Assessing Options for Measurement of Verifiable Changes in Carbon Stocks from Reforestation, Afforestation, and Deforestation and Other Potential Forestry Activities

National Sinks Issues Table
Environment Canada

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Preface

In December 1997, the Parties to the 1992 United Nations Framework Convention on Climate Change adopted a Protocol to the Convention (the Kyoto Protocol) to limit emissions of six greenhouse gases. Canada accepted a target of 6 percent below its 1990 level of emissions.

As part of the National Climate Change Process to investigate how to achieve this target the Sinks Table has undertaken a work program related to carbon sequestration and sinks. This work is one part of the Sinks Table's mandate. The Table will prepare an Options Report that includes a discussion of carbon sequestration. The Options Report is scheduled for completion in the late spring of 1999.

This paper was commissioned by the Sinks Table as background to assist in the production of its Options Report. The Table welcomes comments on this paper or other work that it has commissioned.

The views expressed in this paper are not necessarily those of the Government of Canada, the Sink Table or the organizations and individuals on the Table.

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Executive Summary

This report assesses the options to meet the requirements for verifiable reporting of changes in carbon stocks from reforestation, afforestation, and deforestation and other potential forestry activities in Canada. The report reviews the data needs resulting from the reporting requirements, discusses some of the available methods to obtain these data, and then outlines the design and features of a national C reporting system. The reports concludes that the national reporting requirements can be met through a nationally co-ordinated program designed to provide the framework for synthesis and integration of information compiled from a diversity of sources and processed using a variety of methods and models. Because of the wide range of approaches to data acquisition and modelling of C stock changes in forest ecosystems, it does not seem advisable at this time to recommend a single approach. Instead, we suggest putting in place and supporting a system that provides the framework for the co-ordination of data acquisition, storage and analysis.

Industry, provincial resource management agencies, the Federal Government, and universities can then all use this general framework. Each user group can apply the tools for their regional analyses, using the data acquisition methods and inventories that are appropriate for their region. This will allow some users to build on detailed inventory information available for their forest management areas, while other users can use different methods and less detailed inventory information, e.g. for some remote northern areas with low productivity forests. The role of the reporting framework is to ensure that the results from the different user groups and for different regions are summarised in a spatially-referenced database system. This information can then be synthesised to meet the various reporting requirements.

Data Needs

The reporting requirements under the Kyoto Protocol and the UN FCCC establish a need for a national-scale reporting system that provides information on the following indicators:

1. for reforestation, afforestation, deforestation, and any other activities that may subsequently be approved:
   i) the area affected by each activity since 1990, and
   ii) either:
      a) the C stock (including aboveground biomass, belowground biomass, and soil C) on this area at the beginning and at the end of each commitment period; or
      b) the rate of change in C stock (including aboveground biomass, belowground biomass, and soil C) on this area during each commitment period.
2. the C stocks in 1990 and estimates of changes in subsequent years.
3. the annual anthropogenic greenhouse gas emissions by sources and removals by sinks from land use change and forestry in the "managed" forest.

Requirements 1 and 2 result from the Kyoto Protocol (Articles 3.3. and 3.4). Requirement 3 results from the FCCC and is not altered by the Kyoto Protocol. Because of the growing international scientific interest in the role of boreal forest ecosystems in the global C cycle, the reporting system should also be able to deliver information about the C stock changes in the total forest area of Canada.

The exact definitions of reforestation, afforestation and deforestation (RAD) activities under the Kyoto Protocol have not been negotiated. The outcome of the negotiations will have a large impact on the area of the so-called “Kyoto Forest”. It is comprised of the area on which those direct human activities have occurred since 1990 that will establish a requirement to report the C stock change during the 5-year commitment periods, starting in 2008. It can be anticipated that both afforestation and deforestation activities will be reported under the Protocol. Uncertainty remains, however, about the definition of reforestation, which may either include or exclude the establishment of a forest following harvest. In Canada, about 1,000,000 ha are harvested annually and including reforestation following harvesting would therefore result in a much larger area with reporting requirements under the Kyoto Protocol. Note that the Kyoto Forest will include some areas that have been deforested since 1990 and may now be in a different land-use category.

The data needs for reporting of C stock changes will also be affected by the negotiated definitions of direct human-induced activities, because to qualify for inclusion in the Kyoto Forest an area must have been affected by such activities. Thus observations on changes in forest cover must be supplemented by information on the cause of the observed change in order to determine whether the area will be included in the Kyoto Forest.

Finally, data needs will also be affected by the negotiated definition of the C pools that will be included in the reporting under the Kyoto Protocol. The data needs and the difficulty of obtaining the data increases from aboveground biomass, to belowground biomass, to dead organic matter pools.

The UN FCCC calls for reporting of net C fluxes in the “managed” forest of Canada. This area will include most, but not all of the area of the Kyoto Forest. The extent of the managed forest in Canada depends on the choice of definitions and ranges from 146 million ha for the non-reserved accessed timber productive forest to 245 million ha for the timber productive forest (Lowe et al. 1994). Within the managed forest, all changes in forest C stocks will be reported, regardless of the cause of the change. While there is no direct reference to “verification” of the reported C stock changes, reported estimates should be scientifically credible.

The minimum requirement of a national C accounting and reporting system is to track, store, and report information on past changes in C stocks for three areas: the Kyoto Forest, the managed forest, and the total forest area. Furhtermore, a national C accounting system should:

- be scientifically credible;
- meet the reporting requirements of both the Kyoto Protocol and the FCCC;
- provide the key indicators of C stock changes in annual time steps and for each commitment period as required by the reporting guidelines;
- be based on methods that allow scaling of information to the national level;
- provide estimates that are internally consistent across the various spatial entities for which reporting may occur;
- keep a spatially explicit record of the location of activities that have resulted in the creation of Kyoto Forest;
- calculate the C stock changes either by keeping a record of the C stock in the Kyoto Forest at the beginning and end of each commitment period or by estimating the C stock change during the commitment period using the “flow method”;

- estimate the C stock at the beginning of a commitment period in areas in which a RAD activity occurred during the commitment period;
- estimate C stock changes in all pools included by the Kyoto Protocol, i.e., one or more of aboveground biomass, belowground biomass and soil C;
- be verifiable;
- adapt to the evolving definitions, accounting procedures and methodological guidelines;
- be operational before the first commitment period starts;
- be cost efficient;
- provide estimates of uncertainty;
- be able to provide projections of future C stock changes based on various scenario assumptions (optional); and
- be able to assess consequences of alternative definitions of RAD and other forest management activities on the reported C stock changes (optional).

The main components of the National C Reporting System

The information system will be comprised of several components, each of which will fulfill specific functions. The main functions are data acquisition, data storage, models, parameter databases, reporting tools, and verification (see Table 5.1).

Several options are available to provide some of these functions. The details of the reporting requirements depend heavily on the unknown outcome of future negotiations on the implementation of the Kyoto Protocol, which will determine the extent of the Kyoto Forest, the types of activities and the C pools that need to be tracked. Hence there is at present no single best option. The suggested approach instead is to build an overall framework that will enable the use of the appropriate tools for each function. The most important role of the overall information system will be to provide the structure, standards, and interfaces to integrate the information flow between the various components.

Data acquisition

Six options have been identified for the acquisition of data on the area of the Kyoto Forest and on the C stock and C stock changes in the Kyoto Forest, the managed forest or the total forest area (Table 5.2). These are remote sensing based on comprehensive coverage, remote sensing based on a statistical subsample, determination of change in inventories, activity reporting, ground measurement of C stocks, and ground measurement of C fluxes. The relative contribution of each method to meeting the national reporting requirements will depend on the choice of definitions for the Kyoto Protocol and on which reporting requirement is to be met. In all cases, a mixture of methods will likely be applied, and the most important contribution of the national reporting system will be the integrating framework that can accommodate and combine data from the various sources.

Data Storage

Two data storage functions are required for the national reporting system (Table 5.3). The first database contains the compilation of relevant inventory information, from a variety of sources. It includes information on the location and the area of the Kyoto Forest created from reforestation, afforestation and deforestation activities since 1990. The second database contains derived inventory information on the C stocks of these areas, computed from models that extrapolate measurements in space and time. Both databases should be spatially referenced.

Models

Four types of models will potentially be required for the reporting system (Table 5.4):

- models for the extrapolation of measurements of volume or C stocks in space,
- growth and yield models to project volume dynamics over time,
- ecosystem C dynamics models with which to project above and belowground biomass and dead organic matter pools of individual ecosystems, and
- landscape-level C dynamics that project the age-class distribution and dynamics of many ecosystems.

Some of these models could be nested, i.e. the ecosystem dynamics model could make use of a growth and yield model to drive stand volume projections, and the landscape-level model could incorporate ecosystem-level C dynamics model.

There are dozens of growth and yield models in Canada. Most of these models are maintained by provincial agencies and industry for timber management and planning. These models are calibrated to the species, site and ecological conditions of the region in which they are applied. Generally, such models project stand volume information over time, and many of them are designed to operate with the inventory format used by an agency or forest company. The choice of which growth and yield models to use for the national reporting system will depend on the regional circumstances and the available models. The role of the national reporting system will be to provide the standardised inventory information that will permit the use of regionally calibrated growth models for the projection of stand volume.

Ecosystem dynamics models predict changes in all ecosystem C pools, including above and belowground biomass and dead organic matter pools, such as litter, coarse woody debris and soil organic matter. The two main purposes of these models are to predict the dynamics of all biomass components (not just stem volume) and to link changes in dead organic matter pools to stand dynamics, management impacts, and disturbances.

Ecosystem models are typically research tools that are not used in operational forest management. These models can be driven either by empirical growth equations (i.e. a growth and yield model) or through the simulation of biological processes. The former approach benefits from the large amount of growth and yield research that has been conducted in Canada, and from the very large number of measurements from permanent sample plots. The limitation of empirical growth models is that they are not responsive to global change. A simulation approach based on process modelling, however, will be more difficult to calibrate to regional and site-specific conditions, but may be designed to account for the impacts of global change on C dynamics.

Landscape-level C dynamics models are required to integrate the changes in C stocks over a larger area. These models calculate changes in C stocks from the area and C stock information of individual stands, and from the age-class distribution of the stands in the landscape. Operational forest management often employs landscape-level models of stand volume dynamics for planning of harvest schedules or other management activities. For the analysis of C dynamics the indicators generated by such models need to be expanded to include C stocks in all ecosystem C pools.

The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2, Kurz et al. 1992, Kurz and Apps 1999) is a landscape-level C dynamics model that has been applied to analyses at various spatial scales. Landscape-level models that provide similar functions are required to operate with the information that will be contained in the inventory of the Kyoto Forest, or with inventories of the managed or the total forest area.

Parameter Databases

One important contribution of a national C reporting system can be to develop and maintain databases with parameters, methods and other information that will be required for all analyses of forest ecosystem C dynamics. The reporting requirements of C stock changes will result in an increased need for parameters and methods with which to expand the readily available information on stem volume dynamics to other ecosystem C pools. Thus numerous analysts in resource management agencies, forest industry, and research organisations will be facing the same challenges, and will embark on reviews of a limited number of research studies. The nationally co-ordinated development of methods and parameter databases will greatly increase the credibility of the models that will be required to develop verifiable estimates of C stock changes, and it will facilitate the verification of the reported results.

Parameters and methods are required for converting stem volume to other aboveground biomass components, for calculating belowground root biomass, and for initialising and simulating dead organic matter pools.

Reporting Tools

The reporting tools required for the national reporting system must be able to query and summarise the information contained in the database of projected C stock estimates. These tools must be able to report C stock changes for various areas such as a region, Province, the Kyoto Forest, the managed forest, or the total forest area of Canada. Ideally, the tools should also be able to incorporate the various evolving definitions and accounting methods of the Kyoto Protocol, thus permitting an analysis of the consequences of selecting specific definitions.

The important contribution of a nationally co-ordinated approach will be to ensure that the methods used for accounting C stock changes are consistently applied and are in agreement with the international protocols. This also will facilitate verification of the reported results.

Verification

Two separate aspects of reported C stock changes could be verified: the reported values with their underlying component estimates of area and C stocks, and the system that was used to derive these estimates. At present, the term “verifiable estimates” used in Article 3.3 of the Kyoto Protocol is not specified further and either or both of these aspects may have to be verified in the future. The decision about the required verification process may be the outcome of future negotiations on the implementation of the Kyoto Protocol. The national C reporting system can contribute significantly to the verification process by providing peer-reviewed data acquisition, models, parameter sets and reporting methods. The system should also provide a mechanism for model comparison, evaluation and peer review. It may even be appropriate to consider the concept of certification of models and methods that may be employed to operate on the primary information contained in the central inventory. Only results obtained from such approved models will then be accepted in the database of projected C stocks.

Summary of Options for Various Reporting Requirements

Various combinations of spatial scales, reporting protocols, and ecosystem C pools result in a potentially large number of different reporting requirements. These can be met with a system that provides the functional components discussed above. Several functional components can be provided through multiple options. The various reporting requirements primarily affect the way in which the area data will be acquired and the choice of tools to represent ecosystem C dynamics. In all cases, an overall framework is required to store, analyse, and report the C stock information. Examples of how the options change with the reporting requirements are discussed in the report.

The choice of the specific methods used to provide each of the functions and their relative importance will be affected by future definitions for the implementation of the Kyoto Protocol. For example, if RAD activities are limited to afforestation and deforestation, but exclude reforestation following harvest, the total area of the Kyoto Forest would be small. The most effective method for the acquisition of area estimates may be an activity-reporting system that tracks all afforestation and deforestation activities (although it would be difficult to obtain data from 1990 to the year in which the system is implemented). For the reporting of C stock changes in the total forest area of Canada, data acquisition on the area and age-class distribution of the various forest ecosystem types would best be accomplished through a remote sensing approach, based either on comprehensive coverage or a statistical sample of the area.

Figure 5.1 summarises the structure and relationships of the main functional components of the national C reporting system. Central to the overall system will be an inventory containing data on the last observed state of the area. The spatial extent of this inventory could be only the Kyoto Forest, the managed forest, or the entire forest area of Canada. While the size of the inventory would vary considerably, for the purpose of this general discussion, in each case the inventory fulfills the same functional role, namely to store information obtained from measurements.

