UNITED
NATIONS

Framework Convention
on Climate Change

Distr.
GENERAL

FCCC/TP/2009/1
31 May 2009

ENGLISH ONLY

Cost of implementing methodologies and monitoring systems relating to estimates of emissions from deforestation and forest degradation, the assessment of carbon stocks and greenhouse gas emissions from changes in forest cover, and the enhancement of forest carbon stocks

Technical paper

Summary

This paper provides an overview of the possible steps and requirements needed to develop and implement a monitoring system for estimating emissions from deforestation and forest degradation, assessing carbon stocks and greenhouse gas (GHG) emissions from changes in forest cover, and assessing the enhancement of forest carbon stocks. It provides information on the indicative costs associated with the possible steps and requirements of a national monitoring system. The difference in terms of cost implications and capacities between establishing a national monitoring system for GHG emissions and removals from deforestation and forest degradation, and maintaining and/or upgrading an existing system for monitoring are presented and discussed.

This paper aims to facilitate the better understanding of the associated costs of the implementation of methodologies and monitoring systems related to estimates of emissions from deforestation and forest degradation, the assessment of carbon stocks and GHG emissions from changes in forest cover, and the enhancement of forest carbon stocks. It also illustrates elements that developing countries may need to take into account when developing a national monitoring system.

GE.09-70130

CONTENTS

Page

Annexes

I. Introduction

A. Mandate

1. The Subsidiary Body for Scientific and Technological Advice (SBSTA), at its twenty-ninth session, requested the secretariat to prepare and make available, subject to the availability of supplementary funding, a technical paper on the cost of implementing methodologies and monitoring systems related to estimates of emissions from deforestation and forest degradation, the assessment of carbon stocks and greenhouse gas (GHG) emissions from changes in forest cover, and the enhancement of forest carbon stocks, for consideration at its thirtieth session.[1]

B. Objective and scope

2. In response to the request mentioned in paragraph 1 above, this technical paper provides information that aims to facilitate a better understanding of the associated costs of the implementation of methodologies and monitoring systems related to estimates of emissions from deforestation and forest degradation, the assessment of carbon stocks and GHG emissions from changes in forest cover, and the enhancement of forest carbon stocks.

3. In addition to providing the information referred to in paragraph 2 above, this paper illustrates the elements that developing countries may need to take into account when developing a national monitoring system.

C. Approach to the paper

4. This paper provides an overview of the possible steps and requirements needed to develop and implement a monitoring system for estimating emissions from deforestation and forest degradation, assessing carbon stocks and GHG emissions from changes in forest cover, and assessing the enhancement of forest carbon stocks. The aim of this document is to enhance understanding of the necessary steps for building a cost-effective and robust monitoring system. This paper provides information on the indicative costs associated with the possible different steps and requirements of a national monitoring system. The data on cost are being compiled from different sources and might not be fully comparable due to the different assumptions made, which are not always explicit. However, these data can provide a range of cost estimates.

5. The range of activities to be monitored, whether this is a limited or a broad set of activities, has implications for the design and cost of implementing an appropriate monitoring system. Different developing countries have varying capacities and may undertake different actions for reducing emissions from deforestation and forest degradation. This may result in varying requirements for monitoring resources and capacity development.

6. The focus of this paper is on monitoring at the national level, but practical experience with implementing and estimating costs of monitoring different types of activities has been gained at project level and thus is included where appropriate. Moreover, the difference in terms of cost implications and capacities between establishing a national monitoring system for GHG emissions and removals from deforestation and forest degradation, and maintaining and/or upgrading an existing system for monitoring are presented and discussed.

7. For the purpose of this paper, "monitoring" refers to the collection of data and information, and the performance of the necessary calculations for estimating emissions from deforestation and forest degradation, carbon stocks and GHG emissions from changes in forest cover and the enhancement of

[1] FCCC/SBSTA/2008/13, paragraph 41.

forest carbon stocks, and their associated uncertainties, at the national level. In addition, the terms "REDD" and "REDD activities" used throughout this paper refer to all activities[2] as included in paragraph 1 (b) (iii) of the Bali Action Plan (decision 1/CP.13).

II. Elements needed for monitoring emissions and removals of greenhouse gases from REDD activities

8. Monitoring emissions and removals of GHGs from REDD activities is affected by how forests and REDD activities are defined. A definition of forest is provided in the annex to decision 16/CMP.1 based on thresholds of crown cover, tree height, and minimum forest area. This definition is being used by developing countries when participating in land use, land-use change and forestry (LULUCF) project activities under the clean development mechanism (CDM).

9. The Intergovernmental Panel on Climate Change (IPCC) *Good Practice Guidance for Land Use, Land-use Change and Forestry* (hereinafter referred to as the IPCC good practice guidance for LULUCF) provides an effective framework for approaches and methodologies to estimate and monitor emissions and removals of GHGs and changes in carbon stocks resulting from REDD activities. All REDD activities are covered by the following three categories in the IPCC good practice guidance for LULUCF: (i) forest land converted to other land, which includes deforestation; (ii) forest land remaining forest land, which includes forest degradation, forest conservation, sustainable forest management and enhancement of carbon stocks; and (iii) other land converted to forest land, which includes enhancement of forest carbon stocks. Methodologies included in the IPCC good practice guidance for LULUCF are generally supported by Parties as a framework for designing monitoring systems.

10. Emissions and removals of GHGs from changes in the use and cover of lands are estimated as the area that changed from one category of land use to another multiplied by the difference in carbon stocks between the two land-cover classes. The estimates are modified depending on the assumptions regarding what happens to the carbon stocks after change (e.g. whether they are oxidized immediately or whether they decompose slowly over a fixed time) and they can be annualized by dividing by the number of years over which the change in area took place.

11. The IPCC good practice guidance for LULUCF refers to the following two basic inputs with which to estimate emissions and removals of GHGs: activity data and emissions factors.

12. With regard to REDD, activity data refer to the areal extent of an emission and removal category. For example, in the case of deforestation, it refers to the area of deforestation in hectares over a known time period. The IPCC good practice guidance for LULUCF presents the following three approaches for obtaining activity data: (i) only identifying the total area for each land category (approach 1); (ii) tracking of land-use changes between categories (approach 2); and (iii) tracking land-use changes using sampling or wall-to-wall mapping techniques (approach 3). Approach 3 is the only approach that tracks forest and other land conversions on an explicit spatial basis, including gross deforestation and gross change in other land cover classes.

13. Emission factors refer to the emissions or removals of GHGs per unit activity for example, the amount of carbon dioxide (CO_2) emitted or sequestered per ha. Emissions or removals resulting from land conversions are manifested in changes in ecosystem carbon stocks in the five IPCC eligible pools: aboveground biomass, belowground biomass, litter, deadwood and soil organic carbon. Carbon stock

---

[2] Activities referred to in decision 1/CP.13, paragraph 1 (b) (iii) are reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries. These activities are referred to as REDD plus in other documents.

estimates for each pool can be obtained at different tier levels, requiring increasing levels of data, cost and analytical complexity.

14. There are three tiers of data for emission factors in the IPCC good practice guidance for LULUCF that are currently derived from ground measurements:

(a) Tier 1: uses IPCC default values such as for aboveground biomass in different forest ecoregions (six ecological zones in Africa, Asia, and Latin America) and new default values are included the IPCC Emission Factor Database. Tier 1 estimates provide limited resolution of how forest biomass varies sub-nationally and have a large error range (~ ±70 per cent or more of the mean) for aboveground biomass in developing countries;

(b) Tier 2: improves on tier 1 by using country-specific data (i.e. data collected within the national boundary) and by estimating forest biomass at finer scales through the delineation of more detailed strata;

(c) Tier 3: uses actual inventories with repeated direct measurements of changes in forest biomass on permanent plots. Tier 3 is the most rigorous approach and involves the highest level of effort. Tier 3 can also use parameterized models with plot data and can include model transfers and releases among pools that reflect more accurately how emissions are generated over time.

15. Moving from tier 1 to tier 3 increases the accuracy of GHG estimates, but also increases the complexity and the costs of monitoring, which will be discussed in chapter IV E of this paper.

16. The quality of estimates of emissions and removals from a monitoring system relies not only on the robustness of the science that underpins the methodologies and the associated credibility of the estimates, but also on the way this information is compiled and presented. Ideally all information presented must be well documented, transparent and consistent with the UNFCCC reporting guidelines

17. Five general principles can be used to improve the estimation and reporting of emissions and removals of GHGs: transparency, consistency, comparability, completeness and accuracy. The principles of completeness and accuracy will represent major challenges for many developing countries and necessary support will be needed. In order to allow for progressive improvements, the concepts of key categories and significant pools are used by the IPCC good practice guidance for LULUCF. The full implementation of these principles imply the application of higher IPCC tiers.

18. Achieving greater completeness and accuracy in a monitoring system means higher costs, as it is likely that more carbon pools would need to be monitored and that the monitoring would need to result in accurate and precise estimates of emissions and removals. Progressive improvements may spread the cost over time.

19. The Conference of the Parties (COP) in its decision 2/CP.13 encourages well-documented information that follows the principles of transparency and consistency. In this decision, the implementation of demonstration activities calls for estimates of reductions or of increases in emissions to be results based, demonstrable, transparent and verifiable, and estimated consistently over time. There was general agreement at the workshop on methodological issues relating to reducing emissions from deforestation and forest degradation in developing countries held in Tokyo, Japan, from 25 to 27 June 2008[3] on the need for robust and cost-effective methodologies for monitoring REDD

[3] FCCC/SBSTA/2008/11.

activities. National monitoring systems of GHG emissions and removals from REDD activities will facilitate the review of results.

III. Elements and capacities for building national carbon monitoring systems for REDD

20. Countries currently undertake different levels of forest monitoring depending on a number of economic, sociocultural and environmental factors. Therefore, the quality and characteristics of current forest monitoring in developing countries may not satisfy the requirements of a system to monitor emissions and removals of GHGs. Despite the broader benefits of monitoring national forest resources, there are some requirements for establishing a national forest carbon monitoring system for the implementation of REDD activities. These include:

(a) Being part of a national REDD implementation strategy or plan;

(b) Systematic and repeated measurements of all relevant forest-related carbon stock changes;

(c) The estimation and reporting of carbon emissions and removals at the national level that either use or are in line with the methodologies contained in the IPCC good practice guidance for LULUCF due to the need for transparency, consistency, comparability, completeness and accuracy that should characterize such systems (see also discussions by Grassi et al., 2008).

21. The design and implementation of a monitoring system for REDD can be seen as an investment in information that is essential for the successful implementation of REDD activities. Developing countries may already have useful forest data and capacities that they can build on when establishing a carbon monitoring system. However, many developing countries would need further investment in capacity development, in addition to establishing and maintaining a national carbon monitoring system in the long term. The following chapters of this paper will provide a more detailed description of the possible steps and required capacities: chapter III A provides a summary of the elements and defines what is required; explicitly tracking and chapter III B provides a general overview of the capacity status of countries, which helps to define the ‘capacity gap.’ Chapter III C explains how the assessment of the ‘capacity gap’ should form the first step in designing and implementing a forest carbon monitoring system for each country; and chapter IV gives details of planning for the associated costs.

A. Key elements and required capacities

22. The development of a national monitoring system for REDD activities should be seen as a process. A summary of key components and required capacities for estimating and reporting emissions and removals from forests is provided in table 1.

23. In the planning and design phase, the monitoring objectives and implementation framework should be specified, taking into consideration the following points:

(a) The guidance for monitoring and implementation provided or that will be provided by the COP of the UNFCCC;

(b) Monitoring should be part of the national REDD implementation strategy and objectives;

(c) Knowledge of the use and application of the methods contained in the IPCC good practice guidance for LULUCF and any other relevant guidance by the COP;

(d) Existing national forest carbon monitoring and inventory capabilities;

(e) Existing expertise in estimating forest carbon stocks and human-induced changes in carbon stocks;

(f) The consideration of the different requirements for monitoring forest changes in the past and such changes in the future with actions taken on REDD.

24. The planning and design phase could result in a national REDD monitoring system (including definitions, monitoring variables and necessary institutional arrangements), a plan for capacity development and long-term improvement, and an estimation of the anticipated costs.

Table 1. Components and required capacities for establishing a national monitoring system for estimating emissions and removals from forests

Phase	Component	Capacities required
Planning and design	1. Need to establish a forest monitoring system as part of a national REDD implementation strategy	• Knowledge of international UNFCCC process on REDD and of guidance for monitoring and implementation • Knowledge of national implementation strategy and objectives for REDD
	2. Assessment of existing national forest carbon monitoring framework and capacities, and identification of gaps in existing data sources	• Understanding of estimation and reporting guidance provided in the Intergovernmental Panel on Climate Change (IPCC) *Good Practice Guidance for Land use, Land-use Change and Forestry* and any other relevant guidance under the Convention • Synthesis of previous national and international reporting, if any (i.e. national communications and the Food and Agriculture Organization of the United Nations Forest Resources Assessment) • Expertise in estimating terrestrial carbon stocks and related human-induced changes, and monitoring approaches • Expertise to assess usefulness and reliability of existing capacities, data sources and information
	3. Design of a forest carbon monitoring system driven by UNFCCC reporting requirements, with objectives for historical period and future monitoring	• Detailed knowledge of the application of methodologies in the IPCC *Good Practice Guidance for Land use, Land-use Change and Forestry* and any other relevant guidance under the Convention • Agreement on definitions, reference units, and monitoring variables and framework • Institutional framework specifying roles and responsibilities • Capacity development and long-term improvement planning • Cost estimation for establishing and strengthening institutional framework, capacity development, and actual operations and budget planning
Data collection and monitoring	4. Forest area change assessment (activity data)	• Reviewing, consolidating and integrating the existing data and information • Understanding of deforestation drivers and factors, and management practices • If historical data records are insufficient, particularly with the use of remote sensing, the following capacities are required: − Expertise and human resources in accessing, processing and interpretation of multi-date remote sensing imagery for forest area changes − Technical resources (hardware/software, Internet, image database) − Approaches for dealing with technical challenges (i.e. cloud cover, missing data)

Table 1 (continued)

