Forest carbon accounting at the operational scale

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Canada's forests play an important role in the global carbon (C) cycle. Forest management activities, implemented at the operational scale, can have a significant impact on the C budget of Canada's forests. With the increasing national and international recognition that forest management activities can contribute to national C sources and sinks, forest managers could benefit from having a scientifically credible tool to assess the potential impacts of alternate management activities on the C stocks and stock changes on their land base. Such a tool must incorporate the best available science, be compliant with evolving international accounting rules and have enough flexibility to address the types of scenarios and management questions that are of interest to forest managers. To be cost effective and efficient for use by forest managers, the tool should make use of existing information on inventory, growth and yield, and disturbances that their analysts routinely use in their forest management planning activities. The readily available information must be augmented with additional data and modelling to estimate changes in those C pools that are not commonly included in forest inventories, such as carbon in the dead organic matter associated with litter, coarse woody debris and soil C. Building upon the past decade of work in the development and application of the C Budget Model of the Canadian Forest Sector (CBM-CFS2), the Canadian Forest Service C Accounting Team is now working with the Model Forest Network to develop, test and deliver an operational scale C accounting tool and its supporting databases with regional parameter values. When fully developed (2004), the operational model will be made available without charge to anyone interested in using it to estimate landscape level forest C stocks and C stock changes. Expertise developed within the extensive network of Model Forests and their partners in Canada will facilitate technology transfer and training of the larger user community. The tools and the technology transfer program will empower forest managers to include considerations of the impacts of the planned activities on forest C stocks. This will increase the potential use of forests and forest management activities in contributing towards a greenhouse gas emission reduction strategy.

Keywords: carbon cycle, carbon accounting, forest management, operational scale, land-use change, model forests, CBM-CFS2

Les forêts du Canada peuvent jouer un rôle important dans le cycle global du carbone (C). Les activités d'aménagement forestier, implantées à l'échelle opérationnelle, ont un impact significatif sur le bilan de C des forêts canadiennes. Suite à l'accroissement de la reconnaissance nationale et internationale que les activités d'aménagement forestier peuvent contribuer aux sources et aux réserves nationales de C, les aménagistes forestiers pourraient tirer partie d'un outil scientifiquement crédible pour évaluer les impacts potentiels des activités d'aménagement forestier sur les stocks de C et sur les variations de stocks sur leurs territoires. Ce type d'outils doit incorporer les meilleurs aspects scientifiques disponibles, être conforme aux règles internationales de comptabilité sans cesse en évolution et être suffisamment flexible pour faire répondre aux types de scénarios et de questions d'aménagement qui intéressent les aménagistes forestiers. Pour être efficient au niveau des coûts et d'utilisation par les aménagistes forestiers, cet outil doit tenir compte de l'information existante au niveau de l'inventaire, de la croissance et du rendement, et des perturbations que leurs analystes utilisent régulièrement dans leurs activités de planification de l'aménagement forestier. L'information déjà disponible doit être accompagnée de données additionnelles et doit être modeler pour estimer les modifications survenues dans les réservoirs de C qui ne sont pas habituellement compris dans les inventaires forestiers, comme le carbone dans la matière organique morte associée à la litière, aux débris ligneux grossiers et au C pédologique. À partir des travaux de la dernière décennie sur l'élaboration et l'application du Modèle de calcul du C du Secteur forestier canadien (CBM-CFS2), l'équipe de calcul du C du Service canadien des forêts travaille actuellement avec le Réseau des Forêts modèles pour élaborer, tester et produire un outil de calcul comptable du C à l'échelle opérationnelle tout en élaborant des banques de données contenant des valeurs des paramètres régionaux. Une fois l'élaboration terminée (2004), le modèle opérationnel sera mis à la disposition sans frais de toute personne intéressée à l'utiliser pour estimer le niveau des stocks de C pour un paysage donné ainsi que les variations dans les stocks de C. L'expertise développée au sein du réseau extensif des Forêts modèles et de leurs partenaires au Canada facilitera le transfert technologique et la formation pour les communautés plus importantes. Les outils et les programmes de transfert technologique permettront aux aménagistes forestiers d'inclure des considérations relatives aux impacts des activités planifiées sur les stocks de C. Cela accroîtra l'utilisation potentielle des forêts et des activités d'aménagement forestier au niveau de la contribution reliée à la stratégie de réduction des gaz à effet de serre.