Associated with this inventory should be a database system that contains information on past (e.g., 1990), current and future states of the area included in the inventory. The database will contain, for each area in the inventory, the estimated size of each C pool at various points in time. This information will be extrapolated in time and in space using stand- and landscape-level models of ecosystem C dynamics. The results contained in the database can the be summarised and presented with the reporting tool.

Recommendations and Next Steps

1. We recommend that a national system for measurement and reporting of C stock changes in Canada should:

    - be a modular system whose primary role is to provide the framework for data compilation, synthesis and analysis,
    - provide a central data storage facility that compiles primary inventory information
    - provide the database structure to store the projected values of C stock estimates for past and future years,
    - built upon the large body of data and knowledge developed for the purpose of forest management, including forest inventories, growth and yield models, and landscape-level planning models,

- develop and maintain methods and databases required for analyses of C stock changes, including biomass expansion factors, root biomass estimation, and dead organic matter dynamics,
- develop and maintain stand and landscape-level C dynamics models with which to estimate C stock changes for the areas included in the primary inventory, including the C dynamics affected by natural and human disturbances and climate change,
- co-ordinate the process and research required to improve and enhance the available data and models required for C stock reporting.

2. Establish a steering committee to take responsibility for carrying through with implementing the C accounting system, beyond the current lifetime of the Sinks Table. This will be needed in order to make "demonstrable progress" by 2005, as is required under the Protocol. Implementing the accounting system should be the responsibility of a specific *sector*, such as the CFS, rather than of a *program* such as the NFI.

3. One very important role of the Steering Committee for the national C reporting system will be that of co-ordination and synthesis of ongoing activities, data collection and the development of information systems. It is therefore important to provide the institutional framework and the long-term commitment and funding (i.e. at least to 2012, the end of the first commitment period) to support the development and implementation of the reporting system.

4. The Steering Committee should ensure that the reporting system employs methods and models that are meeting the requirements of the verification process (once it is defined by the international negotiators).

5. Use systems analysis to identify the data components that contribute the largest uncertainty to total C flux due to RAD activities in order to determine priorities for data, research and methodological development (e.g., which RAD activities require closest monitoring, which C pools require most refined estimates).

6. Based on the results of this prioritisation exercise, implement a spatially referenced Kyoto Forest tracking system. The sooner this is started, the less re-construction of past conditions and events that occurred since 1990 will be required.

7. Recognise that the NFI will meet some needs of the reporting requirements but clearly not all. There is potential to significantly increase the NFI utility through design modifications:
   i) include information on coarse woody debris and soil C;
   ii) increase sampling density and re-measurement frequency in focal areas (i.e., in areas with high RAD activities); and
   iii) formalise the relationship between the NFI and the C measurement and reporting system.

8. Build a spatially-explicit accounting framework that can be applied consistently across the country and can work with various data formats (i.e., provinces or forest companies can apply it and populate it with their own data). Ensure it is supported and documented, and allows national roll-up of the results.

9. Develop, test and demonstrate methods for land-use change detection via remote sensing.

10. Collect and compile data on litterfall and other large plant residue inputs to dead organic matter pools on PSP's. Develop and compile data on decay rates in various ecosystem types across Canada. Maintain link between litter / dead organic matter parameter databases and the national C accounting system.

11. Special attention needs to be given to the impacts of stand history on the size of dead organic matter pools, which will differ greatly between stands that were previously affected by logging and those affected by wildfire or insects. Methods and inventory information need to be developed that assist in the determination of stand history and the resulting amounts of dead organic matter pools in forest ecosystems across Canada.

12. The national C reporting system can most effectively be developed if it seeks to build upon the large body of scientific knowledge developed in the Canadian growth and yield modelling community. While it is recognised that most growth and yield models have limited capability to respond to the changes in growing conditions from global change, they do provide the synthesis of a large number of actual measurements of stand conditions and their change over time from ecosystems across all of Canada.

13. To address the issues of global change, some of the ecosystem dynamics models employed in the analyses of C stock changes should be process models that simulate ecosystem dynamics based on site and climate conditions.

14. One or more landscape-level C dynamics models will be required to integrate the C dynamics of a large number of ecosystems, as these are affected by growth, natural disturbances, and forest management activities.

15. The Carbon Budget Model of the Canadian Forest Sector can be used for sensitivity analyses to determine priority research needs and to conduct preliminary analyses of past and future C stocks in Canada's forest ecosystems.

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1.0 Background

The objective of the United Nations Framework Convention on Climate Change (FCCC) is to achieve “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (Article 2). The Convention commits signatory nations, of which Canada is one, to limit their greenhouse gas emissions, protect and enhance carbon sinks, and report on their progress towards these goals.

The Kyoto Protocol, which becomes legally binding once ratified, commits signatory nations to a specific emission reduction target relative to 1990 emissions. The reduction target is to be achieved by the first commitment period, which includes the five years 2008 to 2012. The Protocol also begins to lay out the means by which performance towards this target will be evaluated. In particular, the Protocol specifies that the “verifiable changes in carbon stocks in each commitment period” due to “direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990” shall be used to help meet the emission reduction commitment (Article 3.3). The net change in carbon (C) stocks due to qualifying activities will be subtracted from the gross emissions during each commitment period. If the net change in C stocks is positive, i.e., C has been transferred from the atmosphere to terrestrial C stocks, this C uptake will contribute towards meeting the emission reduction target. In the inverse case, i.e., a reduction in C stocks occurred during the commitment period, the C emissions from qualifying activities will be added to the gross emissions from other sources. This will make it even more difficult for a nation to meet the emission reduction target.

The Kyoto Protocol requires that parties take steps to improve the reliability of their national carbon flux data (Article 10). It specifies that the estimation of C emissions and removals is to be done using methods that, once finalized, will have to be accepted by the Intergovernmental Panel on Climate Change (IPCC) and agreed upon by the Conference of the Parties (Article 5.2). In particular, the Protocol creates two main national reporting requirements, which may be summarized here as:

1. the verifiable change in carbon stocks during each commitment period

a) due to afforestation, reforestation, and deforestation (the so-called ‘RAD’ activities) since 1990, and
b) due to other activities that may be approved in subsequent negotiations.

2. data that establish the level of C stocks in 1990 and allow an estimate of changes in stocks in subsequent years (Article 3.4), (although the intended use of these data is not specified in the Protocol).

Note that the FCCC specifies an additional reporting requirement:

3. national inventories of anthropogenic greenhouse gas emissions by sources and removals by sinks using comparable methodologies to be agreed upon by the Conference of the Parties (Article 4).

This report summarizes and builds upon the results of a meeting held in Vancouver, BC, on 25-26 January 1999. The meeting was convened and sponsored by the National Issues Table on Sinks to discuss measurement and verification issues arising from the FCCC and the Kyoto Protocol. This project is one of several initiatives that will provide background information for an Options Paper. Together with the papers produced by the other 14 Issues Tables, this Options Paper will be used as the basis for a draft implementation strategy to be presented to the Joint Environment and Energy Ministers at the end of 1999.

2.0 Objectives

The ultimate objective of the project is to define and assess the available options for implementing a system with which Canada can meet the reporting requirements of the Kyoto Protocol and the FCCC. Specific objectives are to:

1. identify the requirements of a system for measurement, verification and monitoring of changes in carbon stocks from forestry activities; and
2. identify and assess the options for measurement, monitoring and verification of changes in carbon stocks (including above and below ground biomass as well as soil carbon) from RAD and other potential forestry activities that would meet the requirements of the Kyoto Protocol and of the FCCC and could be implemented prior to the first commitment period.

3.0 System Requirements

3.1 Scope

The minimum requirement of a national C accounting and reporting system is to track, store, and report information on past changes in C stocks for specified areas. It is possible to design the system such that it can also be used to project future C stock changes under various alternative scenarios. Moreover, a system with scenario analysis capabilities could be used to assess how alternative definitions and accounting rules for the Kyoto Protocol would affect reported future C stock changes.

The definitions of terms, accounting rules, and methods required to implement the Kyoto Protocol are still under development. The Intergovernmental Panel on Climate Change (IPCC) has been mandated to prepare a Special Report on Land Use, Land Use Change and Forestry which will provide scientific analyses in support of future international negotiations on the implementation of the Kyoto Protocol. The Special Report is scheduled for publication in May 2000.

Among other issues, the Special Report may provide international negotiators with suggestions for:

- the definition of “forest”;
- the definition of “reforestation”, “afforestation” and “deforestation”;
- the definition of “carbon stocks”;
- what additional activities may be included under Article 3.4 of the Protocol;
- the definition of “verifiable”;
- the area for which carbon stocks changes must be reported under Article 4 of the FCCC and Article 3.4 of the Protocol.

Because of the remaining methodological uncertainties, any system designed to meet the national reporting requirements must, at this time, be flexible and must be able to evolve with changing definitions and C accounting methods. Ideally, the system should be able to accommodate the full range of possible definitions and C accounting methods.

Meeting participants agreed to avoid debate over the likely definitions and to consider the full spectrum of possible definitions during the discussion of measurement options. It was also agreed to begin with a free exploration of alternative measurement options. The feasibility and practicality of alternatives was subsequently assessed.

3.2 Reporting Indicators

The key indicators that must be reported by the C information system are:

1. for reforestation, afforestation, deforestation, and any other activities that may subsequently be approved:
   i) the area affected by each activity since 1990, and
   ii) either:
      a) the C stock (including aboveground biomass, belowground biomass, and soil C) on this area at the beginning and at the end of each commitment period; or
      b) the rate of change in C stock (including aboveground biomass, belowground biomass, and soil C) on this area during each commitment period.
2. the C stocks in 1990 and estimates of changes in subsequent years.
3. the annual anthropogenic greenhouse gas emissions by sources and removals by sinks from land use change and forestry in the “managed” forest.

Requirements 1 and 2 result from the Kyoto Protocol (Articles 3.3. and 3.4). Requirement 3 results from the FCCC and is not altered by the Kyoto Protocol. It may further be desirable to stratify the reporting indicators by Provinces and/or ecological zones. Stratification by Provinces may require prior agreements on future reporting of results from the C accounting system.

Note that the reporting requirement is for the change in C stocks during each commitment period. These changes could be calculated using either a stock-based (ii.a) or a flow-based (ii.b) approach. The two alternatives will be discussed in more detail below.

Canada is also required by 2005 to make “demonstrable progress” towards meeting its Kyoto requirements (Article 3.2).

3.3 Temporal Specifications

The C accounting system must cover events from 1990 on an annual basis. There are no reporting requirements for seasonal (intra-annual) variation in C stocks. The system can therefore track and report C stock changes in annual time steps. Special consideration will have to be given to the calculation of the C stock at the beginning and end of each five-year reporting period.

If the system will be designed to include the capability to project future C stock changes under alternative scenarios, the time horizon should extend about 100 years into the future. This time horizon is approximately one timber rotation.

3.4 Spatial Specifications

The meeting participants agreed that the spatial scope of the C accounting system should be limited to those areas in Canada that currently can support forest or might do so in the next 100 years. Thus only those areas in the far northern regions (i.e., the subarctic and arctic terrestrial ecoszones) that will not support tree growth are explicitly excluded from the spatial scope.

Other areas that currently do not support forests, such as agricultural land, wetlands, or other non-forested biomes could through afforestation or reforestation activities be converted to areas for which C stock changes need to be reported under the Kyoto Protocol. The system must therefore be able to account for these areas if activities occur that establish a reporting requirement for the areas and their C stock.

One requirement of the C accounting system is that it must deal with various spatial scales such that it will be possible to summarise the information at the national scale. Moreover, the approach should be consistent across spatial scales. This does not imply, however, that information for all areas is collected with the same level of resolution or that all possible areas are included in the C accounting system.

Conceptually, the system could account for three different spatial entities in Canada:

1. **The Kyoto Forest** – the area on which certain activities since 1990 have established the need to report the C stock at the beginning and end of each commitment period. This area will increase over time from 0 ha in 1990. It will include some non-forested area resulting from deforestation activities that occurred since 1990. The area of the Kyoto Forest will be non-contiguous and will be concentrated in areas of human activity and development. The extent of the Kyoto Forest will be affected by the definitions of the activities that establish the reporting need.

2. **The Managed Forest** – the area of the managed forest in Canada. Note that there are various estimates or proxies for the total area of the managed forest. These estimates range from 146 million ha for the non-reserved accessed timber productive forest to 245 million ha for the timber productive forest (Lowe et al. 1994).

3. **The Total Forest** – the area of the total forest in Canada as defined, for example, in the National Forest Inventory. By definition, this will include all of the managed forest, and most, but not all of the Kyoto Forest (e.g., it would exclude deforested areas). While Article 3.4 of the Kyoto Protocol specifies that nations should report their level of C stocks, it does not explicitly state that this reporting requirement is limited to the managed forest, though it is frequently interpreted in this way. The main reason, however, why the reporting system should be able to include C stock changes in the entire forest is to permit full C accounting frameworks to be compatible with Protocol and FCC reporting frameworks. The atmospheric C concentration is affected by the C stock changes in all forest land and these changes are therefore at least of scientific interest. Workshop participants emphasized that to assess whether or not the objectives of the FCCC are met, it will be important to assess C stock changes in the entire forest area.

The area of the “managed forest” is entirely included within the total forest area (Figure 3.1). The deforested part of the area with RAD activities (Kyoto-Forest) will be outside both the managed and the total forest area (e.g., where land-use change has occurred). The Kyoto Forest will be highly fragmented areas for which qualifying RAD activities have occurred. Reported C stock changes at one spatial scale should be consistent with the reported changes for the same area reported at a different spatial scale.

Figure 3.1: The three spatial entities with C stock reporting requirements.

Note that different reporting standards apply to each of the three spatial entities. Reported C stock changes within the Kyoto Forest will be applied towards the emission reduction targets and must therefore be verifiable. The standards for the remaining areas are less stringent (unless there are changes to the Protocol as a result of negotiations. For example, it is possible that, as a result of negotiations, verifiable changes in C stocks on all managed forests might be applied towards emission reduction targets). The issues of monitoring and verification will be discussed later in this report.

The spatial resolution of the C accounting system should depend on the aggregate significance of the activities that would be captured or missed at various spatial resolutions. There is probably no one level of resolution that can be deemed appropriate for all purposes. For example, selecting a definition of a minimum reported area or of a minimum width of forest could result in systematic omission of RAD activities such as small deforestation events or afforestation of shelter belts.

