SIMULATION IN THE SERVICE OF SOCIETY (S^3)

John McLeod • Technical Editor **Suzette McLeod** • Managing Editor

MISSION EARTH

Modeling $C0_2$; Another View

Some readers may remember that we published "CO_2; A Balancing of Accounts" by Yasumasa Fujii in our November 1992 issue. That article considered CO_2 in broad terms, from a global point of view. Now we have a report that considers CO_2, as well as carbon in other forms, in great detail for one region only.

The report—93 pages, with 20 figures, 11 tables, and 7 appendices—is far too much for us to cover in these non-technical columns, but the subject is so important, and the treatment so informative, that not to tell our readers ANYTHING about it would be contrary to the purpose of our project MISSION EARTH. So we will try to indicate through the following edited excerpts enough for readers to decide whether or not they wish to read the complete report.

The Carbon Budget of the
Canadian Forest Sector: Phase I

W.A. Kurz, T.M. Webb, P.J. McNamee
ESSA - Environmental & Social Systems Analysts Ltd.
Vancouver, British Columbia, Canada
and
M.J. Apps
Forestry Canada, Northwest Region
Northern Forestry Centre
Edmonton, Alberta, Canada

Abstract

An assessment of the contribution of Canadian forest ecosystems and forestry activities to the global carbon budget has been undertaken. The first phase of this study consisted of the development of a computer modeling framework and the use of published information to establish the sector's current role as a net source or a net sink of atmospheric carbon.

The framework includes age-dependent carbon sequestration by living forest biomass, net detrital litter fall of carbon to the forest floor, subsequent accumulation and decomposition release in three soil compartments, retention of carbon in manufactured products derived from harvested forest biomass, and burning of forest biomass for energy.

There is explicit representation of the role of ecosystem disturbances, such as fire, insect-induced stand mortality, and harvesting (clear-cutting, clear-cutting and slash burning, and partial cutting), as they affect carbon releases and transfers to the forest floor and to the forest product sector. Regrowth of biomass and changes in soil decomposition processes following disturbance are also simulated within the model.

In the first phase of the work, national and provincial data bases were used to provide the first comprehensive estimates of the net carbon exchange between Canadian forest ecosystems and the atmosphere for the reference year 1986.

Foreword

The following report is based in part on ENFOR Project P-387, which was carried out under contract by ESSA (Environmental and Social Systems Analysts Ltd., of Vancouver, British Columbia). ENFOR (ENergy from the FORest) is a contract research and development program managed by Forestry Canada and aimed at generating sufficient knowledge and technology to realize a marked increase in the contribution of forest biomass to Canada's energy supply.

The program was begun in 1978 as part of a federal interdepartmental initiative to develop renewable energy sources. The ENFOR program deals with biomass supply matters such as inventory, growth, harvesting, processing, transportation, environmental impacts, and socio-economic impacts and constraints. A technical committee oversees the program, developing priorities, assessing proposals, and making recommendations. Approved projects are generally carried out under contract.

General information on the operation of the ENFOR program is available upon request from:

The ENFOR Secretariat; Forestry Canada
Place Vincent Massey
351 St. Joseph Blvd.
Hull, Quebec K1A 1G5, CANADA.

Please direct communications to: John McLeod, 8484 La Jolla Shores Drive, La Jolla, California 92037
Voice: (619-454-0966); FAX (619-277-3930); Bitnet:MCLEOD@SDSC.BITNET.

Introduction

Forests and forest sector activities play an integral role in the short-term (less than 100 years) dynamics of the global C cycle. Through photosynthesis, forests remove CO_2 from the earth's atmosphere and retain some of this C for decades or even centuries. Decomposition of dead organic matter, wildfires, and other disturbances release C back into the atmosphere. Forest harvesting transfers biomass C from forest ecosystems to the forest product sector, where it is converted into construction lumber, pulp and paper products, or energy.

Each of these forms of end use has a different C-retention profile, resulting in different rates of C release into the atmosphere. The net flux of C between the forest sector and the atmosphere determines whether forests and forest sector activities are part of the problem or part of the solution with respect to changes in atmospheric CO_2 concentration.

Forests can contribute to increases in atmospheric CO_2 if, through deforestation and land-use change, large amounts of C are released into the atmosphere. There are, however, ways in which forests can contribute to strategies that limit the rate of atmospheric CO_2 increase. For example, large-scale afforestation increases the area of forest that actively sequesters C.

Less obvious is the role of biofuel. The replacement of fossil fuel energy sources with fuels from biomass reduces the rate of fossil C input to the atmosphere; as long as the forest (or other vegetation) that provided the biofuel regrows, the use of biofuels for the production of energy is sustainable. Reductions in fossil C consumption decrease the rate at which inactive fossil C enters the active biospheric C cycle.