Mots-clés: cycle du carbone, bilan du carbone, aménagement forestier, échelle opérationnelle, modification de l'utilisation du territoire, forêts modèles, CBM-CFS2

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Introduction

Canada's forests play an important role in the global carbon (C) cycle. Forest management activities, implemented at the operational scale, can have significant impacts on the C budget of Canada's forests at the operational and regional scale, and the cumulative effects can be of importance to the national net balance of greenhouse gas sources and sinks. With the growing national and international awareness that land use, land-use change and forestry can contribute to increasing C sources and sinks, it is generally anticipated that forest managers will need to assess the consequences of their actions on terrestrial C stocks. Forest managers are trained to conduct planning exercises that span decades or centuries, extend over large areas, and address multiple management objectives including timber, wildlife, socio-economic and other performance goals. Assessing changes in terrestrial C stocks, however, has until recently not been part of the considerations of most forest managers.

A net release of C from forests emits C into the atmosphere (source), while a net C uptake in forests removes C from the atmosphere (sink). Forest managers have the opportunity to contribute to reducing C sources and enhancing C sinks to address growing international concerns about C accumulation in the atmosphere, and the resulting impacts on the global climate system. Forest managers will likely face growing pressures from consumer groups to demonstrate that their actions do not have adverse impacts on the atmosphere. Tools are required to empower forest managers to assess and document the influence of their actions, and to help identify those management options that are beneficial to the atmosphere while also meeting other management objectives.

Much of the information required for analysing forest C stocks and stock changes is already gathered by forest managers for use in management planning activities. Detailed inventories, growth and yield information, and data describing natural disturbances required for forest management planning can also be used to assess forest C changes. This information must be augmented, however, with additional data and modelling to address those C stocks that are not commonly included in forest inventories, i.e. dead organic matter C stocks including litter, coarse woody debris and soil organic C. A scientifically credible tool is needed to bring together all of this information so that analysts can address the types of scenarios and management questions that are of interest to forest managers. As with all sustainable management issues, intense international scrutiny may be expected for any claims of carbon benefits through forest management. Scientific credibility is essential: the tool must be based on the best available science and must be compliant with evolving international C accounting rules.

Building upon the past decade of work in the development and application of the C Budget Model of the Canadian Forest Sector (CBM-CFS2) (Kurz *et al.* 1992; Kurz and Apps 1996, 1999; Apps *et al.* 1999), the Canadian Forest Service (CFS) C Accounting Team is now working with the Model Forest Network to develop, test and deliver an operational scale C accounting tool and its supporting databases with regional parameter values. This paper describes the ongoing development of this tool and how it is expected to support interested forest managers in their assessment of the influence of their actions on forest C stocks and stock changes.

Climate Change and Canada's Forest Sector

Human perturbations to the global C cycle, largely resulting from the burning of fossil fuels and the conversion of forests to non-forest land uses, have led to increased concentrations of carbon dioxide (CO_2) and other greenhouse gases in the earth's atmosphere. These gases are changing the earth's energy balance and are already resulting in observed impacts on the global climate system (Houghton *et al.* 2001). These impacts will have important consequences for the forestry sector in Canada. Although forest resources are likely to be significantly affected by anticipated climatic changes (Gitay *et al.* 2001), forest management can contribute to national efforts to mitigate these impacts (Kauppi *et al.* 2001). Several international processes, including Criteria and Indicators reporting, forest certification, the UNFCCC reporting requirements, and the Kyoto Protocol recognize the important contribution of forests to global biogeochemical cycles. Some of these processes involve voluntary measures. Countries that ratify the Kyoto Protocol make a legally binding commitment to limit their greenhouse gas emissions. Activities resulting from land use, land-use change and forestry can contribute both C sources and C sinks. Under the Kyoto Protocol, Canada's greenhouse gas emissions reduction target for all sectors would be 6% below 1990 levels during the five-year commitment period (Jan. 1, 2008 to Dec 31, 2012).