Some events, such as the construction of small oil rigs may result in the deforestation of only small patches of forest (e.g., 50 x 50 m or 0.25 ha), but if these events are numerous they might collectively result in substantial annual deforestation. On the other hand, it would be extremely costly to monitor land use change in all of Canada with a 0.25 ha spatial resolution. Moreover, even a 0.25 ha standard (i.e., minimum 50 m width) may be inadequate for detecting changes such as the afforestation of shelter belts.

In some cases, such as the “urban forest”, the detection threshold should probably be based on aggregate C content or number of trees rather than on area *per se*. These C stock changes cannot readily be captured using an area-based approach.

To address these spatial issues, the potential importance of processes at various spatial scales should be assessed prior to finalizing a decision about the approach. Several projects are currently in progress to identify the RAD activities in Canada by type, extent and location. This information can be used for sensitivity analyses on the importance of various RAD activities and the appropriate spatial scales at which information should be collected. It may be appropriate to use more than one spatial resolution to capture the functional role of various processes. For example, areas in which certain small-scale events result in deforestation or afforestation could be classified as focal areas within which a different spatial resolution will be applied than in areas with activities that operate over larger areas.

The resolution at which forest cover maps are currently developed is limited to 1 – 2 ha in most Provinces.

Meeting participants agreed to consider non-forest systems only to the extent that they are part of land use change processes, i.e., the C accounting system will not track the C stock changes on peatland or on agricultural land unless this is converted to or from forest since 1990.

Note that the decision to exclude agricultural lands may have to be revisited depending on future negotiated agreements on how to report C stock changes from land use. If such a reporting requirement is established, it would best be served through a single, integrated, national-scale system. Note further that C stock changes on agricultural land derived from forests since 1990 (i.e., areas with a reporting requirement under the Kyoto Protocol) must be accounted separate from C stock changes associated with agricultural land use to avoid double counting.

Participants further agreed to limit the discussion of C tracking to “on-site” activities (i.e., not off-site C storage, forest product accounting, or fossil fuel substitution). It was noted, however, that the accounting system would have to provide an explicit linkage whereby harvested C stocks are transferred to another accounting system to monitor and report their changes. The Kyoto Protocol does not specify whether or not C in forest products will be reported. If future negotiations establish a reporting need for forest product C, the C accounting system would have to be expanded accordingly.

3.5 Actions and Processes

To perform the intended reporting functions, the national C accounting system must be able to represent a number of different management actions and processes. Under the Kyoto Protocol, deforestation, reforestation and afforestation will all establish a reporting requirement for the areas in which these activities have taken place since 1990. Furthermore, additional forestry activities may be added to the Kyoto Protocol under Article 3.4, and require monitoring of C stock changes that could also be used towards the emission reduction targets.

One primary task of the system, therefore, will be to develop an inventory of the areas in which such activities have taken place. The challenge will be to develop methods for detecting where in Canada such activities have occurred since 1990.

The second task of the system will be to estimate and report the C stock of these areas at the beginning and end of each commitment period. Given that it is unlikely that the C stocks of all areas will be measured at the reporting times, the system must also be able to project, forwards or backwards in time, C stock estimates obtained through various means and at various times.

To project changes in C stocks over time, the system must be able to account for the major ecosystem processes that alter C stocks in above and belowground biomass, and in soil and dead organic matter pools. This requirement will be discussed in more detail below.

The definitions for the three RAD activities will not be finalized until after the completion of the IPCC Special Report and the ensuing international negotiations. For the purpose of discussing measurement options and reporting requirements, workshop participants compiled and discussed activities that may be included in the definition of activities that result in the creation of Kyoto Forest.

3.5.1 Deforestation

Deforestation is commonly defined as an activity that results in the removal of forest cover, a change in land-use, or both (Lund 1999). The definitions of deforestation under the Kyoto Protocol may specify a prerequisite of direct human impact, thus excluding deforestation resulting from biome shifts associated with climate change or regeneration failure following natural disturbances.

Deforestation could be defined in terms of a land-cover (physical) change or in terms of a land-use (administration) change. If the definition were based on land cover, the associated change could be observed. If deforestation were based on a definition of land-use change, the activity could only be observed if the change in land use designation were associated with a change in forest cover. All other change in land use designation can only be detected if there were a continuously updated, nation-wide system of land use designation.

All causes of deforestation listed in Table 3.1 are associated with a change in land cover – i.e., they result in visible change and they can potentially be detected by aerial observation. If the methods for the Kyoto Protocol require that deforestation results from direct human impacts, it would first be necessary to ascertain the cause of the observed change in forest cover (e.g., wildfire set by lightning and followed by regeneration failure might not count as deforestation). Also, most importantly, repeat observations would probably be required to differentiate areas that are expected to regenerate from those in which a land cover change has occurred (e.g., sustainable forest harvesting vs. clearing for rangeland).

Most activities in Table 3.1 result in a rapid change in forest cover. Climate change and pollution impacts could result in a gradual reduction of forest cover and may therefore be more difficult to detect by methods that rely on repeat observation of forest cover. While these causes of deforestation are not likely to be included in the RAD activities defined by the Kyoto Protocol, they could affect C changes in the managed forest or in the Kyoto Forest. These processes, therefore, need to be included to address C stock changes in the managed forest and in the Kyoto Forest during the commitment periods.

Table 3.1: Activities that may be considered "Deforestation" in Canada.

Category	Possible Deforestation Activities
Agriculture & Forestry	land clearing for agriculture / rangeland drainage of forested wetland, followed by clearing for agriculture / rangeland encroachment of rangeland into forest livestock destruction of riparian forest removal of shelterbelts harvesting followed by failure to establish forest cover within a specified time period any disturbance caused by humans (e.g., some fires) if followed by failure to establish forest cover within a specified time period
Industrial & Urban	urban clearing road building (either direct forest clearing or associated flooding of forests) seismic lines, mines, oil wells utility corridors (pipelines, power lines) air strips flooding of forests for hydroelectric head ponds recreational structures (ski resorts, golf courses, park buildings)
Climate Change & Pollution	climate change leading to forest death pollution impacts (e.g., acid rain)

Whether it is necessary to distinguish intentional from accidental causes of deforestation remains an open question. For example, the removal of tree cover on some parts of the Avalon Peninsula resulted in the invasion of heath and long-term conversion to non-forest vegetation (Mallik 1994). Although this was not intentional it was a human-induced deforestation and, events that occurred since 1990 may therefore establish a reporting requirement.

The international negotiators might agree on a definition of deforestation as the removal of forest cover with either the intent of land use change or with a failure to regenerate trees within X years. A deforestation event can then only be detected if the intended land use change is known or obvious (i.e., infrastructure development can be observed) or by repeat observation X years after the initial forest cover removal was observed.

3.5.2 Afforestation

Afforestation is commonly defined as an activity that results in the establishment of forest cover in areas that have historically not contained forests (i.e., non-forested biomes such as grass lands, wetlands, or the arctic) (Lund 1999). Some definitions also consider afforestation to occur when there has not been a forest for many years. The latter definition creates a continuum between afforestation and reforestation, the difference between the two defined merely by the time since the last forest was removed.

Table 3.2: Activities that may fall under "Afforestation" in Canada. Note that the distinction between "reforestation" and "afforestation" will depend on the time frame adopted for each definition.

Category	Possible Afforestation Activities
Agriculture & Forestry	any land-use change to forestry from some other use, including farm abandonment change from non-tree crop to trees addition of shelterbelts exclusion of livestock to allow forest establishment on rangeland
Industrial & Urban	urban tree planting
Other Land Management	wetland drainage followed by forest establishment land reclamation followed by forest establishment
Climate Change & Pollution	expansion of forested land due to biome shifts expansion of forested land due to human-assisted biome shifts

3.5.3 Reforestation

Reforestation is commonly defined as an event that establishes forest cover in areas that previously contained forest (Lund 1999). Some definitions require that forest cover has been absent for some minimum amount of time, thus excluding forest regrowth following harvest from the definition of reforestation. The definition of reforestation selected by the international negotiators will have a large impact on the reporting requirements of a country with active forest management. The extent to which activities listed in Table 3.3 will result in the creation of Kyoto Forest, will strongly affect the total area of the Kyoto Forest and the monitoring requirements.

The selection of regeneration methods following harvesting is a silvicultural decision based on site characteristics, the ecology of the tree species and competing vegetation, economic considerations, and forest management objectives. The definition of reforestation selected by international negotiators will affect the difficulty of obtaining data on this process. For example, definitions that include some regeneration mechanisms and not others would make reporting, accounting, and verification much more difficult. Moreover, more than one regeneration method could be used in the same site (e.g., infill planting in a forest that has otherwise been established through natural regeneration). Planting after partial cutting will likely not fall under the definition of reforestation because, in that case, forest cover has never been removed. Partial cutting and subsequent regeneration will result in C stock changes but, depending on the outcome of negotiations, these may not be included in the reporting requirements for the Kyoto Protocol.

Table 3.3: Activities that may fall under "Reforestation" in Canada. Note that the distinction between "reforestation" and "afforestation" will depend on the time frame adopted for each definition.

Category	Possible Reforestation Activities
Agriculture & Forestry	any land-use change to forestry from some other use (e.g., range exclusion) assisted regeneration after natural disturbance any of the following forms of regeneration following harvest: - natural regeneration - natural regeneration, with a special effort to protect existing advanced regeneration during harvest, or with seed-tree retention, or any other form of assistance (e.g., ensuring jack pine cones are scattered throughout the site) - natural regeneration with management of competing vegetation - site preparation followed by natural regeneration - site preparation followed by seeding - natural regeneration supplemented by infill planting - planting - site preparation followed by planting

Afforestation and reforestation are more difficult to detect from aerial or remote sensing observations than deforestation. The associated change in land cover is slow and gradual, and trees may not be readily observed among the competing vegetation. As a result, intent may figure more prominently in the definition and detection of afforestation and reforestation events. Intent, unfortunately, is difficult to verify and reforestation success can only be confirmed years after the activity.

While it is harder to detect afforestation and reforestation from observation, both activities will generally result in C stock increases. Obtaining information on these beneficial activities through a system based on the reporting of activities undertaken is therefore more likely to be successful than obtaining information on deforestation through such a system. There will likely be benefits or incentives to report activities that result in the increase of C stocks.

3.5.4 Other Activities

Article 3.4 of the Kyoto Protocol specifies that other (as yet undefined) "additional human-induced activities related to changes in greenhouse gas emissions and removals in the agricultural soil and land-use change and forestry categories, shall be added to or subtracted from" the calculated emissions. The protocol outlines the process by which these activities shall be decided. Commonly cited examples include forest fertilization, vegetation management, thinning, forest protection and other activities that will alter the dynamics of C stocks in forest ecosystems other than those forests established since 1990.

The challenges for a measurement and reporting systems are similar to those of the RAD activities. First, the area in which these events have occurred since 1990 needs to be identified, and second, the C stock at the beginning and end of each commitment period has to be established. It is possible that only the incremental change resulting from the activity will be included in the reported changes. C stock measurement would then be significantly more difficult. For example, in the case of forest fertilization, only the increase in C accumulation due to fertilization would be reported. This would require that, somehow, the baseline change in C stocks would also be determined using verifiable methods.

Increasing or decreasing forest C stocks could result from activities included in Article 3.4 or from other forest management activities that do not remove or establish forest cover. For example, commercial thinning or other forms of partial cutting may not reduce forest cover below the threshold defined in future negotiations, but they will alter C stocks. Changes in C stocks resulting from activities included under Article 3.4 would have to be reported under the Kyoto Protocol. Changes in forest C stocks of the managed forest from all causes have to be reported under the FCCC reporting requirements.

3.6 Other Requirements

Some ambiguity remains about whether the reported C stock change is strictly calculated based on the estimates at the beginning and end of each commitment period (e.g., 2008-2012). For example, forest harvesting in the year 2009 followed by planting in 2010 results in C dynamics of the aboveground biomass C pool as shown in Figure 3.2. One possible set of definitions would exclude harvesting from the activities that result in the creation of Kyoto Forest, but would include planting as a reforestation activity. Technically then, the event that resulted in the designation of the area as Kyoto Forest did not occur until 2010. There are three options for reporting the C stock changes. Option 1 would calculate the difference in C stock 2012 – 2008 and report a substantial reduction in C stock. Option 2 would calculate the difference in C stock 2012 – 2010 and report a small increase. A third option would be that neither activity would result in the creation of Kyoto Forest, and hence no C stock change would be reported at all. The situation is further complicated if belowground and soil C pools are added to the calculations. Obviously the choice of definitions, therefore, will affect the data requirements for reporting of C stock changes.

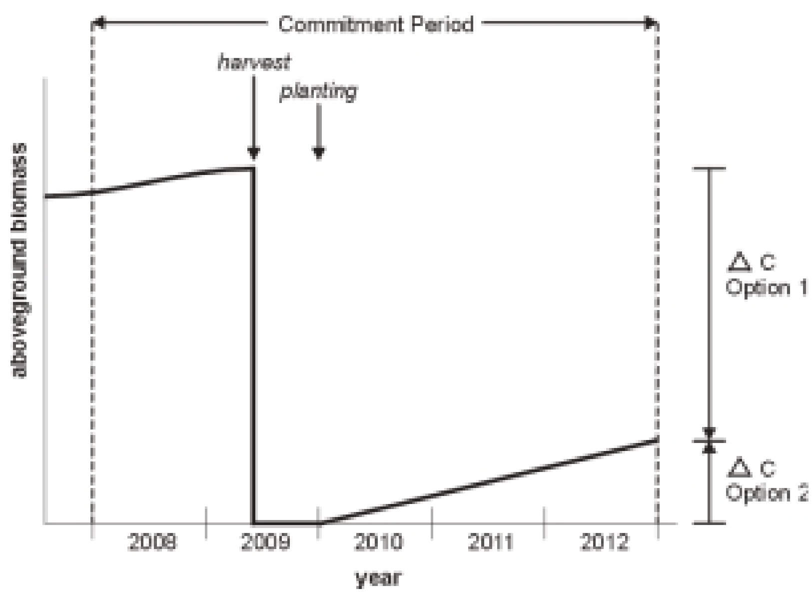

Figure 3.2: Forest harvesting followed by planting during the first commitment period could result in three possible accounts of the change in C stocks. Option 1 would calculate the difference between C stocks in 2012 and 2008, Option 2 would consider harvesting to be excluded from the RAD activities but reforestation to be included, resulting in a reported increase in C stocks; and Option 3 would exclude both harvest and replanting from the RAD activities. The definition of RAD activities that will ultimately be selected by the international negotiators will have a significant impact on the measurement requirements for the Kyoto Protocol.