Phase	Component	Capacities required
	5. Changes in carbon stocks (emission factors)	• Understanding of human-induced processes influencing terrestrial carbon stocks • Consolidation and integration of existing observations and information, that is, national forest inventories or permanent sample plots involving: − National coverage and stratification of forests by carbon density and threat of change − Conversion to carbon stocks and estimates of carbon stock change • Technical expertise and resources to monitor carbon stock changes, including: − In situ data collection of all the required parameters, and data processing − Human resources and equipment to carry out fieldwork (vehicles, maps of appropriate scale, global positioning system, measurement units) − National inventory and sampling (sample design, plot configuration) − Detailed inventory of areas of forest change or "REDD action" − Use of remote sensing (stratification, biomass estimation) • Estimation at sufficient IPCC tier for: − The estimation of carbon stock changes due to land-use change − The estimation of changes in forest land remaining forest land − The consideration of the impact on five different carbon pools
	6. Emissions from biomass burning	• Understanding of national fire regime and related emissions of different greenhouse gases • Understanding of slash and burn cultivation practices and knowledge of the areas where this is being practiced • Fire monitoring capabilities to estimate areas affected by fires caused by humans and associated emission factors • Use of satellite data and products for active fire and area burned • Continuous in situ measurements (particularly emission factors) • Separating fires leading to deforestation from degradation
	7. Accuracy assessment of activity data and uncertainty analysis of emission factors	• Understanding of sources of error and uncertainties in the assessment process of both activity data and emission factors, and how errors propagate • Knowledge of the application of best efforts using appropriate design, accurate data collection processing techniques, and consistent and transparent data interpretation and analysis • Expertise on the application of statistical methods to quantify, report and analyse uncertainties for all relevant information (i.e. area change, change in carbon stocks, etc.) using, ideally, a higher-quality sample
Data analysis	8. National greenhouse gas information system	• Knowledge of techniques to gather, store, archive and analyse data on forests and other data, with the emphasis on carbon emissions and removals from changes in forest area • Data infrastructure, information technology (suitable hardware/software) and human resources to maintain and exchange data, and quality control • Data access procedures for (spatially explicit) information presented in a transparent form

Table 1 (continued)

Phase	Component	Capacities required
	9. Analysis of drivers and factors of forest change	• Understanding and availability of data for spatial-temporal processes affecting forest change, socio-economic drivers, spatial factors, forest management and land-use practices and spatial planning • Expertise in spatial and temporal analysis and use of modelling tools
Reference emission levels	10. The establishment of reference levels of emissions, which is regularly updated	• Data and knowledge of processes relating to REDD , associated greenhouse gas emissions, drivers and expected future developments • Expertise in spatial and temporal analysis and modelling tools • Specifications for a national implementation framework for REDD
Reporting	11. National and international reporting and verification	Consideration of uncertainties and understanding procedures for independent international review and verification

25. Implementing measurement and monitoring procedures in order to obtain basic information to estimate GHG emissions and removals requires capabilities for collecting data on a number of variables. Irrespective of the choice of method, the uncertainties of all results and estimates need to be quantified and reduced as far as is practicable. The application of best practices using suitable data sources, appropriate data acquisition and processing techniques, and consistent and transparent data interpretation and analyses constitute key steps in reducing uncertainties. Expertise is needed for the application of statistical methods to quantify, report and analyse uncertainties, for the understanding and handling of sources of error, and for approaches for a continuous improvement of the monitoring system both in terms of reducing uncertainty for estimates and in terms of more complete estimations (i.e. including additional carbon pools).

26. All relevant data and information should be stored, updated and made available through a common data infrastructure that will need to be developed and could be part of a broader national GHG information system. The information system should provide the basis for the transparent estimation of emissions and removals of GHGs and should be able to provide data in a spatially explicit and transparent format. The information system should also help in analyses of data (i.e. including information that may help in determining the drivers of, and factors for, forest change), support national and international reporting, as necessary, and should also help in the implementation of quality assurance and quality control procedures, which are followed by an expert peer review.

B. Status of existing capacities and knowledge base

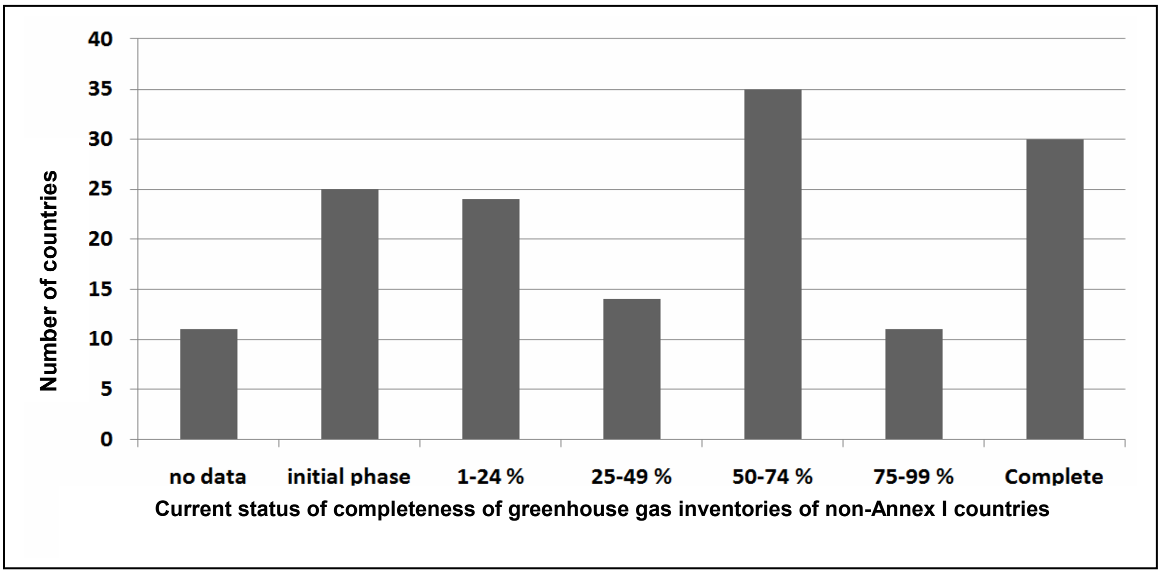
27. The requirements and components contained in table 1 show that capacities are required for the estimating and reporting of emissions and removals of GHGs from activities that take place in forest lands.

28. In order to better understand the needs that have to be met by a specific country when designing and implementing its forest carbon monitoring system, it is important to assess existing information and the current capacity of the country in question. It is not possible to undertake such country-specific assessments in this paper, but an overview of ongoing exercises that may lead to the identification of existing capacities may help developing countries identify their current status (see Hardcastle and Baird, 2008).

29. National communications have prompted countries to establish national GHG inventories and build related national capacities to estimate GHGs. Figure 1 highlights the current status and the level of completeness of national GHG inventories. About one fifth of Parties not included in Annex I to the Convention (non-Annex I Parties) are listed as having a fully developed inventory. An additional 46 countries have taken significant steps to improve their inventories that are 50–100 per cent complete. About half of non-Annex I Parties currently have inventories that are less than 50 per cent complete. The

information in figure 1 refers to the establishment of full GHG inventories, where the Land Use Change and Forestry (LUCF) or LULUCF sector is only one component. The figure gives an idea of the current 'capacity gaps' for GHG estimating and reporting at the national level using either the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* or the IPCC good practice guidance for LULUCF.

Figure 1. Status of completeness for national greenhouse gas inventories as part of the Global Environment Facility support for the preparation of national communications of 150 non-Annex I Parties



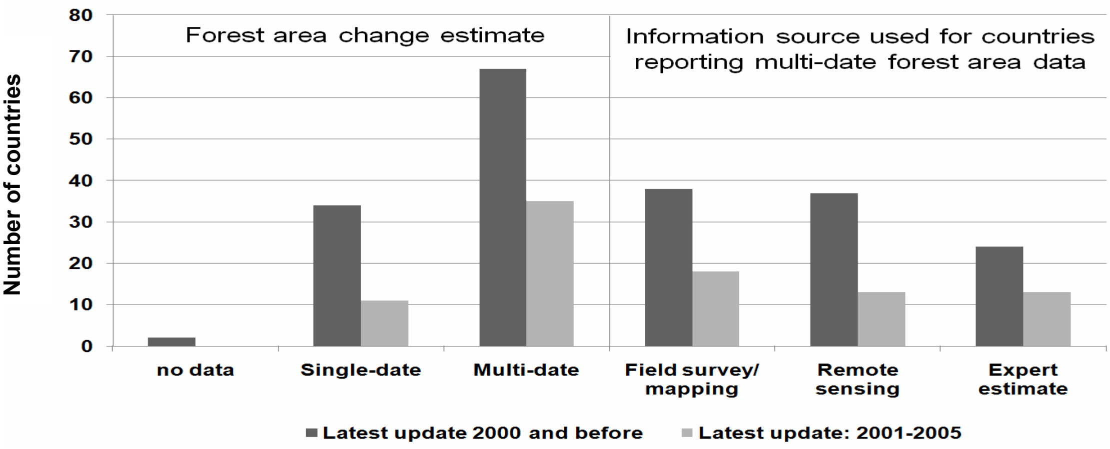
Source: FCCC/SBI/2008/INF.10.

30. An overview of the status of capacities for the monitoring of forest area change and changes in forest carbon stocks is provided in the most recent Food and Agriculture Organization of the United Nations (FAO) Global Forest Resources Assessment (FRA) 2005 (FAO 2006). Assuming that all of the available and relevant information has been used by countries to report for the FRA 2005, figures 2 and 3 summarize the relevant capacities for developing countries.

31. In terms of monitoring changes in forest area, figure 2 shows that almost all developing countries that reported were able to provide estimates of and changes in forest area. About two thirds of countries provided this information based on multi-date data and about one third reported this based on single-date data. Most of the countries used data from the year 2000 or before as their most recent data point for forest area, while 46 out of the 149 countries were able to provide more recent estimates. Of the countries that used multi-date data, there is an almost even distribution for the use of information sources between field surveying and mapping and remote sensing-based approaches, but expert estimates were used less frequently.[4]

[4] Countries may have used multiple sources for reporting such data to the FAO.

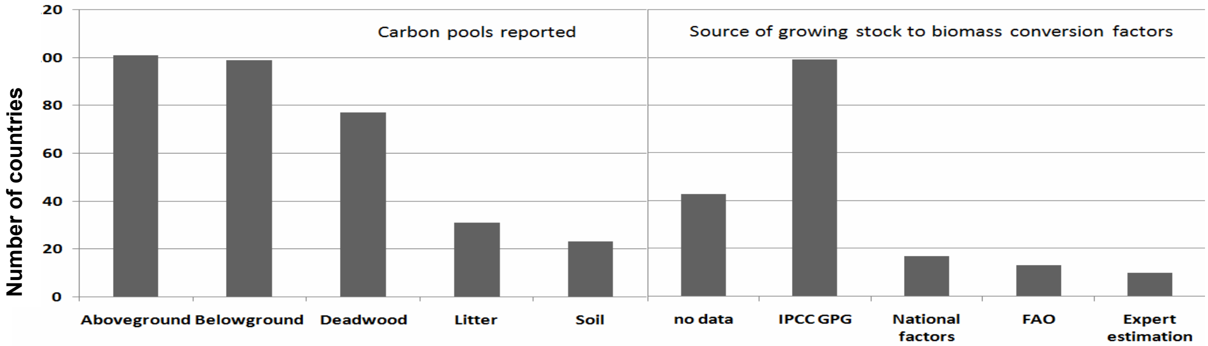
Figure 2. Summary of data and information sources used by 150 developing countries to report on forest area change for the Food and Agriculture Organization of the United Nations Global Forest Resources Assessment 2005



Source: FAO (2006).
Note: Single-date estimates are based on assumptions (i.e. a multivariable model that includes population growth).

32. A number of developing countries provided estimates for carbon stocks (see figure 3). One hundred and one out of 150 developing countries reported on the overall stocks in aboveground carbon pool. As aboveground and belowground carbon pools are correlated, almost the same number of developing countries reported on the carbon in belowground vegetation. Only 23 developing countries were able to provide data on the other pools, in particular for carbon in soils. The forest carbon pool estimates reported are primarily based on an extrapolation of growing stock volume data as the primary observation variable. These data are generally from a subset of the country's forest areas, and often only of forests containing actual or potential commercial timber. Of the 150 developing countries that reported for the FAO FRA 2005, 41 reported no growing stock data; 75 provided single-date data; and 34 provided multi-date data on growing stocks. A number of different information sources were applied by developing countries to convert growing stocks to biomass and then to carbon, with the default factors from the IPCC good practice guidance for LULUCF being the most commonly used (see figure 3). Only 17 developing countries converted growing stock to biomass using specific and perhaps more precise national conversion factors.