Ratification of the Kyoto Protocol will increase the need for accounting of C stock changes resulting from land use and land-use changes. The Protocol separates the accounting of land-use changes from the accounting of land use and forestry. Land-use changes involving forests include afforestation, reforestation and deforestation (ARD). Where afforestation and reforestation activities result in C stock increases during the commitment period, credits will be awarded for the uptake of C from the atmosphere. In the context of the Kyoto Protocol, reforestation is defined as the non-temporary conversion to forest of land that was non-forest on Dec. 31, 1989. Conversely, deforestation, i.e., the conversion of forest to a non-forest land use, can lead to C stock decreases during the commitment period. Net decreases in C stocks will result in C debits. Forest land temporarily non-stocked following harvest or natural disturbances does not constitute a land-use change. The accounting of C stock changes during the commitment period on areas affected by ARD land-use changes since 1990 is mandatory for countries that ratify the Protocol. Where ARD activities result in a net C sink, the credits can be used to offset emissions from other sectors. Where these activities result in a net C source, the debits will be added to the country's emissions balance.

Countries must also decide by 2006 whether or not to include forest management (and other forms of land use) in their national greenhouse gas balance. Where forest management creates a C sink (as defined under the Protocol), the associated C credit can be used, subject to a country-specific cap, to first offset a possible net source from ARD activities, and subject to a second cap, to offset emissions from other sectors. Where forest management activities create a net source, these greenhouse gas emissions will be added to a country's emissions balance.

A country's future forest C balance is affected by the impacts of past disturbances that determine the current forest age-class structure and the stocks of decomposing dead organic matter in the forest floor and soils. Whether or not forest management is a positive contribution to the national greenhouse gas balance therefore involves an assessment of the future forest dynamics under various scenarios of forest management activities, natural disturbance rates, growth rates and decomposition rates. Such analyses require tools that permit scenario analyses, sensitivity analyses, and risk assessment. The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2) has been used to conduct such analyses at the national scale.

Regardless of the outcome of the Kyoto Protocol, there is little disagreement about the observed increase in atmospheric CO_2, its causes and its predicted consequences (Houghton *et al.* 2001, Watson *et al.* 2001). Increasingly, forest managers will be asked to account for the impacts of their actions on terrestrial and atmospheric C stocks. Forest management is one of the few available human activities that can create biological C sinks to help mitigate the atmospheric accumulation of CO_2. The two fundamental options to create sinks include increasing the forest area (through afforestation and reforestation) and increasing the C density in the existing forest area (through forest management; Binkley *et al.* 1997). Conversely, deforestation and forest degradation can lead to a reduction in forest C stocks. Understanding and evaluating the impacts of planned actions on forest C stocks may increasingly lead to forest management choices that include terrestrial C stock changes as one of the decision criteria.

The Role of Forests in the C Budget

Forests exchange CO_2 with the atmosphere through the processes of photosynthesis, respiration, decomposition, and the emissions associated with disturbances like fire, insect defoliation, harvesting and slash burning. Net changes in C stocks (living biomass and dead organic matter) over a specified period of time, e.g., a year, determine whether a single forest stand is a net source or a net sink for atmospheric C. (The storage and release of C from the harvested material is presently not accounted in the Kyoto Protocol accounting rules—a subject of ongoing international negotiations.)

Immediately following disturbance and during early phases of stand initiation and development, individual even-aged or relatively homogeneous forest stands typically act as a net source of atmospheric C until the uptake of C in the regenerating trees (biomass) exceeds the loss of C through respiration and decomposition of dead organic matter (DOM) (Fig. 1). At that time, the stand switches from a net source to a net C sink. The magnitude of the source and subsequent sink, as well as the timing of the transition between them, is determined by growth rates, decomposition rates and DOM pools on site. Hence, forest management activities such as site preparation, planting and stand tending all affect the stand's C balance.