The important data acquisition challenge highlighted by this discussion is that for areas affected by activities that occur within a commitment period, the C stock estimate for those area at the beginning of the commitment may be required. Hence the C accounting system must have a means for estimating the C content of the various C pools for up to five years prior to the event that resulted in the designation of an area as Kyoto Forest. For example, an event in 2012 may establish the need for a C stock estimate in 2008. It is highly unlikely that the national C accounting system would, at the beginning of a commitment period, contain C stock estimates for all areas that might potentially be affected by RAD activities during a commitment period. Other methods for establishing the C stock estimates at the beginning of the commitment period will therefore be required.

The potential challenges from this requirement will become more obvious during the discussion of the methods used to extrapolate C stock estimates in time. Suffice to say here that most of the existing simulation models of stand and organic matter dynamics are unable to project C stock estimates backwards in time.

3.7 Summary of System Requirements

A national C accounting system should:

- be scientifically credible;
- meet the reporting requirements of both the Kyoto Protocol and the FCCC;
- provide the key indicators of C stock changes in annual time steps and for each commitment period as required by the reporting guidelines;
- be based on methods that allow scaling of information to the national level;
- provide estimates that are internally consistent across the various spatial entities for which reporting may occur;
- keep a spatially explicit record of the location of activities that have resulted in the creation of Kyoto Forest;
- calculate the C stock changes either by keeping a record of the C stock in the Kyoto Forest at the beginning and end of each commitment period or by estimating the C stock change during the commitment period using the “flow method”;
- estimate the C stock at the beginning of a commitment period in areas in which a RAD activity occurred during the commitment period;
- estimate C stock changes in all pools included by the Kyoto Protocol, i.e., one or more of aboveground biomass, belowground biomass and soil C;
- be verifiable;
- adapt to the evolving definitions, accounting procedures and methodological guidelines;
- be operational before the first commitment period starts;
- be cost efficient;
- provide estimates of uncertainty;
- be able to provide projections of future C stock changes based on various scenario assumptions (optional); and

- be able to assess consequences of alternative definitions of RAD and other forest management activities on the reported C stock changes (optional).

4.0 Existing Tools and Approaches

This section of the report provides a brief overview of existing tools and methods available to obtain information on forest area and C stocks. It addresses how forest inventories, remote sensing, ground measurements of C stocks, and flux measurements can contribute towards the national C accounting and reporting requirements.

4.1 Inventories

Forest inventories typically provide information on total or merchantable stemwood volume observed in each stand at one point in time. An inventory for a region is often based on a compilation of observations taken at different times. In Canada, forest inventories are compiled and maintained by forest companies, provincial resource management agencies, and by the federal government.

The Canadian Forest Inventory (CanFI) is a compilation of inventory data mapped at a provincial level, converted to a national classification system, and summarized at the national level. Advantages of the system are that it can provide location-specific information, down to the mapsheet level, and that it has nearly complete coverage of Canada's timber productive forest area. The disadvantages of the system are that the observations are of varying age, with some data being as old as 30 years, and that the data are compiled from 48 different source inventories. These source inventories are conducted to different standards and use different definitions and methodologies. Due to methodological changes between successive inventories, CanFI data cannot be used to infer changes in the size of the forest land base or in the growing stock volume. CanFI has been updated every five years, and the next release is scheduled for 2001. This inventory will include forest areas beyond the boundaries of the provincial inventories, such as non-timber-productive areas.

Because of the recognised shortcomings of the existing inventory system, a new National Forest Inventory (NFI) is currently under development. The new inventory methods are expected to meet two primary objectives:

1. the inventory should provide a picture of Canada's forests at a single point in time; and
2. the inventory should allow measurement of changes over time in the forest land base.

The new NFI will be a sample-based system with approximately 22,000 2x2 km^2 photo plots located on a systematic 20 km grid across the country. The photo plots will classify age, height, density etc. with interpretations of land-use and land use change (as described in Section 4.4 on remote sensing). The photo plots will use mid-scale, 1:10,000 or 1:20,000 photography. In total, the photo plots will cover 1% of the forest area in Canada. Land cover variation within the plots, such as lakes etc., will be classified accordingly. The plots are intended to be systematically distributed — providing an unbiased sample of both developed and undeveloped land, and public and private land — although each province can modify this layout if desired. One in ten plots will also be ground sampled. The ground plots are intended to provide independent information (i.e., not to be used to calibrate or adjust the photo data in any way) and will be located at random within the photo plot.

Work is currently proceeding on the standards and definitions that are to be applied in the inventory, and opportunities still exist to suggest additional sample attributes or minor design modifications. The provinces have the option of building their own inventories into the design, and to enhance the design to incorporate provincial data requirements.

The intent is to establish all of the plots over the next five years, with the first national inventory report under the new system due in 2005. All plots are intended to be permanent so that the system can track change in land use, forest cover and other attributes. Plot re-measurements are scheduled on a ten-year cycle. Thus only those stands that have been measured before 2002 will have a re-measurement during the first commitment period of the Kyoto Protocol (2008 – 2012).

The new NFI will include direct measurements for a statistically based, but small proportion of the total forest area. In the first commitment period, the area of the Kyoto Forest will also be only a small proportion of the total forest area. It will therefore only be possible to obtain estimates of RAD activities and the affected C stock in those locations where sample plots of the NFI and the area of the Kyoto Forest overlap. These are areas where RAD activities occur on the sample plots.

It has been suggested that because the NFI is based on a statistical design, it should be possible to extrapolate the observations of RAD activities on the sample plots to the national scale. There are however, several issues that have not been resolved:

1. the sample plots will not detect events that occurred between 1990 and plot establishment unless these can be inferred from the plot conditions at the time of establishment;
2. unless all plots are re-measured in 2012, RAD activities between plot establishment and the end of the first commitment period will not be recorded; and
3. a 10-year re-measurement cycle is insufficient to establish C stock changes on those plots for which changes need to be reported between 2008 and 2012.

A second option to obtain data on the Kyoto Forest is to work with the provincial inventories, which provide complete coverage of the forests in each province. These inventories are expected to be maintained in parallel with the new NFI. A mechanism to detect and record RAD activities in these provincial inventories would have to be established.

A third option is to use remote sensing images (e.g., Landsat) to identify areas with RAD activities and to extrapolate information about these areas from relevant NFI sample plots. Complete Landsat coverage is planned to complement the new NFI sample-based system.

Forest inventories alone, in the current format and without modifications will not be able to meet the reporting requirements under the Kyoto Protocol and the FCCC.

4.2 Inventories of RAD and Other Forestry Activities

The previous section discussed approaches to obtaining estimates from forest inventories of the area affected by RAD and other forestry activities. An alternative approach may be to compile a separate inventory of events that resulted in the creation of Kyoto Forest. For example, in some jurisdictions permits are required for the clearing of forest trees, and planting and other silvicultural activities may be recorded in databases on regeneration. To what extent are such events recorded in Canada?

There is currently no legal requirement or infrastructure for reporting most of the potential RAD activities listed in Tables 3.1, 3.2 and 3.3. Although each province may know, for example, the number of seedlings sold to farmers in afforestation programs, they do not know the eventual fate of these trees or even if they were ever planted. When crown land is sold, no records are kept after the record of sale, and there is no obligation for the private developer to report activities that may result in land cover changes. In some municipalities, by-laws exist that regulate the cutting of trees. Although development permits are required for construction, most jurisdictions do not require permits for the conversion of privately held forest land to agriculture or other uses.

There is some prospect of obtaining data on RAD events with associated revenue flows (e.g., sites cleared for oil rigs) by instituting reporting requirements, but workshop participants thought that this likely will not be effective for other RAD events (such as shelterbelt changes, or livestock impacts on riparian areas).

Some provinces compile information on the rate of regeneration and reforestation in the managed forest. For example, the BC Ministry of Forests maintains two Oracle databases with regeneration statistics: ISIS (Integrated Silviculture Information System) and MLSIS (Major Licence Silviculture Information System). Both databases are used by licensees to demonstrate their compliance with provincial restocking regulations. Once data have been entered into the MLSIS database, they are not used any further by licensees. Licensees use the ISIS database for their own planning purposes (e.g., for scheduling juvenile spacing) and it is therefore considered to be more complete and accurate.

One uncertainty about a voluntary or legislated reporting system of RAD activities is whether foreign observers and auditors would consider such an approach to be an adequate and verifiable source of information. A statistically-based sampling system of change detection may have more credibility than a domestic reporting system. A sample-based system could be used to verify a system based on reporting of RAD activities.

4.3 Remote Sensing

Remote sensing refers to the acquisition of data from both airborne and satellite sensors and includes aerial photography. For the purposes of this report, various potential roles of remote sensing will be discussed.

4.3.1 Establishing Inventory Information

Remote sensing is presently used in Canada as the primary source of information for the development of provincial forest inventories. Remote sensing can be used to derive estimates of forest cover, age and height range, crown closure, stand density, estimated volume and basal area, species composition, land cover classification, and land classification. Information on coarse woody debris and soil C pools cannot be obtained through remote sensing. It is possible to develop statistical correlations between these and other stand and site attributes. Some biophysical and drainage attributes can be interpreted from the images, including land form, mode of deposition, and an approximation of soil texture.

Complete remote sensing coverage of Canada at 80 m resolution is available for every year since 1973 (except for areas obscured by cloud cover at the time of a given image). Coverage with 30 m resolution is available for every year since 1984.

Existing Landsat information could be used to reconstruct the forest cover conditions in 1990.

4.3.2 Detection of Forest Cover Change

Remote sensing could be used to establish change in forest cover by comparing successive images of the same area, preferably taken during the same season. Land cover changes can sometimes be detected from just two images if the change in forest cover is substantial, e.g., through fire, harvest or other land clearing. To establish whether or not the area qualifies as Kyoto Forest, additional information on the cause of land cover change may be required to determine the cause of cover change. This information may in some cases also be obtained from remote sensing information, for example, if an airstrip occurs in the later image where forest was present in the earlier image, deforestation and land use change can be identified. In many cases, however, this additional information will only be available from other sources.

More than two images, or images that are several years apart, will be required to determine processes that involve slow change in land cover, such as afforestation and reforestation. Here too, remote sensing may be able to establish that the land cover change has occurred, while supplemental information on the cause of the change may be required, if the definitions of afforestation and reforestation specify the level of direct human activity.

There are several approaches to detecting and quantifying land cover change. One can classify two dates of imagery and compare changes in classes. Other approaches classify change directly using various combinations of multidate image data. Major changes such as intense burns, clearing, and clearcutting can be detected and delineated with good reliability with some of these and other fairly simple techniques. More sophisticated techniques are available and can be developed to reliably detect small, unusual or slowly progressing changes. Reforestation, afforestation, partial cutting, insect damage and indeed some deforestation fall into this category. Some of these techniques need a time sequence of several images.

The U.S. Landsat 7 program aims to provide global coverage of each of four seasons every year at a cost of $900 per scene. About 500 scenes are required to cover Canada. At a minimum, three sets of these images, covering the years 1990, 2008 and 2012, would be needed to detect the relevant changes. Scenes for 1990 may be available for $225 per scene, and it may be that prices for other years fall dramatically in the early 2000's as the technology develops further. Processing the data, however, also requires significant resources. Full-coverage U.S. forest cover mapping for a single point in time required 20 people working over a 3-year period (60 person-years). The costs for a similar initiative in Canada would obviously go well beyond the mere acquisition of the images.

A CFS-led Canadian Space Agency Long Term Space Plan project termed Earth Observation for Sustainable Development of Forests (EOSD) could have a significant impact on monitoring of RAD activities. The project is in final approval and planning stages. A main focus is to map Canada's forest cover and detect changes on a nominal five-year basis using Landsat-type medium-resolution satellite data. Dates of the data coverage will coincide with the needs of Kyoto reporting.

One complication is that it is usually not possible to get full national coverage during a single season due to the re-occurrence of cloud cover during surveillance. This is true even though Landsat surveillance covers the entire globe once every 16 days. More expensive satellite imaging systems (e.g., SPOT and Radarsat) can be targeted specifically to the areas for which data are missing.

The FAO conducted an analysis of land cover change in tropical countries using remote sensing information. They developed a number of land cover classes and then established the change between classes over a ten-year period using two sets of images. A transition matrix is used to describe the area in each class that remained unchanged (the diagonal elements of the matrix) and the area that changed from one class to another (the off-diagonal elements of the matrix). While this study demonstrated the ability of remote sensing to quantify changes in land cover, detecting cover change will likely not be sufficient for the purposes of reporting RAD activities under the Kyoto Protocol. It may be required to establish the cause of the cover change (e.g., natural disturbance versus direct human-induced change) or the intent of the change (i.e., harvest as part of forest management or deforestation for the purpose of land-use change).

One possible approach to developing a land-cover change-detection system based on remote sensing information could be to combine information from various sensors with a range of resolutions. For example, low-resolution broad coverage of large areas could be obtained and analysed. Where areas with apparent development and activities are identified, additional medium or high resolution information could be acquired and analysed. A network of satellite permanent sample plots could be established where detailed analysis of change is conducted.

4.3.3 Detection of Change in C Stocks

With today's technology, the potential contribution of remote sensing to detecting and quantifying change in C stocks appears very limited. At present, only aboveground biomass can be approximated with remote sensing, and even that indicator tends to be reach saturation at about 50 tons/ha of forest biomass. In many parts of Canada, the forest biomass is well in excess of this value.

Detection of the small changes in aboveground biomass C stocks that occur over a five-year period is not possible with current remote sensing technology. Detection of changes in C stocks is possible where major disturbances such harvesting or wild fire occurred. Again, it may be possible to use low resolution information to identify where the disturbances occurred and to then use high resolution in formation to quantify the impact on C pools (e.g., by establishing the proportion of the burned area that remained after the fire).