Canada occupies a large fraction of the global land mass and much of it is covered by forests. The net budget of C fluxes between the Canadian forest sector

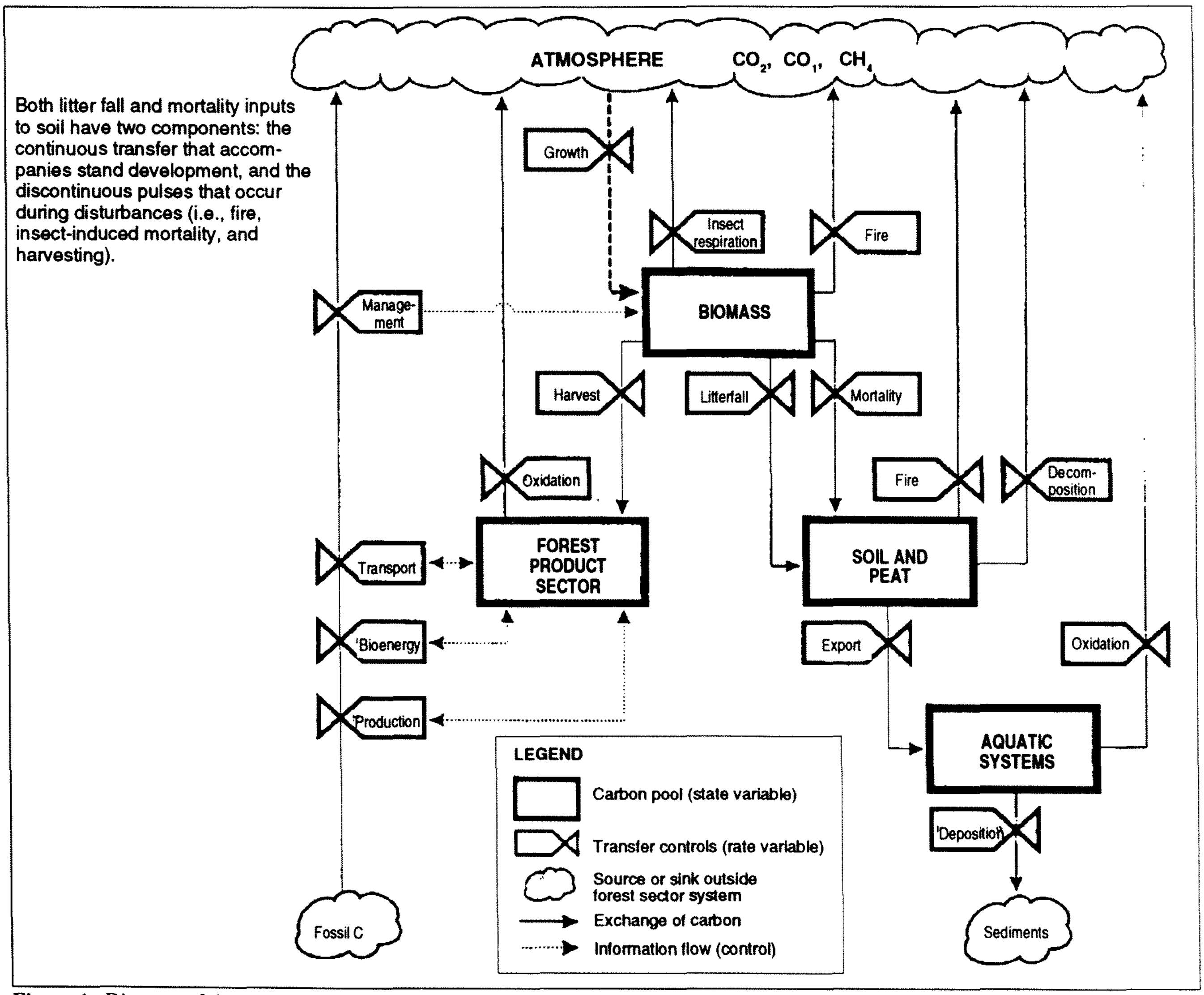

Figure 1. Diagram of the conceptual model of the carbon budget of the Canadian forest sector.

and the atmosphere may, therefore, be of significance to the global C cycle. An interest in quantifying the contribution of the Canadian forest sector to the global C budget resulted in this study, which consists of three phases.

This report comprises the results of the first phase of the study: it addresses the status quo and provides a tool for conducting future analyses. The second and third phases of the study will address the impacts of climate change, the response of Canada's forest ecosystems, and the implications of various policy options for the forest sector C budget.

The specific objectives of the first phase were as follows:

1. to develop a conceptual framework of the C budget of the Canadian forest sector that includes the role of bioenergy production;
2. to calculate (based on the best available information) the annual net balance of the national forest sector C budget, and to provide an assessment of the uncertainties associated with this estimate;
3. to specify the assumptions in this budget;
4. to identify major gaps and deficiencies in available data.

General Overview

The objective of the conceptual framework is to account for all major C pools, transfer pathways, sources and sinks, and to define the bounds of the system. The framework provides an overview of our understanding of the C dynamics of Canadian forests and forest sector activities.