At the landscape level, a forest is composed of many stands, some of which may be a C sink and others a C source, depending on local conditions, stage of stand development and disturbance history at each site. A forest's net C balance can be estimated by adding up the contributions of all stands making up the forest. The overall C balance of a forest at the landscape level is determined by the past disturbance regime, as reflected in the age-class structure, by current growing conditions and disturbance patterns, and by forest management activities. At the landscape-level, a change in the overall disturbance regime is a major determinant of C stock changes (Fig. 2). Transitions in the forest age-class structure resulting from increases in disturbances generally result in C sources, while reductions in disturbances result in C sinks (Kurz *et al.* 1998, Kurz and Apps 1999, Apps *et al.* 2000). At the landscape scale, forest management activities such as suppression of natural disturbances or changing harvest rotation lengths can therefore have a large effect on the forest's C balance (Price *et al.* 1997, Kurz *et al.* 1998). Land-use change, the conversion of forest to non-forest and vice versa, also affects terrestrial C stocks.

Developing a Forest C Accounting Tool at the Operational Scale

Many forest management decisions are made and implemented at the scale of operational management units (100 000 to 10 000 000 ha). Forest managers who want to include C-related goals in their planning processes require tools that assist with the assessment of the influence of alternative management actions on terrestrial C stocks. A C accounting tool would empower forest managers to include considerations of C balances in the management decision criteria.

Although forest types and forest management practices vary considerably across Canada, many of the required capabilities of forest C accounting tools apply to all forests. Moreover, the principles of C accounting are the same across the country. What differ are the regional parameter values that describe key ecological and biogeochemical processes. Analysts who want to include C-related indicators, therefore, are faced with two sets of challenges. First, they have to develop the tools required to perform C analyses, and second they have to develop regional parameter sets for these tools.

To address the need for forest C accounting tools in Canada and to avoid unnecessary duplication of efforts, the CFS C Accounting Team and the Model Forest Network have initiated a co-operative project aimed at developing a forest C accounting tool for use at the operational scale. The objective of the project is to develop, test and implement a user-friendly forest C accounting tool that is consistent with current scientific understanding of forest C dynamics, that is compliant with the evolving international C accounting rules, and that will be readily available to Model Forest partners and other interested parties, including other forest companies and forest analysts.

The approach of this project is to build on over a decade of expertise in the development and scientific application of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2) and to convert what is currently primarily a research tool into a user-friendly decision support tool. The MFN has successfully brought together government, industry, first nations, and small-scale private operators to develop and showcase innovative approaches to sustainable forest management. By joining forces, the CFS and the MFN aim to bring together the expertise of the scientific and operational communities to develop a scientifically credible tool that is capable of addressing the needs of forest managers across Canada.

The first steps in this project are to identify and resolve many of the technical and scientific issues that are generic to forest C accounting at the operational scale in Canada. Many aspects of data management, simulation modelling, and analysis can be addressed through a generic tool. Scientific methods for the conversion of volume information into estimates of aboveground C stocks, for the estimation of belowground (root) biomass (Kurz *et al.* 1996b), or for the estimation of dead organic matter pools

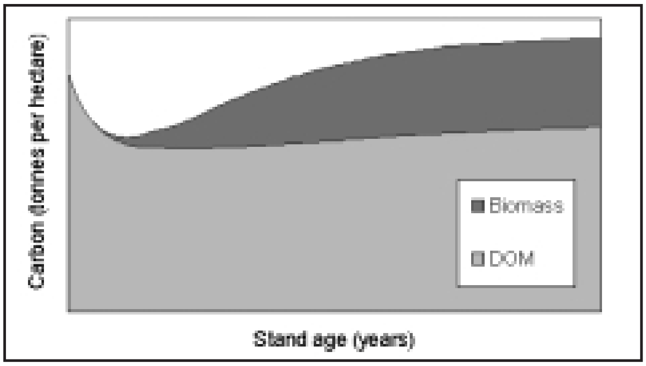

Fig. 1. Carbon dynamics of a typical even-aged stand following stand-replacing disturbance. The magnitude and duration of the changes differ widely amongst different sites and disturbances. At age zero, immediately following disturbance, large quantities of slash and other dead organic matter (DOM) are left on site. For some time after disturbance, C releases from decomposition of DOM exceed C accumulation in biomass: the stand is a net C source. Eventually, the accumulation of C in biomass exceeds the loss of C from decomposing DOM, and the stand becomes a net C sink.