New technologies such as airborne or satellite lidar technology give information on stand and tree heights and may be available operationally by the time the first commitment period begins

Remote sensing is not suitable for the direct estimation of dead organic matter pools or soil C pools. Remote sensing can, however, provide important information on site characteristics, such as drainage, slope position, geological land form, and other attributes that can be useful to derive estimates of dead organic matter and soil C pools.

4.3.4 Providing Data to Support Process Modelling

As an alternative to establishing levels of C stocks in 2008 and 2012, and to then calculate the difference, it has been proposed to simulate the C flows and to calculate the change in C stock from the flow estimates. This approach will be further discussed in Section 4.6.

Remote sensing can provide some of the data that would be required to develop such simulation models. For example, estimates of surface temperature, normalized difference vegetation index (NDVI), leaf area index, and absorbed photosynthetically active radiation (APAR) and other indicators that are correlated with ecosystem net primary productivity (NPP) have been obtained through remote sensing studies.

It is important to emphasise, however, that net primary productivity is not a measure of the net ecosystem C fluxes. To estimate net ecosystem productivity (NEP) it is required to also obtain estimates of decomposition losses. Moreover, estimation of net biome productivity (NBP, i.e. NEP minus losses from forest fires and other disturbances) requires that disturbance information is incorporated into the modelling approach. Remote sensing can again play a role in obtaining such disturbance information, but the information must be combined with various modelling tools.

Remote sensing information could be used to obtain local and between-year variation in factors that determine forest growth and decomposition processes. At present, many ecosystem models that represent C dynamics use average growing conditions. Even if such models are accurate on average, they may significantly over or under-estimate the actual biomass growth in any given five-year period due to annual variation in rainfall, temperature, insect populations etc. Information obtained by remote sensing may be used to assess whether the prevalent conditions in each five-year period were typical or atypical of the conditions for which the models were calibrated.

4.4 Ground Measurements of Carbon Stocks

Ground measurements are used to measure stand volume, to support classification and calibration of remote sensing information, to develop relationships between forest volume and biomass C pools, to obtain estimates of dead organic matter pools, and to calibrate and verify simulation models.

Ground measurements can only provide observations at one point in time, unless they are conducted in permanent sample plots that allow for repeat measurement at the same location. In such plots it is also possible to measure processes, such as litterfall and biomass input to dead organic matter pools. Process information is required for the parameterisation of simulation models that describe the dynamics of C stocks over time.

At present, provincial inventories generally do not include ground measurements of non-timber indicators, such as dead organic matter, coarse woody debris, or soil organic matter. The design for the NFI is recommending that coarse woody debris (CWD) measurements are obtained on a minimum of 50 plots per ecozone. Other soil C attributes, however, are difficult to measure on PSP’s due the destructive nature of the measurement procedures. The NFI may also include shrubs and herbs in biomass units, by species, with a ten-year suggested re-measurement period.

Few PSP’s of the NFI would be expected to fall within the area of the Kyoto Forest. The NFI PSP sample grid suggests the random selection of points within each ecozone, so that some PSP’s could occur on non-forest sites that could be candidates for afforestation. Deforestation events, however, are not likely to occur in a PSP. Some PSP’s may include regenerating sites. It would be possible to experimentally deforest some PSPs (or adjacent areas) in order to obtain ground measurements of the resulting C stock changes.

In the past, one major problem with the available information on dead organic matter pools has been that the information is often collected without adequate reference to the stand conditions in which the samples were collected. Simulation-modelling exercises have demonstrated the importance of disturbance history on the size of dead organic matter pools. Estimates of dead organic matter pools obtained without an indication of disturbance history are therefore of limited use in the calibration of simulation models.

Given the typically very large within-site variability of dead organic matter pools, ground measurements at the beginning and end of a 5-year period may not be able to detect changes in C stocks reliably. The ability to detect change will be greatest in areas affected by RAD activities, such as deforestation and afforestation.

4.5 Carbon Flux Measurements

One alternative to measuring C stocks at two points in time and estimating the annual change is to obtain direct measurements of the C flux of an area. Techniques are available to measure C flux over an area using flux towers. Such installations are very expensive and tend to operate over a limited period of time (i.e., a growing season). They are less suitable for the measurement of C fluxes over a five-year period.

Flux measurements can only determine the net C flux over a specified region. It is not possible to partition the observed net flux to different forest stands within the area over which the C flux is integrated, or to different C pools within that area. In order to contribute to the reporting requirements for the Kyoto Protocol, the entire “footprint” of the tower must be an area for which a reporting requirement is established. If some of the area is inside the Kyoto Forest and the remainder is not, the observed flux cannot be partitioned to the two areas. Moreover, if the international negotiations were to decide that biomass but not dead organic matter C stock changes are to be reported, flux measurements will be unable to partition the observed net flux to the various ecosystem C pools.

Flux measurements for the 5-year commitment period cannot be obtained in areas that have become Kyoto Forest during the commitment period because the time between 2008 and the activity that established the reporting requirement was not monitored.

Flux measurements are, however, the only way in which the net C flux of an area can be quantified. They will therefore continue to play an important role in research and provide data required for the calibration and verification of simulation models.

4.6 Summary

Various tools and techniques are available to address aspects of the reporting requirements of the Kyoto Protocol and the FCCC. Forest inventories provide extensive coverage and information about land cover and timber volumes at one point in time. Simulation models are available to convert timber volume to estimates of biomass C pools, and to simulate stand-level changes in C stocks. Landscape-level models such as the Carbon Budget Model of the Canadian Forest Sector combine information from forest inventories, forest management and disturbance statistics and stand dynamics to estimate C stocks and their changes over time.

Remote sensing information appears best suited to provide information on significant change in land cover associated with deforestation, major burns or clearcutting. Subtle changes such as from partial cutting, insects and diseases, and slow changes such as regeneration and afforestation require sophisticated techniques that require proving and further development. Information from other sources will often be required to determine whether the observed changes resulted from RAD activities and therefore established a reporting requirement. Detailed information required to determine changes in C stocks is difficult or impossible to obtain reliably with current technology. Technological development in the field is rapid, however, and the contribution of remote sensing information to meeting reporting requirements will likely increase as new data acquisition and processing techniques are introduced. Remote sensing has the advantage of being open, transparent and verifiable.

Ground measurements of C stocks or C fluxes provide important site-specific information and are required for the parameterisation and verification of simulation models.

None of the existing tools and approaches alone is capable of meeting the requirements outlined in Section 3 of this report and to satisfy the reporting needs for either the Kyoto Protocol or the FCCC. This objective can only be achieved by combining existing and new technologies into an integrated information system framework. Such a system will be described in the next Section of this report.

5.0 An Integrated Measurement and Reporting System

Reporting requirements exist under the Kyoto Protocol and under the UN Framework Convention on Climate Change. Both require information on the change in C stocks, but they are concerned about different areas: the so-called Kyoto Forest for the Kyoto Protocol, and the managed forest for the FCCC. The international scientific community is further interested in the change in C stocks in the total forest area, because it is ultimately contributing to the net exchange of C between Canada's forests and the atmosphere.

To meet these reporting requirements, information from a wide range of sources needs to be compiled, integrated, and synthesised. At present, there is no information system in Canada that can be used for the purpose, but existing tools and approaches can play important roles in such a system. The following section outlines the major tasks that need to be accomplished by the information system. It describes the main components of the system and the linkages between these components.

5.1 The Main Components of the System

The information system will be comprised of several components, each of which will fulfill specific functions. The main functions are:

- data acquisition
- data storage
- models
- parameter databases
- reporting tools
- verification

Several options are available to provide some of these functions. The most important role of the information system will be to provide the structure, standards, and interfaces to integrate the information flow between the various components. As will be discussed below, there is no single best option. The suggested approach instead is to build an overall framework that will enable the use of the most appropriate tools for the tasks. The relative importance of each option will depend in part on the outcome of the negotiations on the implementation of the Kyoto Protocol, which will determine the extent of the Kyoto Forest and the types of activities and the C pools that need to be tracked.

Table 5.1 summarises the main functional components of the system. One or more approaches or tools can accomplish each function. The purpose of the overall framework is to integrate the required functions to fulfill the reporting and verification requirements. Each main function and the available options will be described below.

Table 5.1: Summary matrix of the main functional components of a national C accounting system. The diagonal cells of the matrix (shaded) describe the primary functions of each component, the remaining cells describe the flow of information from one component (row) to another component (column). A row of the matrix describes the function of and the output from a component and a column describes the function of and the input to a component.

To: From:	Data Acquisition	Data Storage	Models	Parameter Databases	Other
Data Acquisition	Obtain data on: • Area of Kyoto Forest • Stratification of the area • Stand volume & C stock • Dead Organic Matter C	Relevant data on area, stratification, volume, C stocks etc.		Primary data on C distribution among biomass components	For verification, metadata on sources of data and methods used
Data Storage		Spatially explicit compilation of actual measurements, store model projections	Measured data on C stock, stratified area of Kyoto Forest		For reporting and verification, area and C stock at start and end of commitment period, and when measured
Models		Extrapolated data, space time to 2008, 2012 etc, C stock for stands and landscape	Extrapolate measurements in space and time, stand and landscape C dynamics		For verification, description of models
Parameter Databases			Parameters to convert volume to aboveground C, root biomass, dead organic matter, etc.	Aboveground biomass compo-nents, root biomass, dead organic matter dynamics parameters	For verification, metadata on sources of parameters
Other					Reporting Function, application of correct C accounting methods, support verification

5.1.1 Data Acquisition

Data acquisition refers to the tasks involved in obtaining the basic information on where human-induced activities have resulted in the creation of "Kyoto Forest" and information on the C stocks of these areas. Table 5.2 outlines six options for obtaining data on forest cover changes that may result in the creation of Kyoto Forest and options for determining the associated changes in C stocks.

Remote Sensing, complete coverage

One approach to determining all areas that qualify as Kyoto Forest is to obtain complete remote sensing coverage of land cover in 1990, and then again in 2008 and 2012. Any area that changed land cover between 1990 and 2012 is potentially included in the Kyoto Forest, if the cause of the change is one of the qualifying direct human activities. Additional intermediate measurements of land cover may be required to detect sequences of activities that qualify the area as Kyoto Forest but that start and end in the same land cover class. For example, afforestation of marginal agricultural land in 1992, followed by cutting or natural disturbance of the stand in 2010, will in 1990 and 2012 show non-forest, but may result in a reporting requirement of C stock changes because of the afforestation that occurred in 1992.

Remote sensing can provide information on land cover changes, but except in specific cases, the information is insufficient to also identify the cause of the change. Thus the remote sensing information has to be augmented with data on the cause of the cover change, and these data will have to be obtained through alternate means, such as the activity reporting approach described below.

Remote sensing information with complete coverage can play an important role for C stock reporting for the entire managed forest or for the total forest. It will likely play only a supportive role if the Kyoto Forest is limited to areas affected by afforestation and deforestation.

Remote Sensing, statistical subsample

An alternative to complete coverage is to develop a statistical subsample of the area for which the assessment will be conducted. For example, the new National Forest Information system (NFI) will be based on a grid-based subsample of the entire forest area. This will provide a statistically valid basis for extrapolation of the results to a broader area.

The ability of the subsample-based approach to develop accurate estimates of the area affected by RAD activities will depend on the grid-density and on the extent of the Kyoto Forest. If the grid points are sparse and only limited activities will create Kyoto Forest, then the chances of detecting such activities on one of the grid points will be very small. National estimates of C stock changes in the Kyoto Forest that are based on the extrapolation from these few grid points to the entire country may be inaccurate.

Remote sensing with a subsample-based approach can play an important role for C stock reporting for the entire managed forest or for the total forest.

Determination of change in inventories

Forest inventories maintained by industry or governments are an integral part of forest management systems. They will be updated regardless of the future reporting requirements under the Kyoto Protocol or the FCCC. Where these are maintained as spatially explicit inventories and where consistent inventory methods are used, it will be possible to use successive inventories to detect changes in forest cover. As with remote sensing information, two pieces of information are required, the change in forest cover and the determination of its cause. While some inventories may maintain information on the cause of cover change, in others supplemental information from outside sources may be required.

Forest inventories also contain information about stand volume, and often stratify the forest area on the basis of ecological zones, site quality or other information that can be used for the calculation of growth rates and stand dynamics. This information will be very valuable for the estimation of C stock changes because it supports the selection of site-specific growth equations or stand dynamics models.

One limitation of data acquisition based on comparing successive forest inventories is that some RAD activities will likely occur in areas that are not included in the inventory. For example, marginal agricultural land suitable for afforestation may not be included in the forest inventory, and some deforestation activities such as hydroelectric developments or mining activities may occur outside the timber-productive forest area.

Observing change in forest cover in successive forest inventories can play a role in the acquisition of data on the area of the Kyoto Forest, regardless of the definitions chosen by the international negotiators.

Activity Reporting

All previous methods of data acquisition focussed on area first, and then required supplemental information on the cause of the observed changes. An alternative approach focuses on the reporting of those human activities that result in the creation of Kyoto Forest, and then seeks to establish the location and area affected by these activities.

An activity reporting system would require voluntary or legislated reporting of human activities specified in the Kyoto Protocol. A reporting system that tracks RAD activities will play a central role in a national information system in conjunction with some of the other methods for obtaining data on forest cover change because it will enable the attribution of deserved changes to human activities. To permit cross-referencing between the cover changes observed either from remote sensing or inventory information, the RAD tracking system should be spatially explicit. This will also support future verification programs.

Activity reporting could be the most efficient approach if the area of the Kyoto Forest is limited to afforestation and deforestation activities only, and does not include the area affected by reforestation that is part of the forest management cycle. If this were the case, then the area of Kyoto Forest in Canada would be very limited, and approaches based on monitoring changes in land cover would have to cover a large area to find a the very limited area affected by afforestation or deforestation.

Activity reporting is the only feasible approach for the detection of “additional forest activities”, i.e. those activities that may result in a change of C stock that may in the future be included based on Article 3.4 of the Kyoto Protocol. Such activities are likely to change stand growth but not forest cover and are therefore not readily observed through remote sensing.

Ground Measurements of C stocks

The last two methods of this list, both based on direct ground measurements of C stocks or fluxes are not suitable to determine the area of the Kyoto Forest. Ground measurements of forest cover and C stocks can be used to collect detailed data on forest C stocks and their changes over time. They are the only feasible method for obtaining primary data on C stocks in dead organic matter such as coarse woody debris, litter, and soil C. They will also be required to obtain calibration data for growth and yield models and other models of ecosystem C dynamics.