Figure 3. Summary of data for five different carbon pools reported and information sources used by 150 developing counties to convert growing stocks to biomass for the Food and Agriculture Organization of the United Nations Global Forest Resources Assessment 2005



Source: FAO (2006).
Note: Developing countries may have used multiple sources for the conversion process.
Abbreviations: IPCC GPG: IPCC Good Practice Guidance for Land Use, Land-use Change and Forestry, FAO: Food and Agriculture Organization of the United Nations

33. Figures 1–3 emphasize the varying level of capacities among developing countries. Given the results of the FAO FRA 2005, it can be concluded that the majority of countries have limited capacity in providing complete and accurate estimations of GHG emissions and removals from forests. Taking into account the principles mentioned in paragraph 17 above, the gaps in current monitoring capacities can be summarized as follows:

(a) *Consistency*: estimations provided by many countries are based either on single-date measurements or on integrating various different data sources rather than using a systematic and consistent monitoring approach;

(b) *Transparency*: due to the complexity of the processes involved and the lack of information, expert opinions, independent assessments or model estimations are commonly used as information sources to produce forest carbon data (Holmgren et al., 2007); this could potentially lead to a lack of transparency;

(c) *Comparability*: the use of common methodologies and guidance leads to comparable results. Few developing countries have experience in using the IPCC good practice guidance for LULUCF as a common approach for estimation;

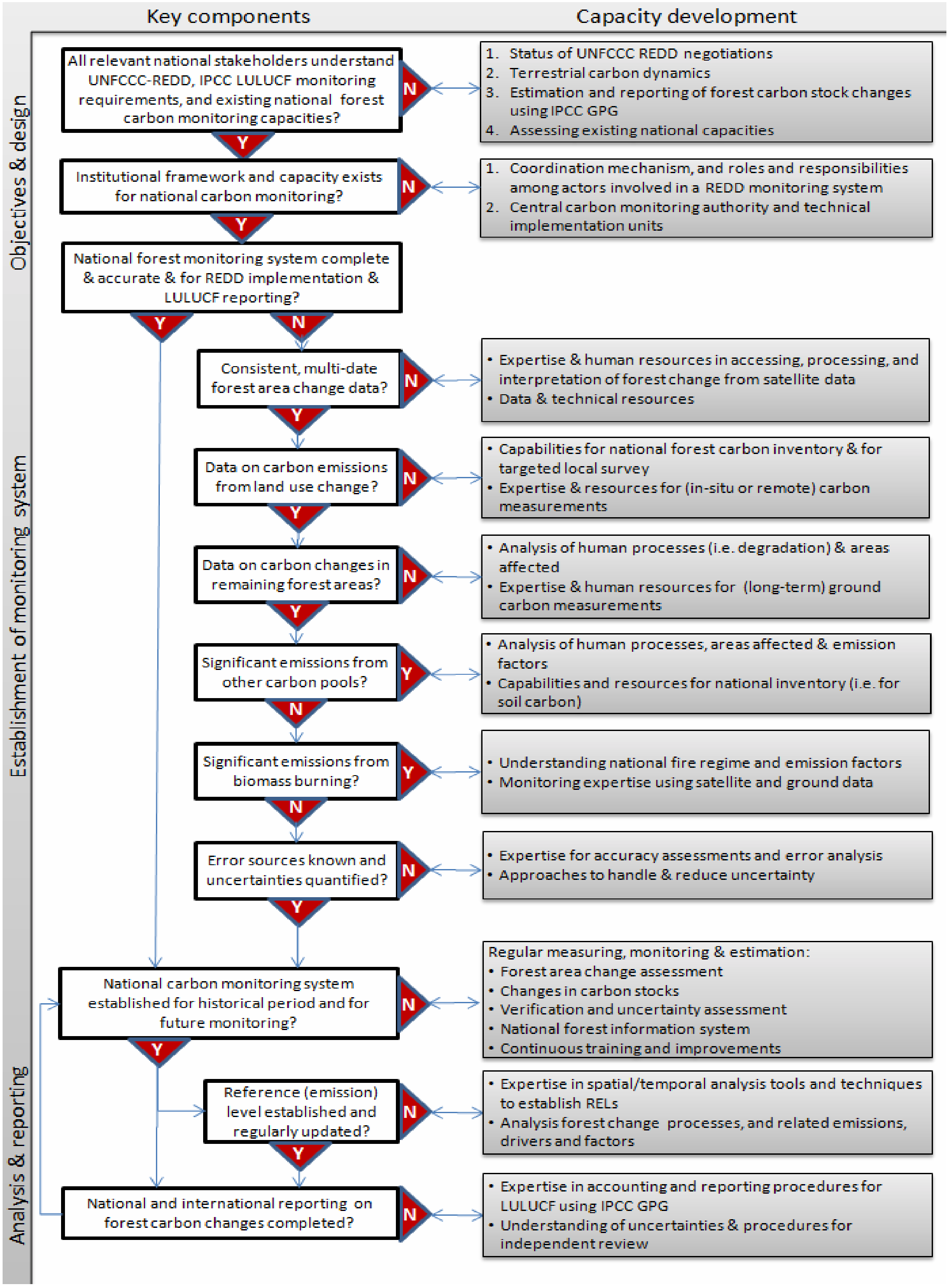
(d) *Completeness*: the lack of suitable forest resource data in many non-Annex I Parties is evident for both data on area change and changes in carbon stocks. Carbon stock data for aboveground and belowground pools are often based on estimations or conversions using IPCC default data and very few countries (see para. 33 (c) above) are able to provide information on all five carbon pools (although data for all pools may not be warranted). In addition, only limited country-specific information to support carbon estimations is available;

(e) *Accuracy*: there is limited information on the sources of error of the estimates and reliability levels by countries on approaches used to analyse, reduce and deal with sources of error for international reporting.

C. Key steps for establishing national monitoring systems for REDD activities

34. The pathways and cost implications for developing countries to establish their monitoring system require an understanding of the 'capacity gap' between the status of current monitoring capacities and what is needed for such a system to be established (see table 1). The important steps to be considered by developing countries are outlined in figure 4. Fundamental to this is the understanding by all relevant national actors about the guidance provided by the Convention, the status of implementation of national REDD activities, knowledge of and expertise in using the methodologies available in the IPCC guidelines, and knowledge of terrestrial carbon dynamics and human-induced changes in forests.

Figure 4. Flow chart of the processes required to establish a national monitoring system, linking key components and required capacities



Note: Based on the Global Observation for Forest and Land Cover Dynamics (GOFC-GOLD) (2008).

35. Uncertain input data (i.e. data on forest area change and carbon stock change) is common when dealing with forestry information, but adequate methods to improve monitoring capabilities exist. A starting point is to analyse critically existing forest data and to assess monitoring capabilities for the purpose of systematic estimation and, eventually, reporting. Table 2 lists the two key data sources, observations and information, that may already be available and that are usually considered useful.

Table 2. Examples of important data sources that may be useful for establishing REDD national monitoring systems

		Possible available data sources	
Variable	**Focus**	**Observations**	**Information**
Area changes (activity data)	Deforestation Forest degradation and regrowth (if required)	Archived satellite data and air photos Field surveys and forest cover maps Maps of forest use and settlements or infrastructures	Maps and rates of deforestation and/or forest regrowth Land-use change maps National statistical data
Changes in carbon stocks/emission factors	Land-use change (deforestation)	Forest inventories, site measurements Permanent sample plots, research sites Forest/ecosystem stratifications Forest concessions/harvest estimates Volume to carbon conversion factors Regional carbon stock data/maps	Estimates of carbon stock change and emissions per ha
	Carbon stock changes in areas remaining forests Different carbon pools (i.e. soils)		Long-term measurements of human-induced carbon stock changes
Biomass burning	Emissions of several greenhouse gases	Records of fire events (in-situ) Satellite data Emission factors (available in publications and databases) Records of areas under slash and burn cultivation	Maps of burnt areas Fire regime, area, frequency and emissions
Ancillary (spatial) data	Drivers and factors of forest changes	Topographic maps Field surveys Census data Geographic information systems, including – data sets on population, roads, land use, planning, topography and settlements	

36. Forest inventory data on commercial timber are currently the most common data source for the estimation of changes in forest stocks. However, most of the existing forest inventories have not been designed for carbon stock assessments. Ideally, and in contrast to traditional inventories, the design of national carbon stock inventories should take into account the following requirements:

(a) The stratification of forest area by carbon density classes and relevant human activities affecting forest carbon stocks;

(b) The move towards national coverage with most detail, accuracy and precision required in areas where activities relevant to REDD are implemented;

(c) Site measurements that place emphasis on measurements of carbon stocks, including all key carbon pools, that is, those containing quantities of carbon that would significantly change in response to deforestation, degradation or enhancement;

(d) Consistent and recurrent measurements of carbon stock change over time, that is, for deforestation and in areas remaining as forests (i.e. areas where there may be degradation);

(e) Reducing uncertainties, including verification and considerations for the independent international review of estimates.

37. In case there are no consistent time series data on historical forest area change, the country in question should consider using archived satellite data and should establish the monitoring capacities that it requires (Global Observation for Forest and Land Cover Dynamics (GOFC-GOLD), 2008).

38. The investments and priority setting for monitoring carbon stock changes in forests and in different carbon pools (i.e. soils, biomass) may depend on how significant the related human-induced changes are on the overall carbon emissions and removals and on the national REDD implementation strategy. For example, if the country has no fire regime and no significant emissions from biomass burning, it is not necessary to invest in good fire data.

39. It could be more time-consuming and costly to monitor carbon stock changes in forest land remaining as forest land than for deforestation. This is because in forests, the carbon stock change per ha is lower than for areas that are deforested, resulting in higher monitoring costs per unit of carbon and, usually, a lower level of accuracy and a higher level of uncertainty (see chapter IV E). On the other hand, monitoring of forest degradation is important because the cumulative emissions can be significant.

40. Updated data may be also useful to track displacement of emissions, if any, from reduced deforestation. Understanding and regularly monitoring the human processes causing decreases or increases in forest carbon stocks in the country will be very helpful for designing more cost-effective monitoring systems in this case, that is, through repeated assessments of degraded forest areas. The establishment of a forest carbon monitoring system should put particular emphasis on building the required capacities for undertaking ground-based measurements in the long term.

41. Monitoring other carbon pools in addition to aboveground and belowground biomass may also be time-consuming and costly. To date, very few developing countries report data on soil organic carbon. This may not be significant in many developing countries where conversion of forests on mineral soils to other land uses involving perennial plants, such as pasture or woody vegetation, occurs, as emissions from such soils often result in low overall net emissions. However, if deforestation or degradation occurs on peat swamp forests or areas with large amounts of organic litter, emissions of GHGs from the soil can be very significant. Also, if forest land is converted to land used to grow annual crops, then emissions may be significant depending upon the carbon content in the soil and litter.

42. If a country decides to include the soil carbon pool or any other key pool in its monitoring system based on for example key categories,[5] the related monitoring component should be established from the beginning to provide the accuracy and certainty required for estimation and reporting. The current IPCC good practice guidance for LULUCF provides guidance that allows for a cost-effective use of available resources, by indicating that priority should be given to the most relevant key categories and/or carbon pools.

[5] Key categories are sources of emissions and removals that contribute substantially to the overall GHG emissions in the national inventory (in terms of absolute level of emissions and/or emission trends). According to the IPCC good practice guidance for LULUCF, key categories or pools should be estimated using higher tiers (tier 2 or 3), which means that tier 1 should be used for non-key categories or pools.

D. Data collection for historical periods

43. Limitations in the quality and amount of existing data and information may affect the accuracy and completeness of the information to be reported for historical periods and even length of the historical period itself. For example, the limited availability of activity data and emission factors may constrain the completeness and accuracy of determining historical emissions for most activities in most developing countries where degradation of forest or enhancement of forest carbon stocks has occurred.

44. The monitoring and estimation activities for historical periods should include a process for building the capacities within the country required to establish the monitoring and reporting procedures as part of a long-term system. Consistency between the estimates for historical periods and future monitoring is essential and the existing gaps and known uncertainties of the historical data should be addressed in future monitoring efforts as part of a continuous improvement and training programme.

IV. Cost implications of a national forest monitoring system

45. There are several categories of costs to be considered for countries when designing a forest carbon monitoring system. Pagiola and Bosquet (2009) provide a summary of the different factors, including opportunity costs and costs for transactions and implementation. Monitoring, reporting and verification of forest carbon to ensure that a REDD activity has achieved a certain amount of emissions reductions are primarily reflected in the transaction cost. The resources needed for monitoring are a smaller component of the total cost for REDD implementation in the long term, but they may be significant in the country's preparatory phase (also known as 'readiness phase'), since many developing countries require the development of basic capacities.

46. The estimation of costs for REDD monitoring has to take into consideration several issues that depend on country-specific circumstances. Firstly, there is a difference in the cost structure between the establishment of a monitoring system and its implementation and operation. For developing countries starting with limited capabilities, significantly larger amounts of resources are anticipated, particularly for monitoring historical forest changes, the establishment of reference emissions levels and for monitoring efforts in the near term. It is often assumed that readiness costs require significant public investment and international support (Hoare et al., 2008). Secondly, different components of the monitoring system have different cost implications depending on the method used and the level of accuracy and uncertainty to be achieved. As estimates of emissions and removals are based on both activity data and emission factors, a balance needs to be achieved between the level of effort made to improve these components. Combining a highly accurate estimate of area change from remote sensing data with tier 1 or low-level tier 2 data for emission factors will result in an overall emission or removal estimate that is still inaccurate and uncertain.

47. Specific information on the costs for carbon monitoring in developing countries beingscarce; for this paper the estimates are based on the following sources:

(a) Ongoing forest monitoring programmes involving developing countries, ranging from local case studies to global assessment programmes (e.g. FAO activities);

(b) Idea notes and proposals submitted by developing countries to the World Bank Forest Carbon Partnership Facility;

(c) Scientific literature on monitoring and case studies regarding REDD activities;

(d) Expert estimates and considerations documented in reports (e.g. consultant reports) and documents from international organizations and panels (i.e. GOFC-GOLD REDD Sourcebook);

(e) Examples from operational national forest monitoring (e.g. from India).

48. There are a number of predictions of lump sum costs for REDD monitoring. For example, Hoare et al. (2008) estimated that USD 1–6 million would be required for the establishment of reference emissions levels and a monitoring system in each country. This assessment is largely based on work by Hardcastle and Baird (2008) which estimated costs for monitoring based on different national circumstances and building on knowledge of existing capacities.

49. Operational monitoring costs are often provided as per area unit numbers (e.g. as per area unit). The aim of the section IV is not to provide specific cost estimates since these costs will vary depending on national circumstances and country-specific strategies regarding REDD, and assumptions needed in the calculations (e.g. whether external consultants are involved or if only national). Chapter IV takes into account the list and description of the important steps required following the elements and capacities described in chapter III and, as a minimum, aims to provide information and the cost implications for the different options that could be available.

A. Establishing a national monitoring infrastructure

50. The costs for monitoring and technical capacity development will be an important component in planning for REDD activities. Understanding historical forest change processes is fundamental for developing a national REDD strategy that is based on current forest and environmental legislation. Establishing a national reference emissions level for deforestation and forest degradation and establishing a sustained national system for monitoring, reporting and verifying emissions and removals from forest land in the long term involves progressive capacity development.

51. Table 3 provides an overview of the major components of the REDD readiness phase and indicated costs from the Readiness Plan Idea Notes (R-PINs) submitted by several developing countries to the World Bank Forest Carbon Partnership Facility. The cost figures include costs for developing national reference levels or emissions levels and the design of the monitoring, reporting and verification system. On average, both components together require an estimated USD 1.5 million of the USD 3.3 million total average for readiness activities. This estimate does not include annual monitoring costs once the system is operational.