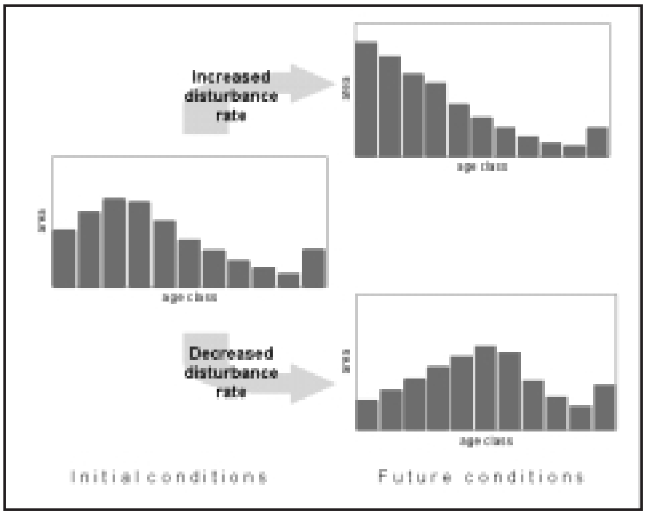

Fig. 2. Transitions in the forest age-class structure resulting from changes in forest disturbance regimes generally result in the forest acting as a C source or sink. Increases in disturbance rates shift the age-class structure to the left, reduce the average forest age, and typically result in a loss of forest C (C source). Decreases in disturbance rates shift the age-class structure to the right, increase the average forest age, and result in a C sink.

(Kurz and Apps 1999) have been developed and will be accessible through the tool.

By avoiding duplicated expenses for the development of C accounting tools, it is hoped that more resources will be available for the development of regional parameter sets, and for the testing and application of the tool in Canada's forest management community.

At the core of the forest C accounting tool are the ecosystem simulations performed by the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2) (Kurz and Apps 1999, Kurz *et al*. 1992). This model was developed to analyze past and future forest biomass and dead organic matter C stock changes in Canada. It has been used to analyse C stock changes in the entire forest area (Kurz and Apps 1999), in the managed forest, in individual provinces or regions (Kurz *et al*. 1996a, Peng *et al*. 2000), and at the scale of operational units (Price *et al*. 1997, Kurz *et al*. 1998). It has also been coupled to a forest products simulation module at both the national scale (Apps *et al* 1999) and for the Foothills Model Forest (Price *et al* 1997). The model has been continuously updated to incorporate the best available science and to remain compliant with evolving international C accounting rules. To support policy analyses at the national and provincial scales, the model has been used to explore future scenarios that assume a range of natural disturbance rates, harvest rates, growth rates, decomposition rates, and combinations of these.

Most recently, at the request of the BC Ministry of Forests and with their support, the model was used to analyse C stock changes in all timber supply areas (TSAs) and most tree farm licences (TFLs) in British Columbia. That application of the model required extensive revisions to accommodate the detailed provincial inventory information and volume-based yield curves. Although still in research mode, the application demonstrated in principle, that the approach chosen for the CBM-CFS2 is applicable at the operational scale.

Conceptual Approach and Data Requirements

The forest management community has a very good understanding of the impacts of their actions on those performance indicators that centre on the volume of growing stock and future yields. The knowledge base for forest management and planning is developed from forest inventories, temporary and permanent sample plots, and a system of growth and yield and timber planning models. Although the details differ between regions in Canada, an extensive information base is available for nearly all areas.

The approach to forest C accounting implemented with the CBM-CFS2 builds on this extensive knowledge base. Where available, the model makes use of the same types of information that would be required for a regional timber supply analysis, but augments this information with additional data and simulation modelling approaches to cover those aspects of ecosystem C dynamics that are not normally included in timber supply modelling (Fig. 3).

Conceptually, the accounting process starts with a detailed forest inventory, stratified to enable assignment of growth and yield information to the various strata. Examples of the strata could be a combination of forest type, cover type and site class, or a combination of ecological and productivity classes. The model requires forest inventory information such as used by timber supply models on the area of each of the different strata, further divided into age classes.