One limitation of existing databases and inventories of dead organic matter pools is that they typically do not contain information on the disturbance history of the stand. Past disturbances are, however, a major factor determining C pool size, and without this information the available data are of limited use for the calibration of ecosystem C dynamics models.

Ground measurements of C stocks will play a major role in providing data on C stocks and dynamics of selected ecosystems. Such measurements should be stratified according to ecological zones and other criteria that are used to predict stand C dynamics. Ground measurements will also be required for areas not typically studied, e.g. areas deforested after 1990 that may continue to emit C during the first commitment period.

Ground Measurements of C fluxes

The approaches listed above all calculate C stock change as the difference between stocks at the beginning and end of a commitment period. An alternative approach is to integrate the C fluxes over the 5-year period for patches of Kyoto Forest. Flux towers can be used to obtain direct measurements of C fluxes for a specific area. Flux towers are a research tool that will likely not play a major role in meeting the reporting requirements because of the very high cost, and the inability to differentiate the exact source and sink pools of the observed fluxes. The primary role of flux measurements in a national C information system will be to obtain independent data for validation and calibration of ecosystem dynamics models.

In summary, various options are available for the acquisition of data on the area of the Kyoto Forest and on the C stock and C stock changes in the Kyoto Forest, the managed forest or the total forest area (Table 5.2). The relative contribution of each method to meeting the national reporting requirements will depend on the choice of definitions for the Kyoto Protocol and on which reporting requirement is to be met. In all cases, a mixture of methods will likely be applied, and the most important contribution of the national reporting system will be the integrating framework that can accommodate and combine data from the various sources.

Table 5.2: Options for the acquisition of data on area and C stocks.

Tool Description	Function	Capabilities / Strength	Limitations / Weakness	Gaps in knowledge	Other issues
Remote Sensing – comprehensive coverage	Obtain data on land cover through aerial photo or satellite	Can cover large areas, can be verified, can detect drastic cover changes, data on areas affected	Limited ability to quantify C stocks, in particular DOM and soil C	Requires additional information on cause of change	Technology evolving rapidly, data for 190 available for reconstruction of past conditions.
Remote Sensing – statistical subsample	Obtain data on land cover for specific grid points only	Statistically valid, more cost effective than comprehensive coverage	Would provide only limited coverage and overlap with RAD area limited	Requires additional information on cause of change	Technology evolving rapidly
Determination of change in Inventories	Compare consecutive inventories to determine changes	Builds on existing tools, least incremental cost, cause of change may be included	Limited coverage, i.e. not farmland (A) and some non-productive areas	Some change due to variation in inventory methods, difficult to verify	Inventories central to forest management, maintained regardless of reporting requirements
Activity Reporting	Compile data on RAD activities through census or other reporting forms	All human-induced RAD activities could be compiled, if incentive is provided	Difficult to verify, compliance will be an issue	Reporting compliance unknown but will determine success	Difficult and expensive to administer
Ground Measurement - Stock	Obtain direct measures of C stock in biomass, dead organic matter and soil	Accurate, verifiable, direct, based on temporary or permanent sample plots	Point measure in space and time, stand history important for C stocks but often unknown	Uncertainties about spatial variability in soil C	Primary data for many models
Ground Measurement - Flux	Obtain direct measures of C flux, e.g. through flux towers	Only way to obtain direct measures of flux, use to verify and calibrate process models	Limited to area of footprint of flux tower, cannot separate sources/sinks within area	Does not measure C flux during disturbances such as fire or harvest	Research tool, limited applicability, expensive

5.1.2 Data Storage

Two data storage functions are required for the national reporting system. The first contains the compilation of relevant inventory information, the second is a database of derived inventory information, computed from models that extrapolate measurements in space and time.

Compilation of Inventories

This database will contain data derived through the various data acquisition methods described above. In addition to storing the relevant information, it will ensure consistency of data formats and a consistent spatial reference system. It will be a spatially referenced inventory system that can be compiled from a variety of data sources. This database should be spatially explicit:

1. to avoid double counting of areas for which information was obtained through more than one source;
2. to facilitate modelling of C stock changes of these areas which may require information about site location and site characteristics;
3. to ensure that the reported area of the Kyoto Forest can be verified and audited through ground measurements; and
4. to track subsequent events, such as human or natural disturbances, that may affect the C stock of the Kyoto Forest.

This inventory should also contain a compilation of areas affected by RAD activities, including additional relevant information that may be available about these areas, such as ecological stratification, C stock prior to human activity, last observed C stock, etc. Compiling the required information on RAD activities from 1990 to the time that the inventory will be created will be a substantial challenge.

The information contained in this compiled inventory can then be extrapolated in space, i.e., to other locations that are in a similar ecological zone and are affected by the same RAD activities, or in time, i.e., to past or future years as required for the calculation of stock changes during a commitment period.

Database of projected measurements

The second database of the reporting systems will contain the projected data derived by combining the inventory information with models that extrapolate measurements in space or time. For example, models could project the actual measurements of C stocks, compiled in the first database and obtained over a period of years, to a common reference year, e.g., 2008, and store this information in the second database.

The rationale for separating the primary information and the derived information into two separate databases is that this will enable a clear distinction between measured C stocks and those obtained from model projections. Moreover, as new models become available, the same primary information can be combined with two or more alternative models and their results could be compiled in separate databases. By separating the databases the size of the individual databases will also be more reasonable.

Table 5.3: The main data storage requirements of a national C reporting system.

Tool Description	Function	Capabilities / Strength	Limitations / Weakness	Gaps in knowledge	Other issues
Forest Inventories	Store information from ground data or remote sensing	Provides info on points in time for large area, well developed technology	Static, most inventories limited to stem volume	Typically no data on dead organic matter C stocks	Need to create a central inventory with standard data format
RAD activity inventory	To store spatially explicit information on RAD activities	Focus on Kyoto Forest, can be comprehensive	Static, would be limited to Kyoto Forest	System does not exist	This is a core requirement, could be component of first database
Database of projected C stocks	Store data on all C stocks from models that project inventory information over space and time	Synthesis framework for all information sources and model results, for Kyoto Forest, managed and total forest area		Database does not exist, will require detailed planning prior to implementation	This is a core requirement, it is the central database for all reporting and verification functions

5.1.3 Models

Four types of models will potentially be required for the reporting system:

- models for the extrapolation of measurements of volume or C stocks in space,
- growth and yield models to project volume dynamics over time,
- ecosystem C dynamics models with which to project above and belowground biomass and dead organic matter pools of individual ecosystems, and
- landscape-level C dynamics that project the age-class distribution and dynamics of many ecosystems.

Some of these models could be nested, i.e. the ecosystem dynamics model could make use of a growth and yield model to drive stand volume projections, and the landscape-level model could incorporate ecosystem-level C dynamics model.

Spatial Extrapolation

Some of the ways of acquiring data on area and C stocks will result in point measurements that need to be extrapolated over wider areas. Extrapolation methods rely on first stratifying the area information into classes with similar attributes, such as ecological zones, site classes, forest types, stand age or others, and then correlating measured C stock values with other attributes. These correlations then become the basis for spatial extrapolations. The most appropriate approach will depend on the regional conditions and the way in which the original data were obtained.

Growth and Yield Models

There are dozens of growth and yield models in Canada. Most of these models are maintained by provincial agencies and industry for timber management and planning. These models are calibrated to the species, site and ecological conditions of the region in which they are applied. Generally, such models project stand volume information over time, and many of them are designed to operate with the inventory format used by an agency or forest company.

Some growth and yield models contain the regional calibration data that enable them to also extrapolate measured information in space. For example, in BC the southern-interior variant of Prognosis uses information on biogeoclimatic variant, slope, aspect and elevation to modify the projections of growth rates.

The strength of many of these models is that their growth equations have been calibrated from permanent sample plots, and their projections are thus often based on very large numbers of field observations. Their limitations are that most are limited to predicting stem volume and that often the dynamics of young stands are poorly represented. Moreover, most models use empirical growth equations that are not responsive to changes in environmental conditions due to global change.

The choice of which growth and yield models to use for the national reporting system will depend on the regional circumstances and the available models. The role of the national reporting system will be to provide the standardized inventory information that will permit the use of regionally calibrated growth models for the projection of stand volume.

Ecosystem Dynamics Models

Ecosystem dynamics models predict changes in all ecosystem C pools, including above and belowground biomass and dead organic matter pools, such as litter, coarse woody debris and soil organic matter. The two main purposes of these models are to predict the dynamics of all biomass components (not just stem volume) and to link changes in dead organic matter pools to stand dynamics, management impacts, and disturbances.

Given that it will not be feasible to measure the C stock of all areas of the Kyoto Forest in the first and last year of each commitment period, ecosystem dynamic models need to be developed with which to extrapolate measurements in both space and time. In the first commitment period, all of the area of the Kyoto Forest will contain stands that are less than 23 years old, because all stands will be created from activities since 1990. The ecosystem C dynamics models must therefore be well calibrated for the dynamics of young stands.

Simulation models will be required to project estimates of C stock forwards or backwards in time. For example, RAD activities that occur after 2008 will establish the need to estimate the C stock of an area in 2008. Simulation models that are based on “look-up” tables are easily capable of simulating backwards in time. Most ecosystem dynamics models, such as the CBM-CFS2 simulate processes and they are typically not capable of running backwards in time. The design of the models that will be used with the national reporting systems must accommodate the need to project C stock changes backwards in time.

Ecosystem models are typically research tools that are not used in operational forest management. These models can be driven either by empirical growth equations (i.e. a growth and yield model) or through the simulation of biological processes. The former approach benefits from the large amount of growth and yield research that has been conducted in Canada, and from the very large number of measurements from permanent sample plots. The limitation of empirical growth models is that they are not responsive to global change. A simulation approach based on process modelling, however, will be more difficult to calibrate to regional and site-specific conditions, but may be designed to account for the impacts of global change on C dynamics.

Landscape-level C dynamics Models

Landscape-level C dynamics models are required to quantify the changes in C stocks over a larger area. These models calculate changes in C stocks from the area and C stock information of individual stands, and from the age-class distribution of the stands in the landscape. They are required to integrate the information on C stock changes from a large number of stands or ecosystems. Many landscape-level processes, such as fire or harvesting cannot be adequately addressed with stand-level models alone.

Operational forest management often employs landscape-level models of stand volume dynamics for planning of harvest schedules or other management activities. Thus three important aspects of landscape-level analyses are routinely addressed in forest management: the scaling from stand to landscape, the simulation of the dynamics of individual stands, and the representation of landscape-level dynamics. For the analysis of C dynamics the indicators generated by such models need to be expanded to include C stocks in all ecosystem C pools.

The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2, Kurz et al. 1992, Kurz and Apps 1999) is a landscape-level C dynamics model that has been applied to analyses at various spatial scales. It is initialised with inventory information and then projects changes in ecosystem C stocks resulting from forest dynamics, natural disturbances, and forest management activities. The model simulates above- and belowground biomass C pools, as well as dead organic matter C pools (including surface litter, coarse woody debris, and soil C).

The model represents forest growth using curves that describe biomass dynamics as a function of stand age for 457 different ecosystem types. It predicts belowground biomass using allometric regression equations (Kurz et al. 1996). Dead organic matter dynamics are simulated based on litter input, decomposition losses, and the input and release of C during disturbances.

The model has been used at scales ranging from a single 1 million ha forest management unit (Price et al. 1997) to the 404 million ha of forests in Canada (Kurz and Apps 1999). At the national scale, model simulations were based on inventory information from the 1985 National Biomass Inventory (Bonnor 1985). The more recent National Biomass Inventory (Penner et al. 1997) provides an opportunity for updating the input data to the model, but this has not yet been done. The CBM-CFS2 has been used for retrospective (i.e., 1920 to 1989) (Kurz et al. 1995, Kurz and Apps, 1999) and projective (i.e., 1990 to 2040) analyses at the national scale (Kurz and Apps 1995).

Landscape-level models that provide similar functions are required to operate with the information that will be contained in the inventory of the Kyoto Forest, or with inventories of the managed or the total forest area. The output of such a model which describes the C stock at various times can then be stored in the secondary databases.

Table 5.4: The main modelling functions required in the national C reporting system.

Tool Description	Function	Capabilities / Strength	Limitations / Weakness	Gaps in knowledge	Other issues
Spatial extrapolation methods	Extrapolate point measures and remote sensing info to larger area	Build on ecosystem classification where available, greatly increases value of ground measurements	Static, relies on correlation,	Need correlation between site / ecological attributes and C stocks	Functionality can be incorporated in growth and yield models
Growth and yield models	Extrapolate point measures of stand volume in time, predict growth	Well established knowledge base and calibration data	Most models are limited to stem volume	Dynamics of young stands poorly understood	Builds on large databases from permanent sample plots
Stand-level C dynamics models	Extrapolate volume to total ecosystem C dynamics or predict C dynamics from process models	Can address all C pools, represent their dynamics	Limited calibration data, mostly research tools	Biggest uncertainties in soil and DOM C dynamics	Essential requirement to project ground measurements in time
Landscape-level C dynamics models	Simulate landscape level C dynamics, disturbances and management impacts	Ultimate tools to integrate many processes operating in space and time	Difficult to obtain initial conditions for dead organic matter, data intensive	Disturbance impacts, soil and DOM C dynamics	CBM-CFS has laid foundation for work in Canada

5.1.4 Parameter Databases

One important contribution of a national C reporting system can be to develop and maintain databases with parameters, methods and other information that will be required for all analyses of forest ecosystem C dynamics. While there is considerable regionally-calibrated information on the growth and yield of stem volume, much less is known about the other biomass components of a stand, root biomass, and the amounts and dynamics of dead organic matter pools.

The reporting requirements of C stock changes will result in an increased need for parameters and methods with which to expand the readily available information on stem volume dynamics to other ecosystem C pools. Thus numerous analysts in resource management agencies, forest industry, and research organizations will be facing the same challenges, and will embark on reviews of a limited number of research studies. The important contribution of a nationally-coordinated reporting system on C stocks could be to support the development (or refinement) of parameter databases that will then be readily available to all analysts that require this information. Canadian analysts would benefit if the required information were compiled, peer-reviewed, and standardised for use in models and other analyses. The nationally coordinated development of methods and parameter databases will greatly increase the credibility of the models that will be required to develop verifiable estimates of C stock changes, and will facilitate the verification of the reported results.