Table 3. First order country estimates based on the Readiness Plan Idea Notes (R-PINs), discussions with developing countries undertaking activities to reduce emissions from deforestation and forest degradation and independent estimates
(thousands of United States Dollars)

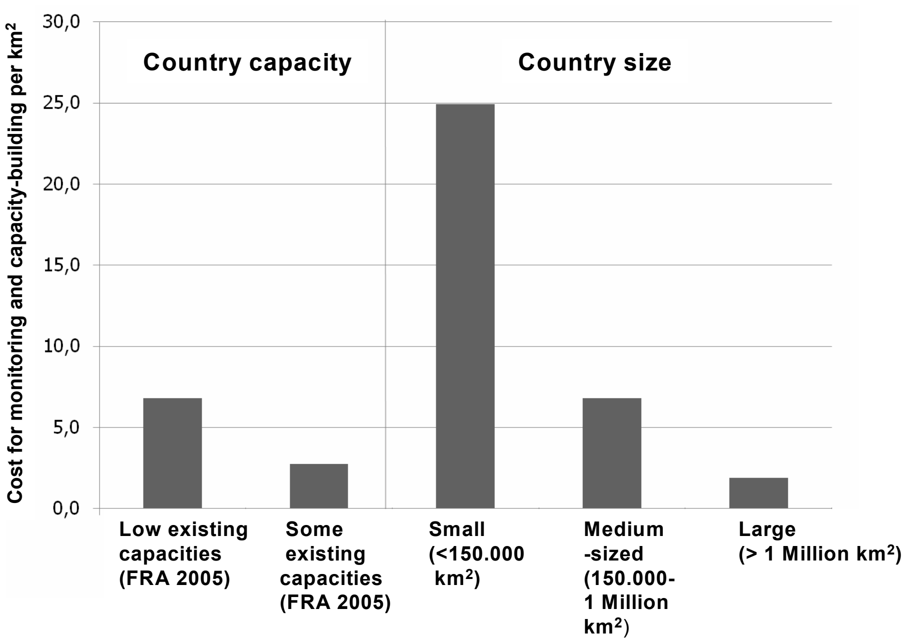
Major components of readiness	Estimate [a]	Country [b]	R-PIN [c]	Average [d]
REDD management	440–490	130–430	550–1 115	525
Develop REDD Strategy	500	200–410	400–690	450
Consultations	420	380–440	350–182	365
Environment and social impacts assessments	50	50	50	50
REDD implementation framework	250–500	300–350	150–500	341
Develop reference scenario	500	200–400	300–1 200	516
Design MRV[in full please] system	1 000–1 300	1 000–1 560	250–940	1 008
TOTAL (without annual measurement, reporting and verification costs)	**3 160-3 760**	**2 2640–3 640**	**2 050–4 627**	**3 255**

[a] Bottom up estimates by the World Bank based on the tasks that need to be performed.
[b] Estimates by the World Bank based on staff missions to several tropical developing countries and R-PINs submitted by countries.
[c] Estimates submitted in the R-PINs, including one or two countries of different tropical regions.
[d] The average estimate reflects cost estimates for smaller/medium-sized countries.
Source: World Bank Forest Carbon Partnership Facility presentation at the second Participants Committee, Gamboa 2009. Data up to October 2008.

52. The distribution of costs for monitoring activities and for capacity development is related to the existing capacities of the country and its size. For example, figure 5 shows an assessment of 15 R-PINs with budget details that have been submitted to the World Bank Forest Carbon Partnership Facility. The combined cost of monitoring and capacity-building activities range from USD 2–25 per km^2 depending on the land area to be monitored and existing capacities in the country. Developing countries with low existing capacities indicated that they required more resources, with a larger proportion used for capacity-building. Similar initial amount of base investments are required for all country sizes, that is, a minimum standard for operational institutional capacities, technical and human resources and expertise in reporting.

Figure 5. Indicative costs per km^2 for monitoring and capacity-building as part of the proposed World Bank Forest Carbon Partnership Facility readiness activities

(in United States Dollars)



Note: The graph shows median values based on 15 R-PINs according to country capacities and land area. Developing countries were considered to have low capacities if they did not report either forest-area change based on multi-date data or data on forest carbon stocks for the last FAO Forest Resources Assessment Report (FAO, 2006).

53. The costs in figure 5 are similar to the indicative costs of operational monitoring systems using satellite data for the bi-annual surveys that India is doing, with an estimated indicative cost of about USD 1 per km^2 for the 330 million ha surveyed, including a field check, and for the annual satellite deforestation survey in the Amazon that Brazil is doing with an estimated cost of about USD 0.25 per km^2 for 400 million ha of forest where only gross deforestation is assessed.

B. Planning and design

54. Planning and design activities should result in a national monitoring framework that includes elements such as definitions, monitoring variables, an institutional framework, a plan for capacity development and long-term improvement of the system, and the anticipated estimation of the costs of setting up such a system. Planning and design efforts should take into account existing data sources and information, and should assess their usefulness for monitoring forest carbon (see table 2). Costs for

historical assessments of forest carbon emissions in particular can be reduced if existing monitoring data can be included in the REDD monitoring efforts.

55. Fundamental to this process is an understanding of the status of the guidance provided by the secretariat and the status of national implementation activities regarding REDD by relevant national actors, knowledge in the application of methodologies in the IPCC good practice guidance for LULUCF, and expertise in terrestrial carbon dynamics and related human-induced changes.

56. Resources for training and capacity-building, participation in, or organizing, dedicated national or regional workshops, and expert support are required. Some initiatives are already offering capacity-building workshops to developing countries for this purpose.[6]

C. Institutional capacities

57. A suitable degree of organizational capacity within the country is required to establish and operate a national forest carbon monitoring programme. Activities include acquisition of different types of data, analysis, estimation, international reporting and the use of forest data. Different actors and sectors need to be working in coordination to make the monitoring system efficient in the long term. Sustainability considerations are important in setting up a REDD monitoring system. As a minimum, a country should consider establishing and maintaining the following institutions with a clear definition of roles and responsibilities:

(a) A national coordination and steering body or advisory board;

(b) Central carbon monitoring, estimation and reporting authority/department;

(c) Forest carbon monitoring implementation units.

58. The amount of resources required for setting up and maintaining institutional capacities depend on several factors. Some developing countries may perform most of the acquisition, processing and analysis of data by their agencies or centralized units; others may decide to involve outside partners (e.g. contractors, local communities or regional centres). While a minimum amount of institutional capacities is required even for small countries, larger countries may need to invest in a more complex and more expensive organizational structure. An example of this is the Forest Survey of India, which is dedicated to national forest monitoring.

D. Cost factors for monitoring change in forest area

59. Fundamental requirements of national monitoring systems are that they measure changes in all forested area, use consistent methodologies at regular intervals to obtain accurate results and that they verify the results with ground-based observations. A suitable practical approach for such monitoring systems is through the interpretation of remotely sensed data supported by ground-based observations.

60. The use of field survey and inventory type data for the estimation of activity data at the national level is performed by several Parties included in Annex I to the Convention (Achard et al., 2008). However, the use of satellite remote sensing observations (in combination with field observations for calibration and validation) for consistent and efficient monitoring of forest area changes can be assumed to be a suitable option to support REDD implementation and reporting activities in developing countries; in particular for countries with limited information on historical periods.

[6] <http://unfccc.int/files/methods_science/redd/technical_assistance/training_activities/application/pdf/cd_redd_concept_note.pdf>.

61. The implementation of a satellite-based monitoring system involves a number of cost factors, such as:

(a) Satellite data, including data access and processing;

(b) Software, hardware and office resources, including satellite data archives;

(c) Human resources for data interpretation and analysis;

(d) Monitoring during the readiness phase;

(e) Monitoring during the operational phase;

(f) Accuracy assessment;

(g) Regional cooperation for capacity-building and technical assistance.

1. Remote sensing data, data access and pre-processing

62. Many data from optical sensors at various resolutions and costs are available for monitoring changes in forest area (see table 4). The choice will depend on the satellite data availability, existing national capacities and gaps, and available resources. Costs for satellite data are provided in per km^2 units, thus developing countries may estimate potential data costs based on the size of the country. These costs are added up for each new survey, thus more frequent monitoring results in more costs for data. All image data sets by Landsat and CBERS are made available free of charge and are publicly accessible on the Web.

63. Coarse resolution imagery (250 m to 1 km) provides high temporal resolution and near-real-time observations. Coarse resolution data cannot be used directly to estimate area of forest change, but the data are useful for identifying locations of rapid change (e.g. forest fires) where further analysis with higher resolution data should be carried out or when an alert system for controlling deforestation should be used. Such data are widely available pre-processed and are available free of charge from the data provider.

Table 4. Utility of sensors of multiple resolutions for deforestation monitoring

Sensor & resolution	Examples of current sensors	Minimum mapping unit (change)	Cost	Utility for monitoring
Coarse (250–1000 m)	SPOT-VGT (1998–present) Terra-MODIS (2000–present) Envisat-MERIS (2004–present)	~ 100–500 ha ~ 10–20 ha	Low or free of charge	Consistent pan-tropical annual monitoring to identify large clearings and locate ‘hotspots’ for further analysis using medium resolution Fire monitoring
Medium (10–60 m)	Landsat TM or ETM+, Terra-ASTER IRS AWiFs or LISS III CBERS HRCCD DMC SPOT HRV	0.5–5 ha	Archived Landsat and CBERS are to be free of charge from 2009 For other costs see table 5	Primary tool to map deforestation and estimate area change
Fine (<5 m)	IKONOS QuickBird Aerial photos	< 0.1 ha	High to very high USD 2–30 per km^2	Validation of results from coarser resolution analysis, and training of algorithms Detailed (local) surveys

Source: GOFC-GOLD (2008).

64. Fine resolution (< 5 m) data, such as those collected from commercial sensors (e.g. IKONOS, QuickBird) and aircraft, can be prohibitively expensive when covering large areas. However, these data can be used to calibrate algorithms for analysing medium and high resolution data and to verify the results, that is, checking the interpretation of satellite imagery or for assessing the accuracy of these results. Such data may also be used efficiently for sampling approaches over larger areas or for detailed local surveys.

65. The use of medium resolution satellite data is the most common choice for forest-area change monitoring at the national level (see table 5). There is almost complete global coverage from these Landsat satellites and data are available at no cost for the early 1990s, early 2000s and the year 2005 from the National Aeronautics and Space Administration (NASA), United States Geological Survey (USGS) or from the University of Maryland's Global Land Cover Facility, and with more detailed temporal coverage for many regions worldwide between 1990 and the present day. These data played a key role in establishing historical deforestation rates, although in some parts of the humid tropics (e.g. Central Africa) persistent cloudiness limited their use.

66. The full Landsat 7 ETM+ USGS archive (since 1999) and all USGS archived Landsat 5 TM data (since 1984), Landsat 4 TM (1982–1985) and Landsat 1–5 MSS (1972–1994) are now available to order at no charge. Landsat-type data around years 1990, 2000 and 2005 will be the most suitable data option for many developing countries to assess historical rates and patterns of deforestation. In addition, SPOT and ASTER data have also been used since near-global archived observations exist, but the cost is high. For future monitoring, different satellite sensor options are available. Alternative sources of optical remote sensing data include ASTER, SPOT, IRS, CBERS or DMC data (see table 5), which vary in terms of cost and availability. For example, SPOT satellite data are comparatively expensive, but SPOT is running three satellites and provides a comprehensive archive of data with complete global coverage.

Table 5. Present availability of key optical and radar mid-resolution sensors (10–60 m)

Entity	Satellite and sensor	Resolution and coverage	Cost for data acquisition (archive)	Feature
United States of America	Landsat–5 TM	30 m 180 x 180 km²	All archived by United States data available free of charge	Images available every 16 days to any satellite receiving station. Operating beyond expected lifetime.
United States of America	Landsat–7 ETM+	30 m 60 x 180 km²	All archived by United States data available free of charge	In April 2003 the failure of the scan line corrector resulted in data gaps outside of the central portion of images seriously compromising data quality.
United States of America/Japan	Terra ASTER	15 m 60 x 60 km²	USD 60/scene USD 0.02/km²	Data are acquired on request. Data are not routinely collected for all areas.
India	IRS–P2, LISS-III and AWiFS	23.5 and 56 m	USD 140/scene of IRS-P2 USD 0.70/ km² for LISS III USD 300/scene of AWiFS	After an experimental phase, AWiFS images can be acquired on a routine basis.
China/Brazil	CBERS–2 and HRCCD	20 m	Free of charge for developing countries	Experimental; Brazil uses on-demand images to bolster their coverage.

Table 5 (continued)

Entity	Satellite and sensor	Resolution and coverage	Cost for data acquisition (archive)	Feature
Algeria/China/ Nigeria/Turkey/ United Kingdom of Great Britain and Northern Ireland	DMC	32 m 160 x 660 km²	USD 4082 (EUR 3000)/scene USD 0.04 (EUR 0.03)/km²	Commercial; Brazil uses this alongside Landsat data.
France	SPOT–5 HRVIR	10–20 m 60×60 km²	USD 2721 (EUR 2000)/scene USD 0.7 (EUR 0.5)/km²	Commercial; Indonesia and Thailand use this alongside Landsat data.
Japan	ALOS/PALSAR	7–24 m 70 x 70 km	USD 250–500/scene USD 0.05–0.1/km²	SAR sensor to complement this in areas where there are persistent clouds
European Union	ERS–1/2 and Envisat ASAR	25 m 100 x 100 km	USD 0–544 (EUR 0–400) /scene USD 0–0.05 (EUR 0–0.04 /km²) (reproduction costs for research and development purposes)	SAR sensor to complement this in areas where there are persistent clouds

Source: GOFC-GOLD (2008).
Note: The exchange rate used (USD 1 = EUR 0.735) is the average United Nations operational exchange rate of 15 May 2009.

67. Other newer types of sensors, such as radar sensors (e.g. ERS–1/2 SAR, Envisat, ASAR and ALOS/PALSAR) and LiDAR sensors, are potentially useful and could be appropriate, for example as complementary data from medium to coarse resolution imagery. Radar, in particular, alleviates the substantial limitations of optical data due to persistent cloud cover in the tropics, but has not been widely used operationally for forest cover monitoring over large areas. Over the coming years, the utility of radar may be enhanced depending on data acquisition, access and scientific developments.

68. The costs indicated in tables 4 and 5 refer to the data itself. Additional resources are required for getting the data ready for interpretation and analysis of forest area change. The most common procedure to access archived satellite data is through the Internet. Some developing countries may face difficulties when carrying this out due to low bandwidth Internet services and the fact that the delivery of data needs to be arranged through other means (e.g. through regional centres, hard- discs or DVDs by post).