At present, the model uses either biomass-over-age or volume-over-age curves to describe the dynamics of the biomass C pools in each stratum. From the early years of model development, a data-driven approach has been preferred over a process- modelling approach. The advantage of this approach is that it is based on actual observed forest growth. In addition, forest managers, familiar with their yield projection systems that are based on the same data, are in a better position to evaluate the model outcomes than they would be were it based on process-level simulations of forest growth.

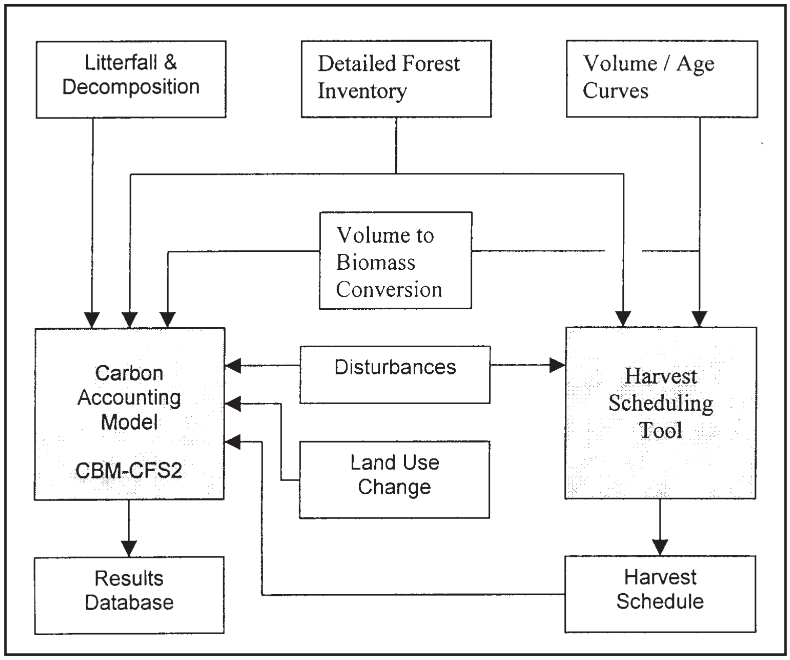

Fig. 3. The CBM-CFS2 is at the core of the operational-scale forest C accounting tool. It combines data from numerous sources, including detailed forest inventory, volume over age curves, output from harvest scheduling tools, volume to biomass conversion factors, model parameters describing dead organic matter dynamics, and information on natural disturbances, harvesting, planting, and land-use change. The CBM-CFS2 can then be used to simulate past, present, or future C dynamics and write output to a results database for further analysis and scenario comparison.

In the short term, however, the disadvantage of empirical growth and yield models is their present lack of responsiveness to changes in climate and environmental growing conditions. Ongoing research activities are aimed at developing process models that could compliment the empirical yield functions in the CBM-CFS2 accounting framework. Planned developments for the CBM-CFS2 core model include the ability to accommodate both empirical growth models and process models to represent stand dynamics.

Inventory and growth and yield models provide the core information to estimate changes in aboveground volume over time. Volume-to-biomass C conversion approaches are being developed and implemented in the ongoing development of CBM-CFS2. The required regional parameter sets have been developed to date only for BC. An ongoing project in the CFS supported by the Federal Panel on Energy Research and Development is currently aimed at developing volume-to-biomass conversion factors for other regions of Canada. The estimation of belowground biomass pools in coarse and fine root biomass uses methods and equations previously developed for the CBM-CFS2 (Kurz *et al*. 1996b, Kurz and Apps 1999).

Most forest inventories in Canada lack information on dead organic matter pools such as snags, coarse woody debris, litter and soil C. Although some may have limited ancillary data that describe waste and breakage factors or standing dead, this is generally inadequate to fully quantify the dynamics of the C in the forest floor and soil. The CBM-CFS2 employs a simulation approach to estimating the size and dynamics of dead organic matter pools (Kurz and Apps 1999). The approach is based on the assumption that stand dynamics, disturbance and management history, together with mean annual temperature are the primary determinants of the size and composition of dead organic matter pools. To implement this approach, parameters are required that define biomass input from litterfall, stand mortality, and disturbance-related transfers as well as losses from decomposition and emissions from disturbances. Such parameter databases have been developed and are periodically updated as new research results are reported.