Three major groups of parameters and methods are identified here.

Expansion factors to convert stem volume to other aboveground biomass components

Growth and yield information readily available for many parts of Canada reports changes in stand volume over time. To assess changes in ecosystem C storage, volume statistics need to be expanded to total aboveground biomass, including non-merchantable stemwood (tops and stumps), branches and foliage.

Parameters and regression equations will be required to convert stem volume to stand biomass C. Through the support of ENFOR and other research programs, Canadian scientists have compiled a large number of regression equations for the prediction of tree biomass of various species. Such equations are, however, typically individual tree equations, and additional work will be required to obtain means of converting estimates of stem volume per hectare to aboveground biomass C per hectare (e.g., Penner et al. 1997). As methods and models are developed for these tasks, they should be compiled in an evolving database system.

Parameters for the calculation of belowground root biomass

If future negotiations on the implementation of the Kyoto Protocol include belowground biomass C and dead organic matter C in the reported C pools, then it will also be necessary to develop means for estimating their size and dynamics.

Methods for estimating belowground biomass C as a function of aboveground biomass have been developed for use with the Carbon Budget Model of the Canadian Forest Sector (Kurz et al. 1996). The database that contains the underlying information from a large number of root biomass studies in temperate and boreal forests should be maintained and updated as new information from root biomass studies becomes available.

The regression equations developed from these studies present an important alternative to excavation and direct determination of root biomass in forest ecosystems. It is recognised that numerous factors could cause a difference between the predicted and the actual root biomass of a specific stand. As long as the same methods are used to predict root biomass at the beginning and end of the 5-year commitment period, these differences will, however, be acceptable for regional analyses. Moreover, there is at present no viable alternative to determination of root biomass at an operational scale.

Parameters for the initialisation and simulation of dead organic matter pools

Perhaps the biggest uncertainties related to the estimation of ecosystem C pool dynamics are associated with the estimates of the size and the dynamics of the dead organic matter pools. These include litter, coarse woody debris and soil C. The CFS has developed a large database on soil C pool sizes in forest ecosystems (Siltanen et al. 1997). This database should be maintained and updated, as new information becomes available.

Additional information is required on the size of dead organic matter pools, and on how they are affected by the disturbance history of a stand. Such information is critically important for the initialisation of dead organic matter pools in stand and landscape-level C dynamics models. The CBM-CFS2 establishes initial conditions in DOM pools based on a combination of information derived from databases and simulation of past stand dynamics and disturbances (see Kurz and Apps 1999 for a description of the approach and the associated uncertainty).

The simulation of dead organic matter dynamics also requires parameters that describe the rate of litterfall and the input of biomass into the various organic matter pools. Moreover, rates on the decay of organic matter pools are also required. The CFS is currently taking part in a multi-year, national study on decomposition rates of dead organic matter (CIDET, Trofymow et al. 1995). The results from this and other studies should be compiled in a database on DOM dynamics parameters.

Table 5.5: The supplemental databases and information requirements of the national C reporting system.

Tool Description	Function	Capabilities / Strength	Limitations / Weakness	Gaps in knowledge	Other issues
Aboveground biomass parameters	Estimate distri-bution of biomass among components (stem, branches, foliage, etc.)	Tree-based biomass equations for many species and some ecosystem types exist	Need stand-level biomass / ha distribution estimates	Major gaps for young stands – which will be most of Kyoto Forest initially	
Root biomass parameters	Estimate stand-level root biomass from aboveground biomass and species	Provides estimates of difficult to measure C stock through correlation with aboveground biomass	High variability between sites and ecosystems	Few studies on only some species and in some ecosystem types	Methods and regression equations published for CBM-CFS, database exists
Dead organic matter pools and dynamics parameters	Parameters for C stocks, litterfall, turnover, decay rates, etc.	Describe basic processes and rates of ecosystem-specific DOM dynamics, initialize models, enable extrapolation	Limited data, large spatial variability, disturbance history often not known	Disturbance response, interaction with management, climate change response	Work is ongoing in Canada, e.g. CIDET, CFS soil C database

5.1.5 Reporting Tools

The reporting tools required for the national reporting system must be able to query and summarise the information contained in the database of projected C stock estimates. These tools must be able to report C stock changes for various areas such as a region, Province, the Kyoto Forest, the managed forest, or the total forest area of Canada. Ideally, the tools should also be able to incorporate the various evolving definitions and accounting methods of the Kyoto Protocol, thus permitting an analysis of the consequences of selecting specific definitions.

The important contribution of a nationally coordinated approach will be to ensure that the methods used for accounting C stock changes are consistently applied and are in agreement with the international protocols. This also will facilitate verification of the reported results.

5.1.6 Scenario Analyses

The system described in Figure 5.1 could perform an additional important function, namely the analyses of future scenarios and the ability of the RAD activities to contribute towards meeting Canada's emission reductions targets. Moreover, the system could be used to assess how various alternative definitions under the Kyoto Protocol will affect the reported changes in C stocks and compare these to the actual changes observed in the inventory and the simulation models.

The main additional system design requirement is to ensure that the simulation models that perform the calculation of past and future C stocks in the database can accept data on RAD activities that have occurred, and also data describing alternative scenarios about future levels of RAD activities.

5.1.7 Verification

Two separate aspects of reported C stock changes could be verified: the reported values with their underlying component estimates of area and C stocks, and the system that was used to derive these estimates. At present, the term “verifiable estimates” used in Article 3.3 of the Kyoto Protocol is not specified further and either or both of these aspects may have to be verified in the future. The decision about the required verification process may be the outcome of future negotiations on the implementation of the Kyoto Protocol.

As discussed in the previous sections, the national C reporting system can contribute significantly to the verification process by providing peer-reviewed data acquisition, models, parameter sets and reporting methods. Moreover, by supporting a national system for tracking RAD activities, the quality of the reported data can be assessed and evaluated in the verification process.

The system should also provide a mechanism for model comparison, evaluation and peer review. It may even be appropriate to consider the concept of certification of models and methods that may be employed to operate on the primary information contained in the central inventory. Only results obtained from such models will then be accepted in the database of projected C stocks that forms the basis of the reporting system.

5.2 Summary of Options for Various Reporting Requirements

As is apparent from the preceding sections, there is a potentially large number of reporting requirements that result from various combinations of spatial scales, reporting protocols, and ecosystem C pools. Moreover, to meet these reporting requirements, different functional roles must be provided by the system. Several of these roles can be fulfilled using various alternative approaches.

The choice of the best options will depend on the future decisions of international negotiators about definitions that will affect the extent of the Kyoto Forest, the pools to report, and the methods to use. It is therefore probably more important at this time to ensure that the overall institutional framework is put into place and assigned the task to develop the reporting system than it is to select specific options for measurement and monitoring.

As will be shown below, the various reporting requirements primarily affect the way in which the area data will be acquired and the choice of tools to represent ecosystem C dynamics. Common to all cases is the need for an overall framework with which to store, analyse, and report the C stock information. As examples of how the options change with the reporting requirements, eight specific reporting tasks are briefly summarised below.

1. C stock changes in the Kyoto Forest limited to Afforestation and Deforestation

The smallest amount of Kyoto Forest would be created if the negotiated definitions of RAD activities would exclude reforestation following harvesting. Thus only deforestation and afforestation from direct human-induced activities would create Kyoto Forest. As a consequence the area of the Kyoto Forest will be quite small and data acquisition to determine the location of the Kyoto Forest should focus on an activity-reporting system, supported by supplemental information from remote sensing. The activity-reporting system could identify geographic focal areas in which afforestation and deforestation activities are located, and remote-sensing information analyses of these focal areas could confirm the spatial extent of the deforestation activities. Remote sensing is less well suited to detect afforestation activities, at least until the trees in the plantations have reached a size that can be detected through remote sensing. Once the area of the Kyoto Forest is determined, the C stocks and C stock changes in these areas will have to be estimated. The amount of C remaining in dead organic matter pools immediately following deforestation can vary significantly between the various options for the treatment of organic debris. Robinson et al. (1999) suggested a simple system to classify the fate of organic matter after deforestation.

To represent the C dynamics during the commitment period, ecosystem dynamics models will have to be calibrated for the two unique situations represented by afforestation and deforestation. For afforestation, i.e. the planting of trees on areas that have historically not contained trees, the challenge will be to find appropriate growth models and to represent the change in dead organic matter pools. Where deforestation results in a land use change to agriculture, the dead organic matter dynamics could be represented with one of the agricultural soil C models (e.g. CENTURY).

2. C stock changes in the Kyoto Forest with Reforestation, Afforestation and Deforestation

In Canada, the area of the Kyoto Forest will increase by at least one order of magnitude if reforestation following harvest is defined as one of the direct human activities that results in the creation of Kyoto Forest. Information on reforestation that is part of harvest cycle can be obtained from forest industry and provincial inventories. The C stock changes during the harvest – reforestation cycle are represented by ecosystem C models. Information on the afforestation and deforestation components can be obtained as described above. While there is considerable knowledge about the dynamics of aboveground biomass in Canada’s managed forest, information gaps remain about the size and dynamics of dead organic matter C pools.

3. C stock changes in the Kyoto Forest limited to reporting aboveground biomass C pools only

One possible outcome of the international negotiations is that the area of the Kyoto Forest will be defined as in 1 or 2 above, but that the C stocks that are included under the reporting requirements are limited to aboveground biomass C pools. This would significantly affect the options for measurement and reporting because following deforestation, there would be no need to track the fate of dead organic matter C pools. Moreover, for afforestation and reforestation, the required data would be limited to growth and yield information and means of expanding volume information to aboveground biomass. There would be no need to account for dead organic matter pools, and therefore less complex ecosystem C dynamics models can be used.

4. Reporting of C stock changes associated with additional activities under Article 3.4

In addition to the need to report C stock changes in those areas affected by RAD activities, it may become necessary in the second and subsequent commitment periods to account for C stock changes resulting from additional activities, as specified in Article 3.4 of the Kyoto Protocol. Data on the area affected by such activities can only be acquired through an activity-reporting system because neither forest inventories nor remote sensing techniques will be able to determine the changes associated with such activities. The additional challenge for the ecosystem C dynamics models will be to represent C stock changes resulting from such activities. Moreover, it has been suggested that only the incremental change in C stocks due to these activities will be credited. If international negotiators accept this approach, then ecosystem C models must be able to provide a baseline against which the incremental change will be determined.

5. Managed Forest (verifiable reporting)

An alternative approach to reporting C stock changes is to not limit the area to the Kyoto Forest but to include the entire managed forest. This would eliminate the need determine the area of the Kyoto Forest, i.e. the need to identify only those areas in which specific human activities have occurred. Instead, the information contained in continuous forest inventories can be used to provide information on the changes in stem volume, the age-class distribution of the forest, and the stratification by ecological zones and site classes. This information, combined with ecosystem dynamics models, and the other components of the reporting system can then be used to provide estimates of the changes in C stocks. To account for C dynamics of the entire managed forest, additional information will be required to account for the impacts of natural disturbances and management actions on the C stock in that area. Information on natural disturbances would otherwise only be required for those that affect C stocks in the Kyoto Forest.

To ensure that the reported C stock changes are verifiable, the system will require a spatially referenced forest inventory information system. This will also ensure that C stock estimates for the Kyoto Forest (which is largely contained within the managed forest) will be consistent with those obtained for the managed forest.

6. Managed Forest for FCCC reporting

The reporting of C stock changes in the managed forest without a need for verification can follow essentially the same methods as described in 5. Without the need for verification, it would be possible to use a non-spatial approach to modelling C stock changes, but the additional spatial information will also be useful for the parameterisation of the ecosystem C dynamics models.

7. C stocks in 1990

One special reporting requirement is the need to determine the C stocks in 1990. This requires data on the forest area, the age-class distribution of the forest, and the distribution of the area by various growth types, ecosystem types and site classes. For each category, the aboveground and belowground biomass and the C stock in dead organic matter pools need to be estimated. The latter requires some knowledge about the disturbance history of each site. The relevant information can be obtained from forest inventory information, ecological classification systems, growth and yield information, and disturbance statistics. As an alternative approach, a complete analysis of remote sensing information collected in 1990 could be undertaken. For example, Landsat images are available with nearly complete coverage of Canada.

The Carbon Budget Model of the Canadian Forest Sector has recently been used to estimate the C stocks in biomass and dead organic matter pools of the total forest area in Canada in 1990 (Kurz and Apps, 1999). This model represents Canada as 42 geographic areas containing 457 different ecosystem types. Improved estimates of the C stocks in 1990 could be obtained by combining the model with more recent forest inventory information that allows a greater degree of spatial resolution.

An alternative method for determining the C stock of a forest management area is to use a recent (after 1990) forest inventory and to extrapolate backwards to the conditions in 1990 using disturbance statistics for the area and a simulation model designed for that task (Kurz and Beukema, unpublished data).

8. C stocks in Total Forest

The C stock changes in the total forest area can be determined using the same approaches as were outlined for the managed forest. The main difference is that the forest inventory information outside the managed forest tends to be of much lower quality or missing. For example, to determine the biomass of those areas in the National Forest Inventory for which volume statistics are not available, both Bonner (1985) and Penner et al. (1997) had to make a series of assumptions about the vegetation characteristics and the age-class distribution of that vegetation. Estimates of C stocks in the total forest area could be improved by compiling more detailed forest inventory information for these areas. To estimate C stock changes, the impacts of natural disturbances and management actions in the total forest area would also have to be determined.

The Carbon Budget Model of the Canadian Forest Sector has been used to conduct analyses of past (Kurz et al. 1997, Kurz and Apps 1999) and future (Kurz and Apps 1995) C stock changes in the total forest area of Canada. As stated above, these estimates could be further refined by linking the model to the most recent national forest inventory.

5.3 Summary of the Integrated Measurement and Reporting System

A national system for measurement and reporting of C stock changes in Canada must be developed to meet the reporting requirements under the Kyoto Protocol, the UN FCCC and for other purposes. While each reporting requirement addresses a different proportion of the total forest area in Canada, the methods required to determine C stocks and their dynamics are rather similar. The functional requirements of a reporting system were discussed in the previous sections.