69. Most importantly, all remote sensing data need to be pre-processed before it can be interpreted. The pre-processing includes geometric and radiometric corrections (for details see GOFC-GOLD, 2008). In addition to archived Landsat data that are provided as ortho-rectified image products, other remote sensing data are not routinely processed without additional cost for this level of geometric accuracy. Additional resources are needed to perform the required corrections using the available standardized techniques.

70. The international Earth observation community is aware of the needs for pre-processed satellite data. The gap between acquiring satellite observations and their availability (in the archives) and processing the data in a suitable format to be ready for use for forest area change assessments is being bridged by space agencies and data providers such as USGS, NASA, the European Space Agency, the Japan Aerospace Exploration Agency, the Brazilian Space Research Institute and the international coordination mechanism of the Committee on Earth Observation Satellites, GOFC-GOLD and the Group on Earth Observations . In the next few years these efforts will further decrease the level of costs and efforts required to use satellite observations for REDD monitoring at the national level.

2. Technical equipment and office resources

71. Hardware, software and office resources add to the basic set-up costs. Depending on the size of the image processing and analysis unit, this involves the following:

(a) A central satellite archive and database (file server) to make data freely available to all relevant stakeholders;

(b) Workstations for data interpretation (one license per data interpreter);

(c) Backup system;

(d) Input and output devices (scanner, printer and plotter);

(e) Image analysis software (one per data interpreter);

(f) Geographic information system (GIS) software;

(g) Travel (field surveys, conferences and training courses);

(h) Fieldwork equipment (cars, global positioning system (GPS), handheld devices, etc. – that are assumed to be shared with teams working on the ground measuring carbon stocks);

(i) Office expenses, such as consumables, rent, equipment and administrative support.

72. There are a number of commercial image analysis and GIS software packages available that range in price from a few hundred to several thousands of USD. Some countries have developed specific image analysis software packages for monitoring of deforestation that are provided through the Internet. Among these is the SPRING system used by Brazil for their operational programme (Moreira et. al., 2004; Câmara et al., 1996). Overall, the costs for supplying technical and office resources should not exceed USD 120,000–150,000 even in larger countries. In addition, an annual budget needs to be allocated for operational costs and for maintaining the hardware and software needs.

73. Remote sensing is capable of monitoring area changes, but requires input from field sampling to verify the image interpretation, with more fieldwork probably being needed in the capacity development phase. Most fieldwork supporting the image analysis may be undertaken by the remote sensing team or in cooperation with field crews measuring carbon stocks and verifying the area changes.

3. Human resources and capacity development for data interpretation and analysis

74. Satellite data processing and analysis is most efficiently performed in centralized units by highly skilled personnel trained in remote sensing and GIS. It is recommended that each unit should, at a minimum, maintain three permanent skilled staff technicians, and one manager if necessary, in order to be operational, absorb staff turnover and allow for continuous internal and external training. More staff may be required depending on the size of the area to be monitored.

75. The annual costs required for technical and management staff depends on the salary rate of the countries. As a guide, GIS or remote sensing technicians may already be employed by governmental agencies, for example, in the areas of planning, environment, infrastructure or resource development. In general, GIS and remote sensing technicians and managers are potentially employable in a number of governmental and private sector jobs in developing countries. The continuous training of new recruits is necessary (Hardcastle and Baird, 2008). The monitoring activities may further include local or regional experts and a ground support team to help in the image analysis and accuracy assessment.

Monitoring in the initial phases

76. For developing countries without existing operational capacities the costs for developing the necessary human capacities required will need to be considered. In the establishment phase, the work of both national and international experts include the following activities:

(a) Assessing and making best use of existing observations and information;

(b) Specifying a methodology and operational implementation framework for monitoring forest-area change at a national level;

(c) Undertaking an analysis of historical satellite data for establishing reference emissions levels or reference levels;

(d) Developing understanding of areas affected by forest degradation and providing an assessment on how to monitor relevant forest degradation processes;

(e) Setting up, if required, a system for real-time deforestation monitoring (i.e. including detection of forest fires and areas burnt);

(f) Completing recruitment and providing training to allow the national team to perform monitoring activities;

(g) Completing an accuracy and error analysis for estimates from historical periods;

(h) Performing a trial of the operational forest area change monitoring system.

77. In addition to the resources required for in-country technical staff, resources would also need to be allocated to external expert support, which is likely to be needed. Such costs are estimated to the order of USD 10,000–30,000 per month (Mollicone et al., 2003; Hardcastle and Baird, 2008). The involvement of one or two international experts for small-to medium-sized countries for one year would be an appropriate estimate for countries with limited existing capacities.

78. Further costs could be anticipated for capacity-building. For example, in the case that three technical staff require training to the level of Master of Science at an advanced facility outside the country, the costs would be in the range of USD 100,000–140,000 per year (Hardcastle and Baird, 2008); this would be in addition to the training provided by the international experts working in the country.

Monitoring during the operational phase

79. Once a monitoring system is consolidated in the readiness phase, the continuous monitoring operation produces annual operational costs for the different components of the system. For example, if a country decides to monitor forest-area change using its own resources and capacities, the annual cost for human resources may be three to four times lower than the cost during the establishment phase (Hardcastle and Baird, 2008).

80. The resources required for operational monitoring depend on the size of the area to be mapped each year and the thematic detail and accuracy to be provided. In general, the smallest implementation unit comprising three skilled technicians should be sufficient to perform all operations for the consistent and transparent monitoring of forest-area change for small to medium-sized countries at two- to three-year time intervals. Costs for data and human resources will increase if an annual monitoring interval of forest-area change is performed. This may be necessary for countries with extensive deforestation or significant forest degradation. Areas affected by forest degradation or by forest fires are best detected using annual observation. This may require at least one or two additional technical staff members being specifically trained and focused on these monitoring issues.

81. An annual budget should be allocated for continuous recruitment and training, and further professional development in order to maintain and continuously improve the monitoring system.

Creating sustained country capabilities also involves the incorporation of remote sensing training at university level and in curricula in relevant higher education institutions within the country or region.

4. Accuracy assessment

82. The assessment of the performance of the system and the estimation of uncertainties of the results are necessary, yet these are often not included in cost estimates. The understanding of sources of error and uncertainties, and approaches for continuous improvement of the monitoring system are fundamental for verifying that the results and emissions reductions are real. The accuracy assessment itself should be carried out independently from routine monitoring and will, thus, generate additional costs resulting from the need for:

(a) Probably one additional trained staff with expertise in GIS and statistical assessments to quantify, analyse and report uncertainties for all relevant information (e.g. area change, change in carbon stocks);

(b) Resources to acquire and analyse some higher quality reference information for comparison with the remote sensing results. Reference information can be acquired using field surveys, airborne campaigns or higher resolution satellite data.

83. Costs can be reduced if work on accuracy assessment is performed in synergy and jointly with activities on national field measurements of carbon stocks.

5. Regional cooperation

84. The cost per unit area is likely to be larger for small developing countries with a low level of initial capacities. The cost of building monitoring capacity for these countries is often independent of the size of the area to be monitored because a minimum level of technical resources and capacities must be achieved. Such countries could consider the possibility of sharing regional capacity (see table 6). Regional efforts usually do not cost much more than national capacity for one (small) country in terms of technical and office resources and human capital. This may include a range of opportunities for both the area change and carbon stock assessments. The cost for accessing, processing and analysing remote sensing data can be significantly reduced by following a regional approach (Hardcastle and Baird, 2008). There are extra costs involved for establishing regional cooperation, and efforts should build upon existing networks and cooperation activities in order to minimize the amount of resources required for this regional cooperation.

Table 6. Opportunities for regional cooperation and capacity development to reduce costs and efforts for national forest carbon monitoring

Regional capacity	Opportunity for reducing costs and efforts
Centralized access and pre-processing of key remote sensing data sets for national analysis and estimation of forest area change	Reduce cost for data access and pre-processing, while data interpretation may still be carried out within country
Establish a regional remote sensing data interpretation facility	Reduce costs for technical/office resources and human resources
Regional processing and analysis of coarse resolution satellite data for near-real-time detection of forest fires and deforestation	Increase availability of, and reduce costs on, useful data and observations
Focal point for technical capacity-building for forest monitoring in the region	Reduce costs for continuous training and technical support, and foster South–South cooperation
Support for verification and independent accuracy assessments	Standard procedures for transparent and independent verification of results
Standardization of methodologies for estimation and reporting of the land use, land-use change and forestry sector	Interregional exchange of results and experiences

85. In many developing countries some types of regional cooperation already exist. The FAO FRA has long-standing expertise in working with countries and is currently conducting a number of regional capacity-building workshops for countries as part of its global remote sensing survey.[7] In Central Africa, there is already an established partnership among the Central African countries (COMIFAC).[8] In addition, GOFC-GOLD[9] is working on forest and land cover monitoring and related capacity-building (i.e. technical expertise, improved data access, validation) with eight networks in different regions including Africa, Southeast Asia, Latin America (Brady and Naydenov, 2007).

E. Cost factors for monitoring forest carbon stocks

1. Status of estimating forest carbon stocks

86. The IPCC good practice guidance for LULUCF contains methods and good practice guidance for estimating changes in carbon stocks and emissions resulting from LULUCF categories and activities.[10]

87. Estimates of carbon stocks in above-ground biomass of trees are frequently obtained by countries from various sources (see table 7), and for other forest carbon pools default data (for use with the tier 1 approach) provided by the IPCC good practice guidance for LULUCF are normally used.

88. Growing stock volume collected in conventional forest inventories can be used to produce biomass values using methods in the IPCC good practice guidance for LULUCF or other more specific methods (Brown, 1997). Stratification by forest type and management practices, for example mature forest, intensely logged forest, selectively logged forest, fallow, could help to achieve more accurate and precise results. Many developing countries use some country-specific inventory data to estimate carbon stocks of forests, but often they use some of the factors from the IPCC good practice guidance for LULUCF to convert volume to biomass; using country-specific inventory data could be seen to be equivalent to low-level tier 2 factors as defined in the IPCC good practice guidance for LULUCF because not all of the data is country-specific.

89. However, conventional forest inventories are often carried out in forests deemed to be productive for timber harvesting and measurements may have not been stratified and acquired for carbon stock assessments. Also, as shown in table 7, many inventories are old and out of date, and the forests may not be undergoing deforestation.

90. Compilation of data from ecological or other permanent sample plots may provide estimates of carbon stocks for different forest types, but these are subject to the design of particular scientific studies and thus tend to produce unreliable estimates over large forest areas.

---

[7] <www.fao.org/forestry/fra2010-remotesensing/en/>.
[8] <http://www.biodiv.be/comifac2>.
[9] <http://www.fao.org/gtos/gofc-gold/networks.html>.
[10] See chapters 3 and 4 of the IPCC good practice guidance for LULUCF.

Table 7. Comparison of methods to estimate carbon stocks at national to regional scales

Data products/scale	Strengths	Weaknesses	Degree of confidence
Traditional forest inventories rarely on the national scale and usually regional in developing countries.	High confidence in data if they are updated frequently, statistically well designed and adhere to commonly accepted standards.	They may be out of date. They are often focused on forests of commercial value and trees of commercial size and species. They need factors to convert volume to biomass stocks. These can be costly to implement.	This depends on the age of the inventory and if it is updated. Confidence is low on national scale to high on local scale. Degree of confidence is based on age of inventory and level of spatial coverage.
Forest inventory with additional data on canopy cover and high resolution remotely sensed data; updated biomass stocks with new fine resolution remotely sensed data.	Commercial forest inventory data may already be available.	This is often focused on forests with a commercial value and trees that are of commercial size and species. They can be costly to implement.	Medium confidence.
Data from the Food and Agriculture Organization of the United Nations, by country and region.	These are widely available and are based on country reports.	Data are based on forest inventories of varying temporal and geographical scales, or on expert opinion. Data are converted from volume to biomass using general factors from different sources. No standards are in place.	Low to medium confidence depending on the age and scale of the inventory and conversion factors used to convert to biomass.
Compilation of data from plots measured for academic or research interests.	Data available at little to no cost from academic or research literature.	Data are not sampled from the population of interest. No sampling standards are in place. Generally there are too few plots to produce estimates with high precision.	Low confidence.

91. Although carbon stock estimates based on country-specific data (i.e. data collected within the national boundary) and at finer scales (through the delineation of more detailed strata) could qualify as a tier 2 level, it is clear from the information presented in table 7 that the data should have a certain level of quality by adhering to some standards, which have yet to be established. Moreover, some of these data may be subject to many sources of uncertainty and could result in inaccurate estimates with low to medium confidence.

92. For most areas of the tropics, existing data sets are generally insufficient, and so collecting additional field measurements using standard forest carbon inventory methods for each ecosystem type likely to be deforested or degraded will be necessary.

93. The scale of sampling must match the scale of the subject to be measured, in this case the carbon stocks of tropical forests. Data obtained by the direct measurement approach for other research interests, as is commonly used in global estimates of carbon emissions from tropical forests, relies on

measurements from forest plots that are too few, too small, or not randomly sampled from the population of interest, and are often biased in their selection. For example, even though deforestation in Brazil is monitored using remote sensing data at high resolution, a statistically well designed recent inventory of carbon stocks in the Brazilian Amazon[11] is not yet available. The inventory relies mostly on data from research plots that are not systematically distributed over the area.

2. Factors affecting the cost of carbon monitoring on the ground

94. Before initiating a programme to monitor carbon stocks of land cover classes, certain decisions will need to be made concerning the following key questions that directly impact the cost of implementing a monitoring system:

(a) What level of accuracy and precision is to be attained? The higher the targeted accuracy and precision (or lower uncertainty) of estimates of carbon stocks the higher the cost to monitor;

(b) How should forest lands be stratified? Stratification into relatively homogeneous units of land with respect to carbon stocks lowers the cost, as it reduces the number of sample plots;

(c) Which carbon pools should be included? The more carbon pools included the higher the cost;

(d) At what time intervals should carbon stocks in specific areas be monitored over time? The shorter the time interval, the higher the cost and specific areas targeted for REDD implementation activities may require more frequent measurements.