Recent comparisons between independent field observations of soil C and estimates by the CBM-CFS2 yielded reasonable results (Bhatti *et al*. 2002). The CFS is currently in the process of compiling a new national database on ecosystem soil C observations that, in the future, will be used for further model revisions and the refinement of regional parameter sets. Results from a long-term decomposition experiment (Trofymow and CIDET Working Group 1998, Trofymow *et al*. 2002) will also contribute to further refinements of model parameters.

Scenarios of future C stock changes are strongly affected by the assumptions about natural disturbances and harvest rates. Several timber projection models are in use throughout Canada. One step in the development of the operational scale version of the CBM-CFS2 will be to ensure that harvest schedules developed through timber supply planning exercises can be also be used as direct input to the CBM-CFS2. This will allow analysts to add C variables to the suite of performance measures of alternative management scenarios. One recognised shortcoming of this approach is that it does not permit the inclusion of C constraints in the simultaneous optimization algorithms used in some timber supply models. It does, however, maintain the flexibility required to address potential changes Kyoto Protocol accounting rules.

Recent additions to the CBM-CFS2 have added the ability to assess C stock consequences from land-use changes such as

ARD. One challenge to estimating C changes from afforestation and reforestation activities is that the area on which the new forests are established comes from agricultural or pasture lands and hence is not normally included in the forest inventories. Similarly, estimating C stock changes on areas affected by deforestation may require the representation of agricultural systems, which are outside the scope of traditional forestry in Canada and thus may require separate C accounting models. Areas lost from the forest land-base are currently not included in the CBM-CFS2 and their C dynamics will likely not be of concern to operational forest managers. Methods for tracking this sectoral transfer of C are under discussion between CFS and Agriculture and Agri-Foods Canada.

Finally, there are a number of steps that individuals and organizations charged with managing regional forests can undertake in anticipation of reporting requirements that may be required if Canada were to ratify the Kyoto Protocol:

(1) Archiving forest inventory and other information that defines the extent of forest cover in 1990, the base year for tracking land-use change activities.

(3) Maintaining an inventory of land-use changes since 1990, for both afforestation / reforestation and deforestation. Ideally, this inventory should contain spatially explicit records of A/R and D activities since 1990. Deforestation activities that occurred prior to the commitment period will only contribute small C stock changes during the commitment period. A/R activities that occurred between 1990 and the start of the first commitment period have the potential, however, to yield substantial C sinks during the commitment period.

(4) Maintaining a (spatially explicit) record of harvest activities. Although not required under the Kyoto Protocol, this would be a pre-cautionary measure in anticipation of intense international scrutiny that must be expected regardless of a country's decision to ratify the Kyoto Protocol. International monitors, whether these are environmental NGOs or agencies from other countries, will rely heavily on remote sensing. Areas that are harvested and that regenerate to forests are not considered deforestation under the Kyoto Protocol, but it is much easier to detect the loss of forest cover, than it is to detect the regenerating seedlings. The spatially explicit record of harvesting and regeneration activities will facilitate the distinction between land parcels in the harvest regeneration cycle and those undergoing deforestation associated with land-use changes.

(5) Maintaining a record of natural disturbances and forest management activities since 1990.

This information along with other data sources that are used in conjunction with the CBM-CFS2 will also aid in the retrospective accounting of C stock changes in an operational forest management unit.

Development and Implementation Strategy

The objective of the joint project between the Model Forest Network and the CFS C Accounting Team is to develop, test and make available a computer tool to empower any interested forest analyst to assess the consequences of management actions on forest C stocks. The tool can be used to monitor and account for past changes, e.g., from 1990 to the present using actual data on forest management actions and natural disturbances, or to conduct scenario analyses of future C stock changes, based on assumptions of future scenarios.

The development strategy involves four phases: (1) scoping, (2) prototype development and testing in two pilot sites, (3) development and application of a beta-version in multiple Model Forests, and (4) development of a release version and technology transfer through the Model Forest Network.

The scoping phase began in 2001 with two workshops involving many Model Forest partners, provincial analysts, and research scientists. During the workshops, the key issues that managers would like to address with a forest C accounting tool were identified. General profiles of the available data for most Model Forests were developed. Following the workshops, a three-year work plan and development strategy was developed in close collaboration with the Local Level Indicators Committee of the Model Forest Network. Phase 1 of the project has been completed.

