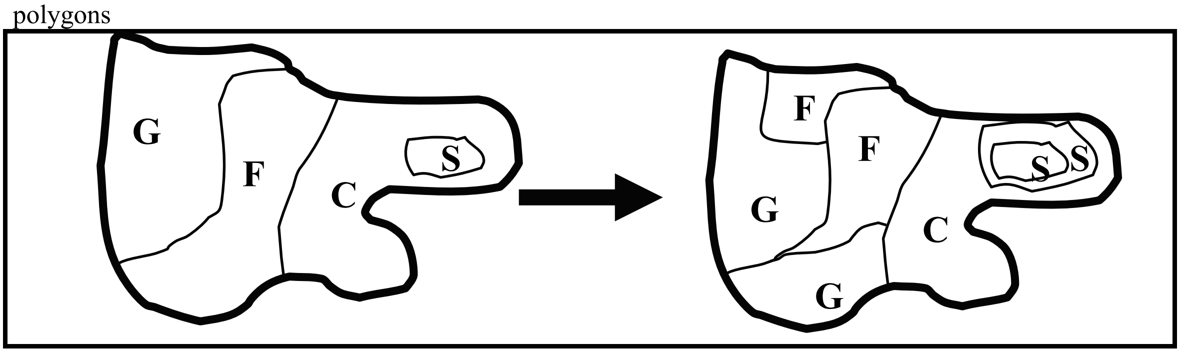


Figure 3A.4.1D Generalised maps can be prepared using the grid cells, which can also be aggregated into polygons



Note: F = Forest Land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other Land

When using Approach 3, inventory compilers should:

- Use a sampling strategy consistent with the advice provided in this chapter. This strategy should ensure that the data are unbiased and can be scaled up where necessary. The number and location of the sampling units may need to change over time in order to remain representative.
- Where remote sensing data are used, develop a method for its interpretation into land categories using ground reference data as set out in this chapter (Remote sensing techniques). Care should be taken to correctly assign land cover information obtained through imagery, into land-use category. Conventional forest inventories or other survey data can be used for this. It is necessary to avoid possible misclassification of land types and map accuracy established by means of ground reference or very high resolution remotely sensed data. The conventional technique is to establish a matrix[5] showing, for any given classification of land, the proportion of misclassification as one of the other candidate classifications.
- Construct confidence intervals for those land category areas and changes in area that will be used in the estimation of carbon stock changes, emissions and removals.
- Derive summary tables of the national areas under different land-use conversion.

[5] Sometimes called the *confusion matrix*.

Annex 3A.5 Default climate and soil classifications

Climate regions are classified in order to apply emission and stock change factors for estimating biomass, dead organic matter and soil C stock changes. The default climate classification is provided in Figure 3A.5.1 and can be derived using the classification scheme in Figure 3A.5.2. This classification should be used for Tier 1 methods because the default emission and stock change factors were derived using this scheme. Note that climate regions are further subdivided into ecological zones to apply the Tier 1 method for estimating biomass C stock changes (see Table 4.1, Chapter 4). Inventory compilers have the option of developing a country-specific climate classification if using Tier 2 and 3 methods, along with country-specific emission and stock change factors. It is *good practice* to apply the same classification, either default or country-specific, across all land-use types. Thus, stock change and emission factors are assigned to each pool in a national inventory using a uniform classification of climate.

Soils are classified in order to apply reference C stocks and stock change factors for estimation of soil C stock changes, as well as the soil N_2O emissions (i.e., organic soils must be classified to estimate N_2O emissions following drainage). Organic soils are found in wetlands or have been drained and converted to other land-use types (e.g., Forest Land, Cropland, Grassland, Settlements). Organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below (FAO 1998):

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

All other types of soils are classified as mineral. A default mineral soil classification is provided in Figure 3A.5.3 for categorizing soil types based on the USDA taxonomy (USDA, 1999) and Figure 3A.5.4 for the World Reference Base for Soil Resources Classification (FAO, 1998) (Note: Both classifications produce the same default IPCC soil types). The default mineral soil classification should be used with Tier 1 methods because default reference C stock and stock change factors were derived according to these soil types. Inventory compilers have the option of developing a country-specific classification for mineral and/or organic if applying Tiers 2 and 3 methods, in combination with developing country-specific reference C stocks and stock change factors (or emission factors in the case of organic soils). It is *good practice* to use the same classification of soils across all land-use types.