95. For estimation of carbon stocks on the land, there is a need for sampling rather than attempting to measure everything, noting that sampling is the process by which a subset is studied to allow generalizations to be made about the whole population or area of interest (Pearson et al., 2005). The values attained from measuring a sample are an estimation of the equivalent value for the entire area or population. Statistics provide us with some idea of how close the estimation is to reality and therefore the certainty or uncertainty of the estimates.

96. There are three critical statistical concepts to be taken into account to achieve an optimum sampling design:

(a) *Bias* is a systematic distortion often caused by flaws in the measurements or sampling methods;

(b) *Accuracy* is the extent to which sample measurements are close to the actual values. Accuracy is the agreement between the true value and repeated measured observations or estimations of a quantity;

(c) *Precision* is how well a value is defined. In sampling, precision illustrates the level of agreement among repeated measurements of the same quantity. This is represented by how closely grouped the results from the various sampling points or plots are.

97. A popular analogy of the concepts of accuracy and precision is a bull's eye on a target. In this analogy, precision is represented by how closely the darts are grouped and accuracy is represented by how close they are to the centre. As shown in figure 6, the points on target A are close to the centre and are therefore accurate, but they are widely spaced out and therefore are imprecise. On target B, the points are closely grouped and therefore precise. However, they could be biased and they are far from

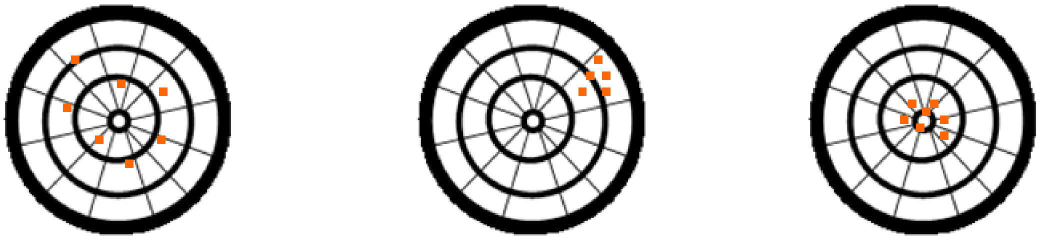
---

[11] In the early 1970s, inventories of the forests of the Brazilian Amazon were carried out under the RADAMBRASIL project but this inventory has not been updated since.

the centre and are therefore inaccurate. Finally, on target C, the points are close to the centre and are closely grouped together, making them both accurate and precise.

Figure 6. Illustration of the concepts of accuracy and precision as they apply to estimates of forest carbon stocks

(A) Accurate but not precise (B) Precise but not accurate (C) Accurate and precise



98. When sampling for carbon, measurements that are both accurate (i.e. close to the reality for the entire population) and precise (closely grouped so the results are highly reliable or have low uncertainty) are needed. Sampling a subset of the land for carbon estimation involves taking measurements in a number of locations or ‘plots’ that are distributed randomly or systematically over the area to avoid any bias in sampling. The average value when all the plots are combined represents the population. A 90 per cent confidence interval, for example, tells us that 90 times out of a 100 the true carbon density lies within this interval. If the interval is small then the result is precise, that is, it has low uncertainty.

99. The accuracy and precision of ground-based measurements depend on the methods employed and the frequency of collection. If there is an insufficient measurement effort, then the results will most likely be imprecise. In addition, estimates can be affected by sampling errors, assessment errors, classification errors in remote sensing imagery and model errors that are carried on to the final estimation.

100. Total monitoring costs are dependent on a number of fixed and variable costs. Costs that vary with the number of samples taken are variable costs, for example, labour is a variable cost because expenditure on labour varies with the number of sample plots required. Fixed costs do not vary with the number of sample plots taken. The total cost of a single measurement event is the sum of variable and fixed costs.

Costs associated with ground-based sampling

101. There are several variable costs associated with ground-based sampling in forest that could include or depend on the following factors:

(a) The amount of labour required, which depends on sampling size;

(b) The level of equipment use and rental;

(c) The level of communication equipment use and rental;

(d) Food and accommodation;

(e) Field supplies for collecting field data;

(f) Transportation and analysis costs of field samples (e.g. drying biomass samples).

102. The variable costs listed in paragraphs 101 (a)–(d) above will vary depending on the number of samples required; the time taken to collect each sample and the time needed to travel from one sample site to another (e.g. costs are affected by the size and spatial distribution of the area), as well as by the number of forest carbon pools required. These are the major factors that are expected to influence overall time taken to carry out sampling. On a national scale, it is likely that travel time between plots

could be as long as or longer than the time required to collect all measurements in a plot. Costs listed in paragraphs 101 (e) – (f) are only dependent on the number of samples required.

103. The cost for deriving estimates of forest carbon stocks based on field measurements and sampling depends on the precision level to be achieved. More plots are needed to attain higher levels of precision and to attain similar precision across the forest area may require more or fewer samples depending on the variability of the carbon stocks in the forest area. A measure of the variability commonly used is the coefficient of variation of the carbon stock estimates. The higher the coefficient of variation the more variable the stocks and the more plots will be needed to achieve the same level of precision. For example, table 8 shows how an increase in the coefficient of variation results in the need for more plots to achieve the same precision level of ±10 per cent of the mean with 95 per cent confidence. The table also shows that the larger the sampling area, the lower the variable cost per ha because larger sampling areas do not necessarily imply that a larger number of plots are needed.

Table 8. Effect of coefficient of variation of carbon stock in trees on variable cost per ha to sample to a precision level of ±10 per cent of the mean with 95 per cent confidence

	Coefficient of Variation (per cent)							
	10		**20**		**30**		**40**	
Area (ha)	Number of plots	Cost USD ha^{-1}	Number of plots	Cost USD ha^{-1}	Number of plots	Cost USD ha^{-1}	Number of plots	Cost USD ha^{-1}
1 000	4	3.28	16	4.40	34	5.54	58	7.78
10 000	4	0.33	16	0.44	35	0.55	62	0.89

Source: Mooney et al. (2004).
Note: Costs are based on the cost of labour and transportation in the United States of America.

104. The main fixed costs identified for monitoring forest carbon stocks are:

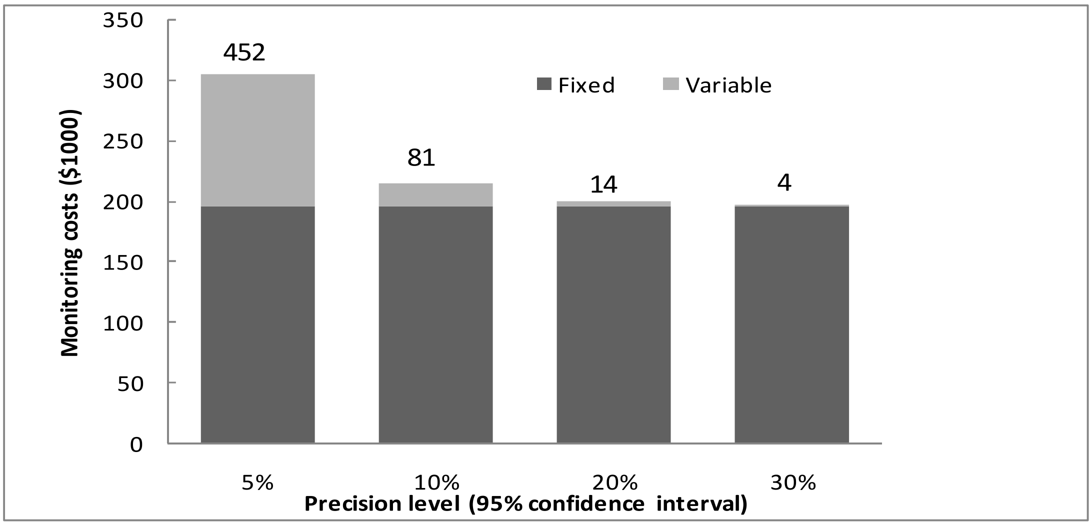
(a) Planning and organization of sampling event, for example mapping and stratifying the area, establishing protocols, staffing, and so on;

(b) Transport from the base location to the field site and back;

(c) Labour cost for sampling and transportation to the monitoring area.

105. Depending on the availability of data, the fixed cost for sampling forest carbon stocks can be high. For example, the fixed costs for one of the earliest pilot carbon projects, the Noel Kempff Climate Action project in Bolivia (a project which reduced emissions by halting deforestation and selective logging), were a significant component of the initial monitoring because a base map had to be produced from remote sensing imagery in order to stratify and design the monitoring system over approximately 640,000 ha. The project area was remote (see figure 7). The variable costs, even to achieve a precision level of ±10 per cent of the mean, were a small fraction of the total costs. If a country already has reliable remote sensing data that can be used for designing the monitoring plan and the area to be monitored is not remote, then the fixed costs could be low and the bulk of the cost would be for the measurements of the sample plots.

Figure 7. Relation between precision level and the fixed and variable costs to monitor



Source: The data are for the Noel Kempff project in Bolivia. (Hardcastle and Baird,. 2008).
Note: The precision level is expressed as 95 per cent confidence interval around the mean of the forest carbon stocks (above-ground biomass, deadwood, litter, understory and soil) in several strata covering about 640,000 ha. The numbers above the bars are the total number of plots that would need to be measured to achieve the given precision level.

Influence of stratification of the forest on the cost of sampling

106. Stratification of forest cover can increase the accuracy and precision of measuring and monitoring in a cost-effective manner (Pearson et al., 2008). Carbon stocks may vary substantially among forest types depending on physical factors (e.g. climate types, precipitation regime, temperature, soil type and topography), biological factors (e.g. tree species composition, stand age and stand density) and anthropogenic factors (e.g. disturbance history and logging intensity).

107. Associating a given area of deforestation with a specific carbon stock relevant to the location that is deforested or degraded will result in more accurate and precise estimates of carbon emissions. The GOFC-GOLD Sourcebook (Pearson et al., 2008) provides helpful guidance, for example on how a country's forest area can be stratified in order to produce cost-effective, accurate and precise estimates of carbon stocks in forests under threat of deforestation.

108. Some indicative information can be drawn on from projects to illustrate the effect of stratifying an area by the cost of monitoring carbon stocks. For example, the 640,000 ha of the Noel Kempff project were originally stratified into five main forest strata resulting in the need for 81 plots in order to achieve a 95 per cent confidence level of ±10 per cent of the mean forest carbon stocks (see figure 7). Combining the data into one stratum resulted in a higher overall coefficient of variation and resulted in the need to establish 117 plots in order to achieve the same precision level or almost half as many plots as originally measured and an increase in variable costs (from about USD 19,000 to USD 28,000).

109. There is a trade-off between the number of strata and sampling intensity in order to achieve a balance between the number of strata identified and the total number of plots needed to adequately sample each stratum. There is no hard and fast rule and a country would need to use expert judgement when deciding on the number of strata to include in their carbon inventory. With knowledge of some basic data, such as the average carbon stock and coefficient of variation for the forest strata, standard

statistical procedures or tools can be used to estimate the number of plots that need to be monitored to achieve a given precision level.[12]

110. In conclusion, stratification, which helps to optimize the number of sampling plots needed, can increase precision and accuracy, and reduces the cost of ground-based monitoring operations.

3. Cost of national scale monitoring

111. Little information is available on the cost of forest carbon monitoring systems at national level. Some indicative data are available in a recent report by Hardcastle and Baird (2008) that assesses the capacity needed to establish a forest carbon monitoring system and the cost to establish such a system for 25 countries in Asia, Africa, and Central and South America. The assessment suggests that many countries have significant capacity in remote sensing but capacity in forest carbon inventories is generally low and very few countries have the capacity to estimate forest carbon stocks beyond IPCC tier 1 level. Cost estimates for these countries depend on an assessment of the existing capacity and the extent of a country's forests (see table 9).

112. In the analysis by Hardcastle and Baird (2008), cost is based on the use of two approaches for stratifying the forest area and on the cost to achieve either IPCC tier 2 or 3 levels. The GOFC-GOLD Sourcebook (Pearson et al., 2008) describes two approaches to stratification, depending on whether a country has produced an accurate land cover map or not. In table 9, approach A uses an existing land cover map to identify different sampling strata and implies that only one sampling event is needed, while approach B suggests a strategy to follow when no land cover map is available. Activity data are assembled during a monitoring iteration, and then carbon measurements are only taken in the locations where change has been identified. Nearby pixels with similar reflectance profiles to the target pixels before the change are monitored to provide a reference carbon stocking level. Use of approach B means there are recurring costs in line with the amount of deforestation that is occurring. Approach A involves a large, one-off effort at the start of the monitoring programme, whereas approach B involves a smaller effort, but this effort has to be repeated for each monitoring iteration. For tier 3, only the use of approach A is assessed so that the first year cost is the same as tier 2. Tier 3 measurements require annual re-measurements made in permanent sample plots. However, it would not be necessary to re-sample at full intensity. Hardcastle and Baird (2008) suggested that permanent monitoring of about one third of the original sample locations would be sufficient to monitor changes in carbon stocks in each stratum over time. This reduction in effort would also be justified because over time some strata will be seen to have very stable carbon stocks (e.g. mature, undisturbed forest) and will require minimal re-sampling.

---

[12] A calculator can be found at <www.winrock.org/Ecosystems/files/Winrock_Sampling_Calculator.xls>. Although this calculator was originally developed for project scale, it can be used for any scale.