During the second phase, the focus will be on adapting the CBM-CFS2 research tool usable only by a small group of highly specialized analysts to a tool that can be used more widely at the scale of operational forest management units. The development will include (1) data pre-processing tools, (2) graphical user interfaces for scenario definition and run management, (3) post-processing tools for the analysis, comparison and display of model results, and (4) continuing improvements to the core CBM-CFS2 model.

The data pre-processing tool will be designed to accommodate the wide range of input data formats encountered throughout Canada's model forest community and to allow users to convert the forest inventory and growth and yield data into a format that is consistent with the CBM-CFS2 input data. Thus, data prepared for input to timber planning models will also be useable by the CBM-CFS2.

The scenario and run manager is used to define the assumptions to be analysed in the model scenarios, including, for example, the rate, timing and location of forest management activities, natural disturbance events, and land-use changes. The post processing tools are required to summarise, tabulate and compare the results of individual or multiple model runs for user-specified areas and indicators of interest. Anticipated revisions to the CBM-CFS2 core model include a significant improvement in the spatial resolution at which the model can operate, improvements to the representation of dead organic matter dynamics, and the incorporation of C accounting rules under the Kyoto Protocol as these are revised by international negotiations.

To ensure that the prototype development can proceed rapidly and that the tool will indeed meet the expectations of the anticipated user community, the CFS C Accounting Team will work closely with two model forest pilot sites. A review team comprised of interested members from several model forests will participate in the review of the resulting model prototype.

In the third phase of the project, the feedback from the review process will be used to guide further model refinement. The prototype will then undergo revisions and extensive testing. The goal will be to extend the model's use to all Model Forests that have expressed interest in developing internal capacity to define, analyse and interpret future scenarios of C stock changes in their forest management areas. The application of the beta-version of the model throughout the Model Forest Network will not only permit extensive testing and feedback, but will also be used to prepare and refine draft model descriptions, user guides and technology transfer material.

In the fourth phase of the project, a release version of the model will be completed for distribution with the assistance of the Model Forest Network and its partners. Potentially, the Model Forest Network may undertake technology transfer, training and education to provide support for its members and other interested users.

It is anticipated that the completed model and its documentation will be freely available to forest analysts and other interested parties in Canada's forest management community. A beta-version of the model is expected for use by Model Forest Partners in the summer of 2003. A release version of the model for the wider community is expected in the summer of 2004. Phase four of the project is scheduled for completion in March 2005.

Throughout all stages of model development, the role of the CFS C Accounting Team will be to ensure that the model incorporates the appropriate scientific representation of forest C dynamics and is compatible with analyses carried out at provincial and national scales. As part of this process, the C Accounting Team will also ensure the model remains compliant with the international C accounting rules and will submit the model to any international certification process that may be developed during the implementation of the Kyoto Protocol.

Conclusions

Forest management can contribute to enhancing C sinks and reducing C sources through a variety of activities. Where forests are managed on a sustainable basis, forest C stocks can be maintained while at the same time providing a continuous annual flow of biomass C to help meet society's needs for timber, fibre or energy.

The CFS C Accounting Team and the Model Forest Network have entered into a partnership to develop a forest C accounting tool that will help forest managers consider the effects of their actions on forest C stocks when choosing among management alternatives. The objective of the collaborative effort is to develop, test and implement a user-friendly forest C accounting tool designed for application at the scale of operational forest management units. The model can be used to either estimate C stock changes between 1990 and the present, based on actual data, or to simulate scenarios of future C stock changes based on assumptions about future natural disturbance rates, harvest rates and other forest management actions.

Users of the model will benefit from the fact that the CFS C Accounting Team will implement scientific and technical improvements as these are identified, and will maintain the model compliance with the evolving international C accounting rules. When fully developed (2004), the operational model will be available without charge to anyone interested in using it to estimate landscape level forest C stocks and C stock changes. The expertise developed within the extensive network of Model Forests and their partners in Canada will facilitate technology transfer and training of the larger user community.

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