Figure 3A.5.1 Delineation of major climate zones, updated from the *1996 IPCC Guidelines*.

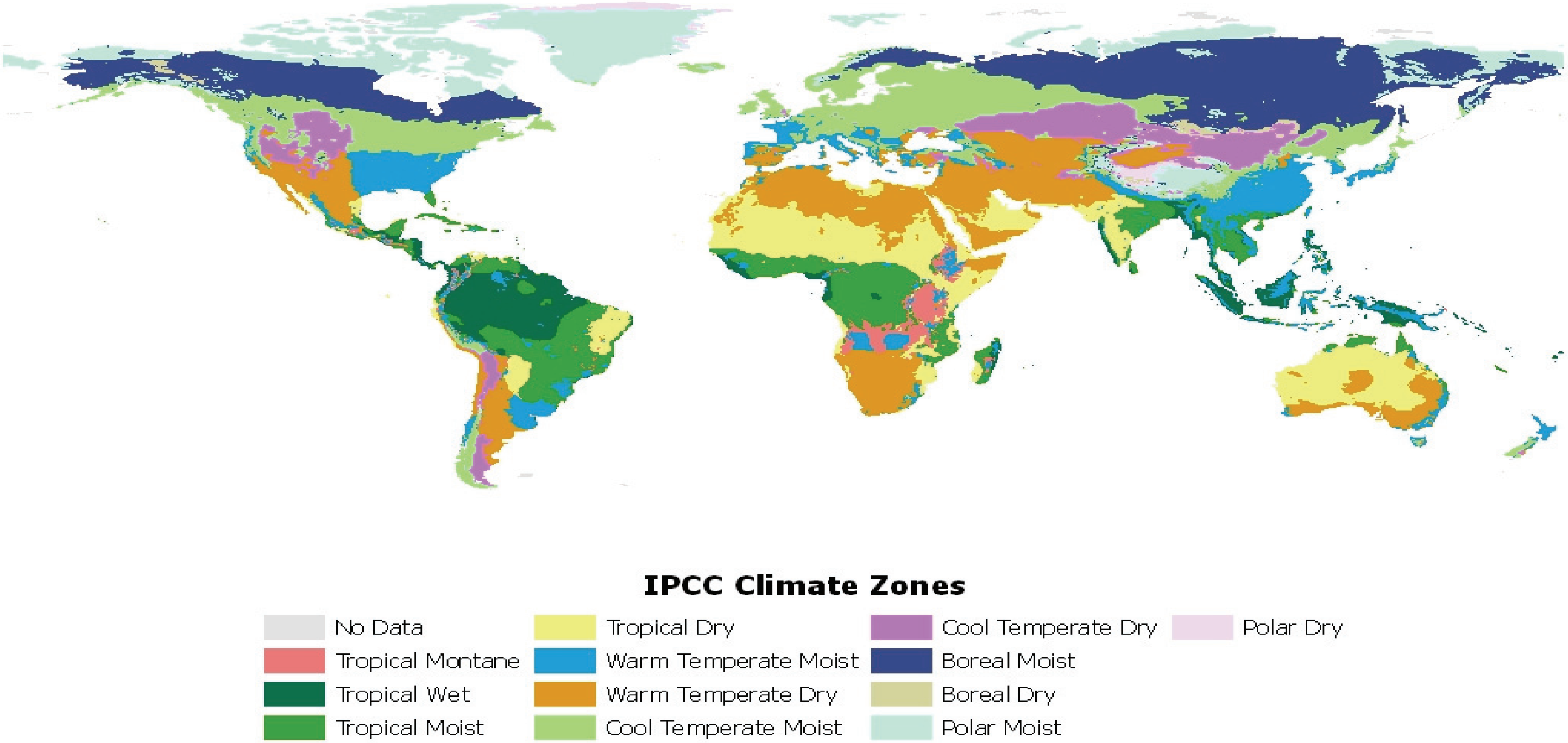


Figure 3A.5.2 Classification scheme for default climate regions. The classification is based on elevation, mean annual temperature (MAT), mean annual precipitation (MAP), mean annual precipitation to potential evapotransporation ratio (MAP:PET), and frost occurrence.