Table 9. Approximate total cost estimates for implementing forest carbon monitoring systems in 25 developing countries
(thousands of United States Dollars)

Country	Forest area (ha)	Carbon inventory costs					
		IPCC tier 2 approach		IPCC tier 3 approach A			
				Ignore degradation		Include degradation	
		Approach A (one-off)	Approach B (recurring)	First year	Recurring	First year	Recurring
Bolivia	58 740	859	212	859	287	998	333
Brazil	477 698	7 728	1 906	7 728	2 587	8 986	2 995
Colombia	60 728	1 030	254	1 030	345	1 198	399
Costa Rica	2 391	287	71	287	95	333	110
Guyana	15 104	287	71	287	95	333	112
Mexico	64 238	0	0	126	126	144	144
Peru	68 742	1 203	297	1 203	402	1 398	466
Bolivarian Republic of Venezuela	47 713	859	212	859	287	998	333
Cambodia	10 447	287	71	287	95	333	110
China	197 290	0	0	0	0	0	0
India	67 701	0	0	0	0	0	0
Indonesia	88 495	1 717	424	1 717	575	1 997	666
Malaysia	20 890	343	85	343	115	399	133
Myanmar	32 222	287	71	287	97	333	110
Papua New Guinea	29 437	516	127	516	172	599	200
Thailand	14 520	287	71	287	95	333	110
Viet Nam	12 931	142	71	142	95	477	110
Cameroon	21 245	0	0	54	54	133	133
Congo	22 471	215	106	215	144	284	166
Democratic Republic of the Congo	133 610	2 318	572	2 318	776	2 696	899
Equatorial Guinea	1 632	287	71	287	95	333	110
Gabon	21 775	431	106	431	144	499	166
Ghana	5 517	454	113	454	136	499	159
Liberia	3 154	287	71	287	95	333	110
Sierra Leone	2 754	287	71	287	95	333	110

Source: Hardcastle and Baird (2008).
Note: The cost estimates quoted in the original table were in pounds sterling. These cost estimates in pounds sterling have been converted to United States dollars. The exchange rate used (USD 1 = GBP 0.661) is the United Nations operational rate of exchange of 15 May 2009.

113. Hardcastle and Baird (2008) developed a reference scenario of the cost to develop and implement a carbon monitoring system for a medium-sized country, starting with zero technical capacity and including no internal GIS/remote sensing and forest carbon monitoring capability. The costs given for the countries in table 9 are derived from comparing existing capacity and forest extent with this reference scenario.

114. Indicative costs for this reference scenario are based on a country with 50 million ha of forest, the use of approach A (an existing land cover map exists, which is common in many tropical countries)

for stratification, and a tier 2 level. Hardcastle and Baird (2008) assumed that 300 sampling locations would be needed to meet the targeted accuracy and precision level and cover the strata present in the country. They further assumed that it would take 19 person days to sample a single location based on preparation time, planning, contact and interviews with locals, travelling to the sampling location, taking field measurements, and conducting data input and analysis. Thus, the total time to sample the 300 plots is 5,700 person days, and depending on level of skill (of field crew and supervisors) the total variable cost would be 360,000 pounds sterling (USD 544,630).[13] Additional fixed costs, including three vehicles for the duration of the measurement programme, laboratory costs for any sample analysis (e.g. drying sub-samples of plant material), field equipment and external consultants (for training, planning and verification) would amount to GBP 207,500 (USD 313,918). The grand total was GBP 567,000 (USD 857,791).

115. Based on extensive field experience in the Noel Kempff project (see figure 7) and a similar project in Belize (The Nature Conservancy's Rio Bravo project), several of these costs calculated by Hardcastle and Baird (2008) appear to be high. For these two projects, field measurements for one plot are estimated to be about four person hours or half a working day (involving a team of four people, including supervision, measuring all trees down to 5 cm diameter and sampling for deadwood, litter and non-tree vegetation) compared to the estimate of four person days for a plot given in Hardcastle and Baird (2008). A reduction from 19 person days proposed by Hardcastle and Baird (2008) to about 10 person days estimated here would reduce the variable cost to about GBP 190,000 (USD 287,443). Assuming similar fixed costs, the total cost would be about GBP 397,500 (USD 601,362). These lower estimated variable costs for pilot projects indicate that the cost in table 9 may be high and could be reduced by about 30 per cent.

116. The FAO recently published a paper on the indicative cost and time required to implement a national forest monitoring and assessment programme in four developing countries (Zambia was included in the analysis, but the cost estimate was for an integrated land-use assessment) (FAO, 2008). The goal of the FAO programme was to assist developing countries in building their national capacities to design, plan and implement national forest inventories (including indicators such as areas of main forest classes, volume and biomass) and to manage the generated information and disseminate it to decision makers. In table 10, only the cost of the field monitoring component is provided.

117. These indicative costs for fieldwork are based on collecting data from 156 to 371 inventory tracts. The fieldwork, on average, spans about 26 months and engages about 43 people. On average, 56 per cent of the total fieldwork time was spent collecting data through measurements and interviews (variable costs), while 44 per cent was spent on planning and transportation to the sample site (fixed costs).

118. The FAO analysis reported that in terms of cost, fieldwork was the costliest activity, varying from 22 per cent to 34 per cent of the total budget depending on the country (see table 10). The share of the measurement component of the fieldwork was between 22 per cent and 35 per cent. There are many factors that influence the time spent in collecting the field data in the plots including the quality and size of the field teams, the density of the forest vegetation and the geomorphology of the land. The quality of the field teams affects the efficiency of work, for example unskilled field team members tend to spend more time collecting data in the plots and large teams can be difficult to manage in the field.

[13] The cost estimate in paragraphs 113–114 were originally quoted in GBP and have been converted to USD. The exchange rate used (1 USD = GBP 0.661) is the United Nations operational rate of exchange of 15 May 2009.

Table 10. Cost of main activities related to the field component of a national forest monitoring programme

Items	National forest monitoring and assessment				
	Honduras (156 IT)	Nicaragua (371 IT)	Bangladesh (296 IT)	Cameroon (206 IT)	Average (257 IT)
Total cost of fieldwork	USD 118 204	USD 273 016	USD 115 000	USD 185 105	**USD 205 714**
Fieldwork/total project budget (%)	23.3	25.6	22.1	34.4	**25.4**
Measurement/fieldwork (%)	34.8	30.6	26.1	22.2	**27.4**
Measurements/total project budget (%)	8.1	7.8	5.8	7.6	**7.0**
International technical assistance (%)	29.3	13.3	38.5	13.8	**23.1**
Supervision by national consultants (%)	19.0	14.0	1.0	5.1	**8.1**
Equipment (%)	1.5	7.9	10.0	16.1	**7.8**
Preparation and management (%)	7.2	8.5	6.7	15.3	**8.1**

Source: FAO (2008).
Abbreviation: IT = inventory tracts.

F. Spatial data infrastructure, access and reporting procedures

119. A centralized spatial data infrastructure should be established to gather, store, archive and analyse all of the data required for national reporting. This requires resources in order to establish and maintain a centralized database and information system that integrates all of the information required for monitoring REDD activities and the associated carbon stock changes. There is a need to establish a data infrastructure, including information technology (e.g. suitable hardware/software) and for human resources in order to generate, manipulate, apply and interpret the data, as well as for capability to undertake reporting using the UNFCCC reporting guidelines and to meet other international reporting obligations. Procedures for accessing spatially explicit data and information in a transparent form should also be considered.

V. The national forest monitoring system of India: a case study

120. The forest monitoring system in India has evolved over time. A comprehensive forest inventory on a relatively large scale began in 1965, using a statistically robust approach and aerial photographs when a project at the national level called the Pre-Investment Survey of Forest Resources started with support from the United Nations Development Programme and FAO. The focus of the survey was on assessing wood resources in forests of the country that are less well explored for establishing wood-based industries. This project was subsequently reorganized into a national forest monitoring system. The data provided for the case study are realistic cost data.

121. The operational cost of monitoring the forests and forest carbon in India is presented here as the current price per unit area for forest cover and forest change assessment, and per sample plot in the case of the forest inventory. The extra cost required to estimate carbon stocks is included.

A. Institutional framework

122. National forest monitoring in India, established in 1981, is carried out through the Forest Survey of India (FSI), under the Ministry of Environment and Forests. Most of the professional staff responsible for the planning, designing and quality control of remote sensing and field inventory data work at the headquarters in Dehradun. They work on a permanent basis or on 4–5 year fixed-term contracts and have formal professional qualifications and experience of fieldwork, remote sensing and statistics. Some have more than 30 years of practical experience. The estimated cost of establishing such an institute is about USD 4 million.

123. The national Geomatics Centre of the FSI is responsible for the remote sensing component that assesses forest cover and changes in the country on a two-year cycle. The data processing and analysis unit for the national forest inventory is located at the FSI headquarters. In addition, four zonal offices located in different parts of the country have a defined area of operation that when taken together covers the entire country. These offices undertake the field inventory, laying out sample plots in forests and non-forest areas, taking measurements and conducting other surveys. The cost of these components has been included in the operational cost of these respective activities.

B. Capacity-building

124. There are many levels of training course in India for building capacity in the field of remote sensing. The Indian Institute of Remote Sensing (IIRS) under the Department of Space offers the following three types of course: (i) the diploma course, which lasts 9 months; (ii) the Master of Science course, which lasts one and a half years; and (iii) the certificate course, which lasts 3 months.

125. FSI offers about ten short courses a year in the application of remote sensing, and GIS and GPS in forest surveys, each lasting one to two weeks. The estimated costs of capacity-building for a three-month course on geomatics in forestry within the country is USD 4,500 for professionals and USD 3,000 for technicians. FSI also offers two short courses a year on forest inventories that last one to two weeks , mainly for technicians. In the past, FSI offered international courses on forest inventories lasting six weeks for forestry professionals in Asia-Pacific countries. At FSI, the cost of a three-month course on forest inventories would be similar to that of a course on geomatics in forestry.

126. FSI has two well qualified statisticians who are skilled in designing the inventory, developing inventory manuals and data entry modules, and continuously supervising the data processing and analysis and accuracy assessments.

C. Forest monitoring operations

127. Forest monitoring for measuring change in forest area due to deforestation or afforestation, and estimation of growing stocks of wood are carried out using the following two independent operations at FSI: (i) assessing forest cover and change through remote sensing technology using a wall-to-wall approach on a two-year cycle; and (ii) undertaking national forest inventories by laying out sample plots following a systematic sampling design to measure growing stock.

Forest cover and change assessment

128. In India, the forest cover and change assessment at national level using satellite imagery started in the early 1980s. In 1987 the forest cover of the country was assessed for the first time. In this assessment, Landsat data of 80 m resolution was visually interpreted on a 1:1 million scale. Since 2001 (the eighth cycle of the inventory), satellite data of 23.5 m resolution have been digitally interpreted on a 1:50,000 scale, allowing for a more objective and accurate assessment of the area changes. Patches of forests up to 1 ha are now being assessed. To date, the country's forest cover has been assessed 10 times

and reports on this matter have been published (FSI, 2007). The eleventh cycle of the assessment will be completed in 2009.

129. The entire process of assessment starting from procurement of satellite imagery (all IRS data from the Department of Space), georectification, interpretation and ground validation takes almost two years using the services of approximately 25 technicians. Three professionals supervise and monitor these activities, which can take up to almost 70 per cent of their time. Each technician is provided with a workstation and the latest software (ERDAS imagine version 9.2). In all, 393 satellite scenes cover the entire country. The current cost for domestic use of one scene using IRS P-6 LISS III (resolution 23.5 m) is 7000 Indian rupees, which is equivalent to USD 140. This cost has been reduced by the Department of Space in the last few years. The cost is higher for users outside of India.[14]

130. In table 11, the average cost of assessing forest cover and changes on a per unit area basis is reported to be to the order of USD 0.60 per km^2. The cost per unit is derived from the total forest cover of the country, which is estimated at 677,088 km^2.

Table 11. Cost of measuring forest cover and changes using satellite imagery in India

Components	**Cost per 100 km^2 (USD)**	**%**
Human resources (cost of data interpretation by technicians, supervision and checking by professionals and ground truthing)	38.5	64.0
Cost of satellite data (IRS –P6- LISS III of 23.5 x 23.5 m) (see note on satellite scenes at the bottom of the table)	6.5	11.0
Equipment (cost of hardware/software with assumed life of 5 years plus day-to-day maintenance, air conditioning plant, network, etc.)	15.0	25.0
Total	60.0	100

Note: Exchange rate used is 1 USD = 50 Indian Rupees. In total, 393 satellite scenes using IRS P-6 LISS III cover the entire country. The area under each scene is about 20,000 km^2.

131. In the assessment of forest cover, the following three classes are defined based on the canopy densities: (i) very dense forests (more than 70 per cent density); (ii) moderately dense forests (density between 40 to 70 per cent); and (iii) open forests (density between 10 to 40 per cent). When density is between 0 to 10 per cent, this is known as scrub and is included as non-forest. The change analysis is carried out using the results of the preceding cycle where the shift of area from one to other class within forests, as well as between forests to non-forests, is determined and presented in a change matrix table.

132. Accuracy assessment is an integral part of the study. Error in forest cover classification creeps in because of inaccurate interpretation or because of an error in the remote sensing systems and other distortions. The level of accuracy is determined by comparing a large number of locations selected randomly or sampling units of the classified imagery with ground data, for example for the 2005 assessment about 4,200 sampling points were compared with ground data collected during the forest inventory.

National forest inventory

133. The large scale ground-based inventory based on statistically sound principles started in 1965, and a new forest inventory design to estimate the country’s growing stock of wood on a two-year cycle was launched in 2002. The new National Forest Inventory (NFI) includes 14 physiographic zones (FSI, 2002) for the country.

[14] The Department of Space charges different rates for different uses of satellite data. Any satellite data purchased by a foreign agency costs more. More information is available at: <www.antrix.gov.in>.

134. The current NFI includes sampling in sixty districts, representing 10 per cent of the total number of districts in the country, which are randomly selected from the physiographic zones and are proportional to size. Inventories in these districts are undertaken and completed in two years to coincide with the forest cover assessment. A systematic sampling approach is used to undertake the inventory. For each district selected, FSI topographic sheets of 1:50,000 (15 minute longitude x 15 minute latitude) scale are divided into 36 grids of 2½ minute longitude x 2½ minute latitude. The area of one grid cell is approximately 17.5 km^2. Further, each grid is divided into four sub-grids of 1¼ minute x 1¼ minute, forming the basic sampling frame. Two of these sub-grids are then randomly selected to lay the sample plots. The intersections of the diagonals of the sub-grids are marked as the centre of the plot at which a rectangular sample plot of 0.1 ha in area is laid out in order to undertake the field inventory.

135. After analysing the data, estimates of growing stock, diameter and species distribution generated first at the level of the physiographic zone and then at the national level are generated on a two-year cycle. The estimates in subsequent two-year cycles improve through the integration of data from the previous cycle(s). The first approximation of the total growing stock of the county's forests in 2003 was carried out using the inventory data collected during 2002–2003 from 60 districts. Based on ongoing field inventory work, the data from an additional 60 districts inventoried during 2004–2005 were also analysed, which gave the second approximation and an improved estimate of growing stock based on 120 districts in 2005 (FSI, 2007). The two estimates, however, cannot be compared when calculating the change in the growing stock of woody biomass.