Figure 5.1 summarises the structure and relationships of the main functional components of the national reporting system. Central to the overall system will be an inventory containing data on the last observed state of the area. The spatial extent of this inventory could be only the Kyoto Forest, the managed forest, or the entire forest area of Canada. While the size of the inventory would vary considerably, for the purpose of this general discussion, in each case the inventory fulfills the same functional role, namely to store information obtained from measurements.

The data compiled in the central inventory could be obtained through various methods of data acquisition such as remote sensing, other inventories, RAD activity reporting, or ground measurements.

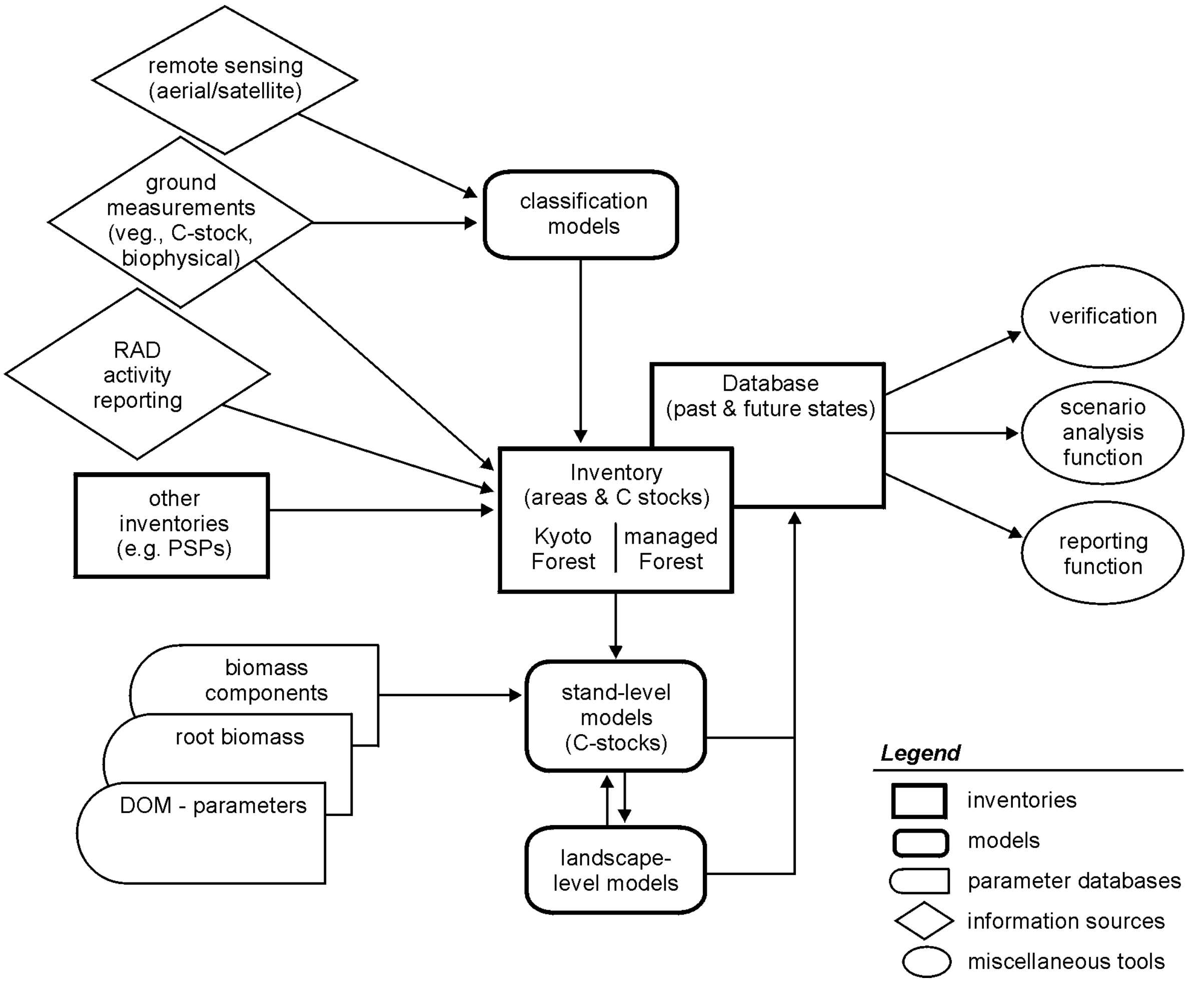

Figure 5.1: The main components of a national C measurement and reporting system.

Associated with this inventory should be a database system that contains information on past (e.g., 1990), current and future states of the area included in the inventory. The database will contain, for each area in the inventory, the estimated size of each C pool at various points in time. This information will be extrapolated in time using stand-level models of ecosystem C dynamics. It can also be extrapolated in space using models that are based on landscape correlation between site attributes, remote sensing information, and stand characteristics.

Landscape-level models can also be used to project changes in C pools due to forest growth, management and natural disturbances and will allow users to explore various scenario analyses. Once the other components are in place, the overall system outlined in Figure 5.1 will be able to provide a reporting function. Finally, the system will be the foundation for any verification and auditing processes.

The choice of the specific methods used to provide each of the functions and their relative importance will be affected by future definitions for the implementation of the Kyoto Protocol. For example, if RAD activities are limited to afforestation and deforestation, but exclude reforestation following harvest, the total area of the Kyoto Forest would be small. The most effective method for the acquisition of area estimates may be an activity-reporting system that tracks all afforestation and deforestation activities (although it would be difficult to obtain data from 1990 to the year in which the system is implemented). For the reporting of C stock changes in the total forest area of Canada, data acquisition on the area and age-class distribution of the various forest ecosystem types would best be accomplished through a remote sensing approach, based either on comprehensive coverage or a statistical sample of the area.

We recommend that a national system for measurement and reporting of C stock changes in Canada should:

- be a modular system whose primary role is to provide the framework for data compilation, synthesis and analysis,
- provide a central data storage facility that compiles primary inventory information
- provide the database structure to store the projected values of C stock estimates for past and future years,
- built upon the large body of data and knowledge developed for the purpose of forest management, including forest inventories, growth and yield models, and landscape-level planning models,
- develop and maintain methods and databases required for analyses of C stock changes, including biomass expansion factors, root biomass estimation, and dead organic matter dynamics,
- develop and maintain stand and landscape-level C dynamics models with which to estimate C stock changes for the areas included in the primary inventory, including the C dynamics affected by natural and human disturbances and climate change,
- co-ordinate the process and research required to improve and enhance the available data and models required for C stock reporting.

We suggest that the primary role of a national reporting system is to provide the framework for synthesis and integration of information compiled from a diversity of sources and processed using a variety of methods and models. Because of the wide range of approaches to data acquisition and modelling of C stock changes in forest ecosystems, it does not seem advisable at this time to recommend a single approach. Instead, we suggest putting in place and supporting a system that provides the framework for the co-ordination of data acquisition, storage and analysis as described in the previous sections of the report.

Industry, provincial resource management agencies, the Federal Government, and universities can then all use this general framework. Each user group can apply the tools for their regional analyses, using the data acquisition methods and inventories that are appropriate for the region. This will allow some users to build on detailed inventory information available for their forest management areas, while other users can use different methods and less detailed inventory information, e.g. for some remote northern areas with low productivity forests. The role of the reporting framework is to ensure that the results from the different user groups and for different regions are summarised in a spatially-referenced database system. This information can then be synthesised to meet the various reporting requirements.

6.0 Recommendations

6.1 From the Workshop

The following recommendations were compiled during the workshop:

1. Use systems analysis to identify the data components that contribute the largest uncertainty to total C flux due to RAD activities in order to determine priorities for data, research and methodological development (e.g., which RAD activities require closest monitoring, which C pools require most refined estimates).

   A first (very rough) approximation of this sensitivity analysis could be a useful component of the options paper that will be prepared by the Sinks Table.

2. Review data, methodological, and process uncertainties to determine priorities for research.

3. Recognise that the NFI will meet some needs of the reporting requirements but clearly not all. There is potential to significantly increase the NFI utility through design modifications:
   i) include information on coarse woody debris and soil C;
   ii) increase sampling density and re-measurement frequency in focal areas (i.e., in areas with high RAD activities); and
   iii) formalise the relationship between the NFI and the C measurement and reporting system.

4. Build a spatially-explicit accounting framework / model that is consistent across the country and can work with various data formats (i.e., provinces or forest companies can apply it and populate it with their own data). Ensure it is supported and documented, and allows national roll-up of the results. The framework, methods and data sources must all be documented, and the underlying data must be locatable (i.e., available on file somewhere).

   Difficulty will be that the provinces each have very different data for input. But a flexible framework can nonetheless be provided, as has been done internationally with the IPCC guidelines. It is highly desirable to co-ordinate a national effort to avoid the inefficiency of every province and forest company having to do independent literature searches for belowground biomass estimates and other parameters, conducting their own model validation and peer-review processes etc. Also, a national framework will provide a consistent set of assumptions for how data are applied, and will allow the provinces to support each other's research and data compilation efforts. Finally a centrally co-ordinated modelling system would ensure that the accounting methods are implemented consistently

5. Develop, test and demonstrate methods for land-use change detection via remote sensing.

6. Reduce the cost of using remote sensing data (acquisition and analysis).

7. Clarify the relationships between the NFI, provincial inventories, remote sensing, regeneration surveys (REGEN program), the National Forest Database, etc.

8. Review the applicability of existing models and identify the remaining gaps in our ability to project the required values (especially dead organic matter dynamics and dynamics of young stands). Ensure that each model to be applied to meeting the reporting requirements is tested and verified against

independent data. Note that the relative importance of data on young stands will decline in later commitment periods as the Kyoto Forest moves toward a broader age-class distribution.

9. Ensure a strong statistical basis underlies the design of sampling programs.

10. Collect and compile independent data sets for testing and verification of models and methods that are employed in the national reporting system

11. Collect and compile data on litterfall and other large plant residue inputs to dead organic matter pools on PSP's. Develop and compile data on decay rates in various ecosystem types across Canada. Maintain link between litter / dead organic matter parameter databases and the national C accounting system.

12. Identify means to extrapolate from plot data and model projections to the full area of interest, whether this is the Kyoto Forest or the entire managed forest. A key question is which ecological attributes should be the basis of the extrapolation procedure.

13. Based on the results of the prioritisation exercise (Recommendation 1), implement a Kyoto Forest tracking system. The sooner this is done, the less re-construction of past conditions and events that occurred since 1990 will be required later. Recall the distinction between area-based and activity-based approaches. The latter requires that some form of reporting incentive be put in place, in addition to a system to receive the data. For reforestation and afforestation, the incentive could be some form of credit (financial, C, or other). Explore how these options could be implemented, and the range of data sources that would have to be considered. The sensitivity analysis should reveal how much incentive is warranted for the acquisition of data on each activity. Note that the workshop participants expressed some concern that existing mandatory provincial reporting requirements do not work.

14. Establish a steering committee to take responsibility for carrying through with implementing the C accounting system, beyond the current lifetime of the Sinks Table. This will be needed in order to make "demonstrable progress" by 2005, as is required under the Protocol. Implementing the accounting system should be the responsibility of a specific *sector*, such as the CFS, rather than of a *program* such as the NFI. This could be consistent with the notion of a CFS "National Forest Information System".

    The steering committee should integrate federal and provincial interests. Membership should be drawn from CFS, and the agencies concerned with Energy, Environment, and Agriculture at both the federal and provincial level. Representatives from industry should be included because industry in many areas is compiling and maintaining forest inventory information.

    If the size of the steering committee exceeds an efficiency threshold, the committee should either appoint an 'executing group' responsible for carrying out or contracting the required work. The steering committee's main role will be to ensure that ongoing activities are integrated into a functional system that meets the national reporting requirements.

15. The C accounting system should be scientifically credible, designed for the long-term and operate through consecutive commitment periods. It should be made operational as soon as possible (substantial progress must be demonstrated by 2005). It must be able to evolve as time moves forward and improved technology becomes available.

16. Workshop participants repeatedly emphasised the importance of developing an information system, comprised of integrated inventories, databases, and simulation models, that applies consistent methodologies across various spatial scales. Such an approach is a prerequisite for the reporting of C stock change estimates that are consistent at the various spatial scales. In fact, such a system could also be applied at smaller spatial scales, such as the management area of a single forest company.

6.2 Additional Recommendations

17. Much of the Kyoto Forest area will be fringe or marginal agricultural or forested land. These areas are not typically included in either forestry or agricultural research. Thus, there is a need for information on C stocks and dynamics after afforestation or deforestation.

18. Special attention needs to be given to the impacts of stand history on the size of dead organic matter pools, which will differ greatly between stands that were previously affected by logging and those affected by wildfire or insects. Methods and inventory information need to be developed that assist in the determination of stand history and the resulting amounts of dead organic matter pools in forest ecosystems across Canada.

19. One very important role of the Steering Committee for the national C reporting system will be that of co-ordination and synthesis of ongoing activities, data collection and the development of information systems. It is therefore important to provide the institutional framework and the long-term commitment and funding (i.e. at least to 2012, the end of the first commitment period) to support the development and implementation of the reporting system.

20. The Steering Committee should ensure that the reporting system employs methods and models that are meeting the requirements of the verification process (once it is defined by the international negotiators).

21. The national C reporting system should provide the structure, standards, databases, and supporting information required to develop the components that will provide the various functions of the system.

22. The national C reporting system can most effectively be developed if it seeks to build upon the large body of scientific knowledge developed in the Canadian growth and yield modelling community. While it is recognised that most growth and yield models have limited capability to respond to the changes in growing conditions from global change, they do provide the synthesis of a large number of actual measurements of stand conditions and their change over time from ecosystems across all of Canada.

23. To address the issues of global change, some of the ecosystem dynamics models employed in the analyses of C stock changes should be process models that simulate ecosystem dynamics based on site and climate conditions.

24. One or more landscape-level C dynamics models will be required to integrate the C dynamics of a large number of ecosystems, as these are affected by growth, natural disturbances, and forest management activities.

25. The Carbon Budget Model of the Canadian Forest Sector can be used for sensitivity analyses to determine priority research needs and to conduct preliminary analyses of past and future C stocks in Canada's forest ecosystems.

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