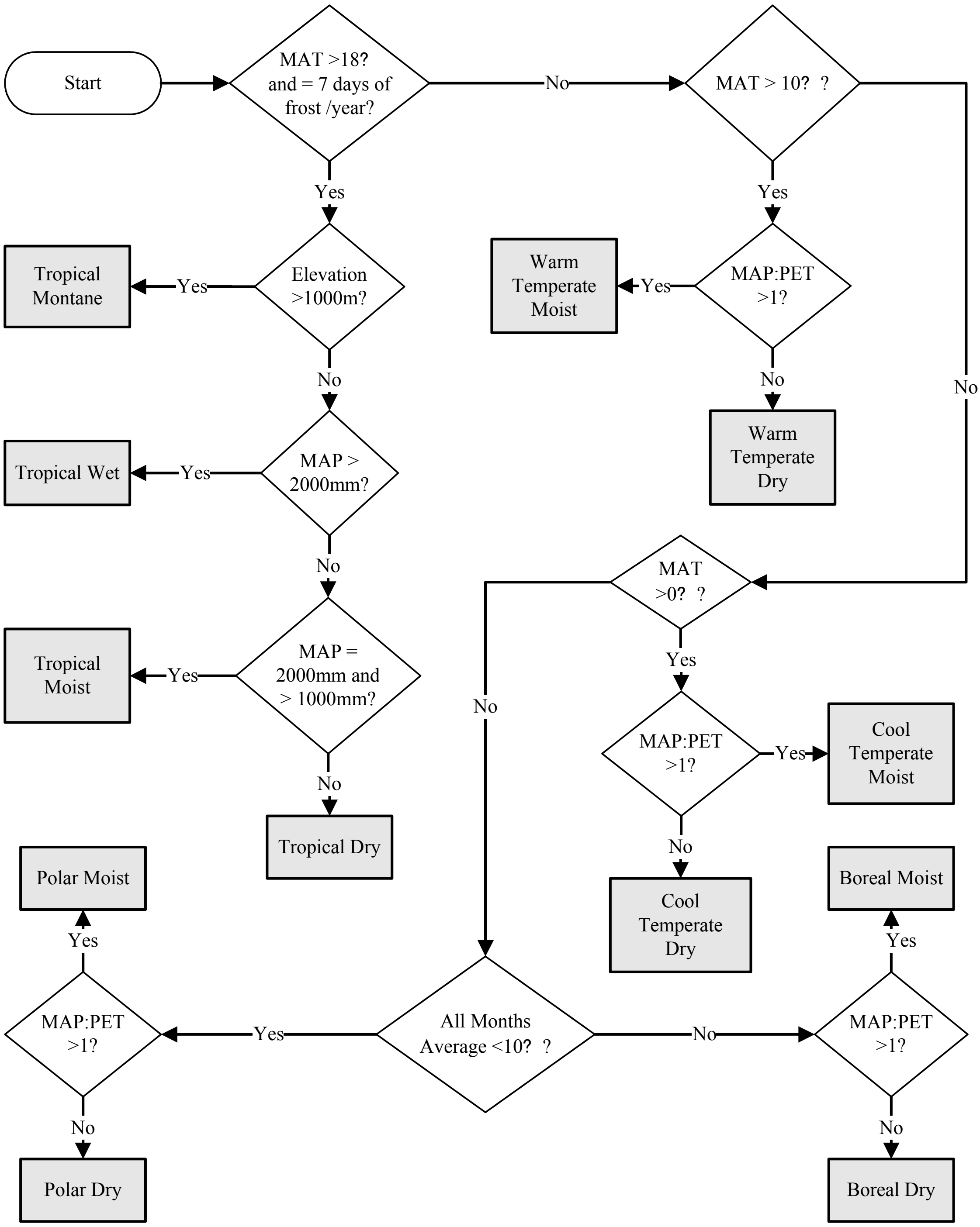


Figure 3A.5.3 Classification scheme for mineral soil types based on USDA taxonomy