136. The present inventory design allows for about 7,000 sample plots representing different physiographic zones in the 60 selected districts to be laid and inventoried in two years. The field operations of NFI are carried out by the four zonal offices of the FSI. About 20 field teams (comprising one technician as the team leader, two skilled workers and two unskilled workers) carry out the field inventory. Fieldwork takes place over eight months of the year, while during the four rainy months the field teams carry out data checking and data entry at the zonal offices.

137. In addition to measurements of tree diameter and height (all trees above 10 cm in diameter), samples of soil and litter (only humus) are also collected in the sample plots for estimating carbon. For collecting data on humus and soil carbon, two sub-plots of the size 1 m x 1 m within the main plot are laid. The humus and litter is first swept and weighed and a portion of it is kept for carbon analysis. In addition, at the centre of the sub-plots a pit (30 cm) is dug and a composite sample of soil of 200 g is kept for carbon analysis. Other observations recorded include regeneration status, presence of herbs and shrubs, and incidence of grazing and fire.

138. To estimate the volume of standing trees, FSI has developed volume equations for several hundred tree species growing in different regions of the country (FSI, 1996). These equations are used to estimate the wood volume of the sample plots. Trees below 10 cm diameter at breast height (dbh) are not considered. The aboveground biomass of other living plants (herbs and shrubs) is also not measured. The cost of various components of forest inventory on a per sample plot basis is presented in table 12.

Table 12. Cost per sample plot for various components under the National Forest Inventory

Components	Cost per plot (USD)	%
Development of methodology, data entry modules and data processing software (professional human resources)	9	5.7
Equipments (vehicle, measuring and camping equipment and hardware and software)	24	15.2
Fieldwork (includes cost of transportation and human resources)	88	55.7
Field supervision and validation (includes cost of transportation and human resources)	13	8.2
Data entry and data verification (human resources costs)	15	9.5
Data processing	7	4.4
Analysis and report writing	2	1.3
Total	**158**	**100**

D. Estimating changes in forest carbon stock for India's second national communication

139. As part of the preparations for India's second national communication, FSI is estimating the changes in forest carbon stocks in all five carbon pools and the associated CO_2 emissions and removals from the land-use categories of forest land remaining forest land and land converted to forest land for the period 1995–2005. For the purpose of this exercise data on forest cover is being integrated with the national forest inventory data. Since forest type and forest density are the two most important factors determining the biomass of a forest, the forest land of the country was stratified by these two variables. The interpreted forest cover data in three density classes which are already available from FSI will be overlaid with forest types maps,[15] as both are in GIS format and on a 1:50,000 scale. This will lead to the stratification of the country's forests into at least 30 to 40 strata.

140. At present, field inventory data that have been collected over the previous six years are available from the NFI. These sample plots are randomly distributed in the above mentioned 30 to 40 strata. The sample plot data falling into a specific stratum are aggregated and analysed to generate woody biomass and carbon content (including soil carbon) factors for the said stratum. To estimate the growing stock at national level, FSI has created a country-wide spatial database in GIS comprising more than 50,000 polygons each of the size 2½ minute × 2½ minute with an approximate area of 17.5 km^2. Each polygon in the vector coverage will be attached with attribute data on forest canopy density with forest type strata, along with the ancillary data, and average altitude, rainfall, temperature, and soil stratum. Using the specific volume factors of the strata and the respective forest area within the polygon, growing stock of each polygon will be estimated. The carbon stock of each forest in the country for a given time can be estimated by the synthesis of forest cover with the growing stock using volume estimates for all the forested grids. The estimation of change in carbon stocks from forest land remaining forest land will be carried out using forest cover layers of the country for two time periods, 1995 and 2005, within a GIS framework. A similar exercise will be repeated for land converted to forest land.

141. This exercise of forest type mapping uses the existing data and outputs of FSI, which includes forest cover maps for both periods, and NFI data and estimates. Therefore, the cost incurred is mainly for analysing the changes in forest cover, statistical analysis and other desk work. The total cost has been estimated to be approximately USD 40,000, which works out to be about USD 6 per 100 km^2.

[15] This exercise of forest type mapping by FSI is almost complete for India's forests.

Estimation of missing components of the forest biomass

142. The current forest inventory does not measure the total biomass of the trees or the biomass of herbs and shrubs, and deadwood. Therefore, a separate exercise has been undertaken to estimate the biomass of these missing components.

143. This exercise involves the following two main components, which both involve destructive sampling:

(a) One component is the measurement of individual trees in order to estimate the volume of trees below 10 cm dbh and volume of branch below 5 cm and stem wood below 10 cm for trees above 10 cm dbh. Only about 20 important tree species in each physiographic zone are covered in this exercise. In all, 100 tree species are covered. The trees and their branches will be cut and weighed in a specified manner to measure the biomass. New biomass equations will be developed for the trees species below 10 cm dbh. For trees above 10 cm dbh the additional biomass measured in this exercise will be added to the biomass of tree species of corresponding dbh whose volume and biomass have already been estimated as part of the NFI.

(b) The other component is laying out of sample plots for measuring volume of deadwood, herbs and shrubs, climbers and litter. Due to the limited time available only a minimum number of sample plots are laid, that is, one district from each physiographic zone. While selecting districts (already inventoried under NFI) due care is taken to ensure that all major forest types (species) and canopy densities are properly represented. About 100 sample points are laid in each district. At national scale there will be about 1,400 sample points. The geo-coordinates of selected points in each district are sent to field teams to carry out the fieldwork. In a stratum based on type and density about 15 sample plots are selected which gives a permissible error of 30 per cent. At each sample there are three concentric plots of sizes 5 m x 5 m for deadwood, 3m x 3m for shrubs, climbers and litter, and 1m x 1m for herbs (FSI, 2008). The deadwood collected from the sample plots are weighed in the field. Green weight of the shrubs, climbers and herbs cut from the ground is also taken and is later converted into dry weight by using suitable conversion factors for different species.

144. This exercise supplemented by the exercise on estimating changes in forest carbon stocks and with the available data from the NFI provide accurate estimates for the following four carbon pools: (i) total above-ground biomass, (ii) deadwood biomass, (iii) litter biomass, and (iv) soil organic carbon. The IPCC default values will be used to estimate the belowground biomass until a new exercise is undertaken to improve these estimates.

145. The additional cost for estimating the missing components of biomass has been worked out to be about USD 52 per plot. The cost could be substantially reduced if the exercise on additional measurements is combined with the NFI. Moreover, the biomass equations developed for trees below 10 cm dbh and those above 10 cm is a one-off exercise. There will be no cost for this when conducting future inventories. The new methodology developed for measuring missing components of forest biomass will be integrated into the NFI to monitor forest carbon through field inventories, which could eventually be integrated into the broader remote sensing methodology module.

E. Opportunities for regional cooperation

146. India's long experience of conducting forest inventories and operating a well established system of forest monitoring offers a great opportunity for regional cooperation. In the past, FSI conducted the forest inventory of Bhutan and offered many courses in capacity-building on forest inventories and data processing to countries in Asia.

Annex I

References

Achard F., Grassi G., Herold M., Teobaldelli M. and Mollicone D. 2008. *The use of satellite remote sensing in the LULUCF sector.* GOFC-GOLD Report Series 33. Available at <www.fao.org/gtos/gofc-gold/series.html>.

Brady M. and Naydenov E. 2007. *Report on the Fourth Meeting of the GOFC-GOLD Regional Networks.* GOFC-GOLD Report Series 29. Available at <www.fao.org/gtos/gofc-gold/series.html>.

Brown S. 1997. *Estimating biomass and biomass change of tropical forests: A primer*. FAO Forestry Paper 134, Rome: Food and Agriculture Organization of the United Nations.

Brown S., Iverson L.R., Prasad A. and Liu D. 1993. Geographic distribution of carbon in biomass and soils of tropical Asian forests. *Geocarto International.* 8(4): pp 45–59.

Câmara G., Cartaxo R., Moura U. and Garrido J. 1996. Integrating remote sensing and GIS by object-oriented data modelling*. Computer & Graphics*. 20(3): 395–403.

Cienciala E., Tomppo E., Snorrason A., Broadmeadow M., Colin A., Dunger K., Exnerova Z., Lasserre B., Petersson H., Priwitzer T., Sanchez G. and Ståhl G. 2008. Preparing emission reporting from forests: Use of national forest inventories in European countries. *Silva Fennica*. 42(1): pp 73–88.

FAO. 2005. *Global Forest Resources Assessment 2005.* Available at: <www.fao.org/forestry/fra2005>.

FAO. 2008. *NFMA approach and process: an analysis of Cost and Time.* National Forest Monitoring and Assessment Working Paper NFMA 39. Rome: Food and Agriculture Organization of the United Nations.

Forest Survey of India (FSI). 1996. *Volume equations for forests of India, Nepal and Bhutan*. Dehradun: Forest Survey of India.

FSI. 2002. *A manual for national forest inventory of India* (unpublished manual). Dehradun: Forest Survey of India.

FSI. 2007. *State of forest report*, *2005.* Dehradun: Forest Survey of India.

FSI. 2008. *A manual for measuring missing components of forest biomass in India* (unpublished manual), Dehradun: Forest Survey of India.

Gaston G., Brown S., Lorenzini M. and Singh K.D. 1998. State and change in carbon pools in the forests of tropical Africa. *Global Change Biology* 4: pp 97–114.

GOFC-GOLD. 2008. *Reducing greenhouse gas emissions from deforestation and degradation in developing countries: a sourcebook of methods and procedures for monitoring, measuring and reporting.* GOFC-GOLD Report version COP13-2. Alberta: Natural Resources Canada.

Grassi G., Monni S., Federici S., Achard F., Mollicone D. 2008. *Applying the conservativeness principle to REDD to deal with the uncertainties of the estaimates*. Environmental Research Letters, 3: 1-12.

Hardcastle P.D., and Baird D. 2008. *Capability and cost assessment of the major forest nations to measure and monitor their forest carbon for Office of Climate Change.* Penicuick: LTS International.

Hoare A., Legge T., Nussbaum R. and Saunders J. 2008. *Estimating the cost of building capacity in rainforest nations to allow them to participate in a global REDD mechanism.* Report for the Eliasch Review produced by Chatham House and ProForest with ODI and EcoSecurities. Available at <http://www.occ.gov.uk/publications/index.htm>.

Holmgren P., Marklund L-G., Saket M. and Wilkie M.L. 2007. *Forest Monitoring and Assessment for Climate Change Reporting: Partnerships, Capacity Building and Delivery*. Forest Resources Assessment Working Paper 142. Rome: Food and Agriculture Organization of the United Nations.

Intergovernmental Panel on Climate Change. 1996. *Revised Guidelines for national greenhouse gas inventories.* Available at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html>.

Intergovernmental Panel on Climate Change. 2003. *Good practice guidance for land use, land use change and forestry*. Available at <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>.

Mollicone D., Achard F., Eva H.D., Belward A.S., Federici S., Lumicisi A., Rizzo V.C., Stibig H.J. and Valentini R. 2003. *Land Use Change Monitoring in the framework of the UNFCCCC and its Kyoto Protocol: Report on Current Capabilities of Satellite Remote Sensing Technology*. EUR 20867 EN. p. 48. Luxembourg: European Communities.

Moreira, J.C., Mello E.M.K., Valeriano D.M., Shimabukuro Y.E., Duarte V., Souza I.M., Barbosa C.C.F. and Souza R.C.M. 2004. *Monitoring the Brazilian Amazon deforestation*. In: Simposio Latinoamericano en percepción remota y sistemas de informacion espacia, 11. Santiago, Chile. Available at <http://urlib.net/sid.inpe.br/Sergio/2005/02.17.13.57>.

Mooney S., Brown S. and Shoch D. 2004. *Measurement and monitoring costs: influence of parcel contiguity, carbon variability, project size and timing of measurement events*. Report to The Nature Conservancy, Conservation Partnership Agreement. Available at <http://www.winrock.org/ecosystems/files/Mooney_et_al_MMCosts-1-15-04.pdf>.

Pagiola S. and Bosquet B. 2009. *Estimating the Costs of REDD at the Country Level.* Forest Carbon Partnership Facility, World Bank. Munich Personal RePEc Archive (MPRA) Paper No. 13726. Available at <http://mpra.ub.uni-muenchen.de/13726/1/MPRA_paper_13726.pdf>.

Pearson T., Harris N., Shoch D., Pandey D. and Brown S. 2008. *Estimation of Carbon Stocks*. *In*: GOFC-GOLD. *Reducing greenhouse gas emissions from deforestation and degradation in developing countries: a sourcebook of methods and procedures for monitoring, measuring and reporting.* GOFC-GOLD Report version COP13-2. Alberta: Natural Resources Canada.

Pearson T., Walker S. and Brown S. 2005. *Source Book for LULUCF Projects.* Available at: <http://www.winrock.org/ecosystems/files/Winrock-BioCarbon_Fund_Sourcebook-compressed.pdf>.

Annex II

List of acronyms

ALOS	Advanced Land Observing Satellite
ASAR	Advanced Synthetic Aperture Radar
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AWiFs	Advanced Wide Field Sensor
CBERS	China-Brazil Earth Resources Satellite Program
DETER	Real Time Deforestation Detection System for Brazil
DMC	Disaster Monitoring Constellation
ENVISAT	Environmental Satellite
ERDAS	Raster graphics editor and remote sensing application
ERS	European Remote Sensing Satellite
ETM+	Enhanced Thematic Mapper
HRCCD	High Resolution Charge-coupled Device Camera
HRV	High Resolution Visible
HRVIR	High Resolution Visible and Infra-Red
IKONOS	high resolution commercial earth observation satellite
IRS	Indian Remote Sensing Satellite
JAXA	Japan Aerospace Exploration Agency
LiDAR	Light detection and ranging
LISS-III	Linear Imaging Self-Scanning System III
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate-resolution Imaging Spectroradiometer
MSS	Multispectral Scanner
PALSAR	Phased Array type L-band Synthetic Aperture Radar
QuickBird	high-resolution commercial earth observation satellite
R-PIN	Readiness Plan Idea Notes
SAR	Synthetic Aperture Radar
SPOT	Satellite Pour l'Observation de la Terre
SPRING	Processing of Georeferenced Information System
TM	Thematic Mapper

- - - - -