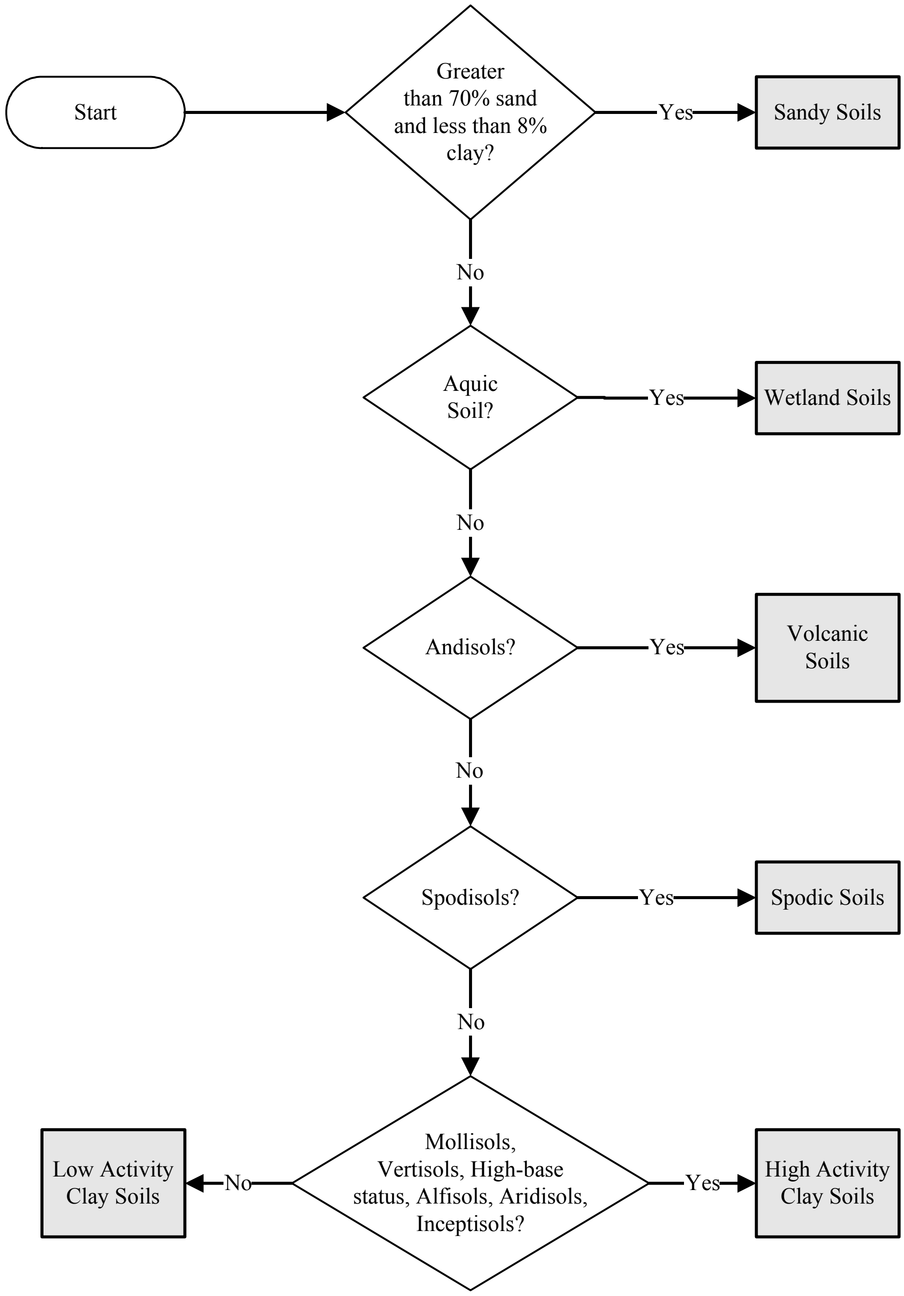
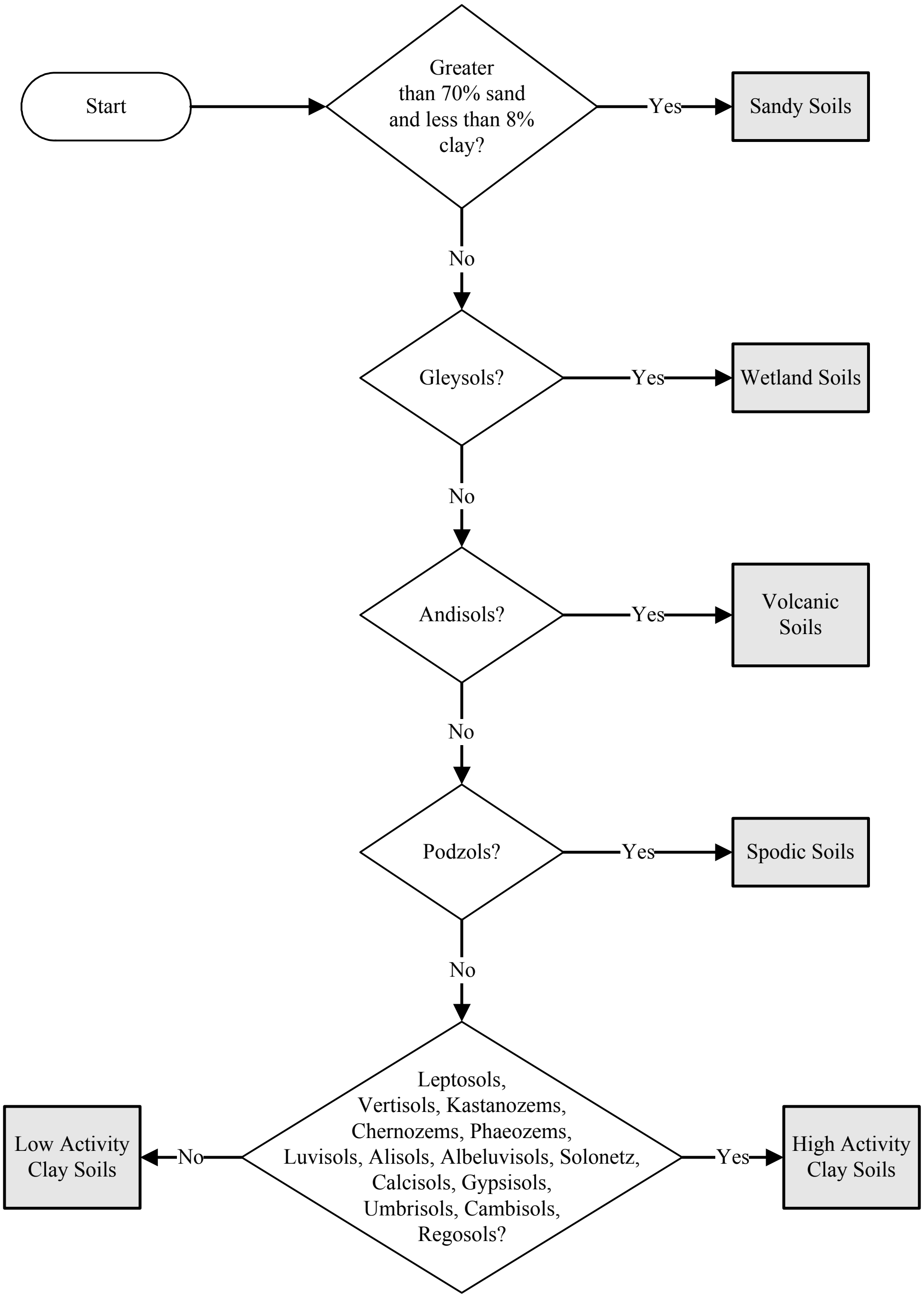


Figure 3A.5.4 Classification scheme for mineral soil types based on World Reference Base for Soil Resources (WRB) classification.



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