The conceptual model, shown in Figure 1, recognizes two major C pools: forest ecosystems and the forest product sector. Forest ecosystems include two C pools: biomass and soils. The biomass C represents all living tree and plant biomass; the soil C pool includes C in detritus, forest floor, coarse woody debris, and soil organic matter. The forest product sector contains C derived from tree biomass harvested in Canada that may have undergone several conversion processes.

Carbon contained in biomass destined for the production of bioenergy is represented as a separate, short-term C pool (biofuel) because of the potential significance of its substitution for fossil C energy sources. By the same token, C released while generating energy from forest biomass (bioenergy) should also be accounted for within the forest product sector.

Forest ecosystems sequester C through photosynthesis. Carbon is released back into the atmosphere through microbial decomposition, respiration, and fires. In the absence of disturbances, the balance between net photosynthesis and decomposition determines the rate of net ecosystem C accumulation, which is calculated as the sum of net changes in the biomass and soil (including detritus) C pools.

Disturbances such as fire, harvesting, or pests affect the C content of stand components, both during the disturbance and for some time thereafter. Fire, for example, transfers C from biomass to soil C pools and rapidly releases some ecosystem C into the atmosphere as CO_2, carbon monoxide (CO), CH4, nonmethane hydrocarbons (NMHC), and particulate matter. Harvesting removes a portion of the biomass C from the forest ecosystem and transfers it to the forest product sector. Harvesting also transfers some biomass C (slash and cull) to the detrital component of soil C pools.

The impact of pests on the C budget of forest ecosystems depends upon the type of pest and the severity of the damage. Low or moderate pest damage may merely reduce the rate of C accumulation, whereas more severe or repeated pest damage can lead to a net ecosystem C release because of tree mortality and subsequent decomposition. Insect respiration also releases small amounts of C directly to the atmosphere.

Disturbances also influence stand development and may set the ecosystem back to an early successional stage. They affect both the future rate of C uptake by the regrowing or recovering vegetation, and the rate of C release from the decomposing C pools remaining after disturbances. The net change of ecosystem C following disturbance depends on many factors, including the type and intensity of disturbance, the amount of C in the main C pools prior to and after the disturbance, and the recovery rate of the ecosystem.

The conceptual model (Fig. 1) also identifies an aquatic pathway and an associated potential sink in sediments. Seepage from forest ecosystems may remove C in solution or as suspended particulate matter. Although the annual rate of C removal by this pathway may not be high, some of this C can be deposited in long-term sinks, such as lake or ocean sediments.

Inputs to the forest product sector originate from the harvesting of forest biomass and its removal from forest ecosystems. This biomass is converted into a large number of different forest products. Carbon releases to the atmosphere occur at different stages of the production process, and the finished products contain varying fractions of the C originally removed from the forest.

The length of time that C is retained in a forest product depends on the product's characteristics and end use. For example, C contained in newsprint may be released into the atmosphere within a few months of production, but if the newsprint is transferred to landfills, some fraction of C may be retained for a very long time. Similarly, C contained in construction lumber may remain in this form for many decades.

Carbon from Fossil Sources

Fossil C sources are used in many processes throughout the Canadian forest sector and are treated in the conceptual model as secondary C sources that may become important in the evaluation of possible C management and strategies. Tree planting, silvicultural activities, fire suppression, pest management, and harvesting involve the use of energy sources that release C into the atmosphere.

Similarly, the production of nitrogen fertilizers requires substantial energy inputs that should be taken into account if increased potential for C storage is a policy objective. Fossil energy is also used in transportation of the harvested wood and for many other processes of the forest product sector.

The conceptual model presented here includes these secondary C sources. The analytical framework contains the appropriate data records and analytical structure to address forest sector energy issues. Calibration data for secondary C sources and energy use in the forest sector, addressed in a separate study, will be incorporated in future developments of the C budget model.

Spatial and Temporal Bounding

The primary emphasis of the first phase of the C budget is on an evaluation of the existing Canadian forest land base under existing climate and management conditions. The analytical structure has been used to provide an estimate of the net C balance of the Canadian forests and forest sector activities for the reference year 1986. The primary data base making this task possible is Forestry Canada's Canadian Forest Resource Data System (CFRDS) 1989, which contains the biomass data needed for this study, based on almost complete coverage of forest land in Canada.

In the next phase, the analytical framework will be extended to permit simulations over a 100-year time horizon. This length of time was chosen because it reflects the rotation age for many forest systems in Canada. Moreover, it is the time frame within which major policy decisions are required in response to predicted large scale changes in climatic conditions resulting from the enhanced greenhouse effect.

For the purpose of this C budget, the following assumptions regarding the scope of Canadian forests and forest sector activities have been made.

Land-use forms

All land areas included in the national forest biomass inventory are also included in the C budget model. In future analyses, changes in land use such as the conversion of forests to urban land or the afforestation of marginal agricultural lands will have to be considered in the C budget model. However, these land-use changes are not considered in the analysis of C dynamics for the single year 1986.

Peatlands

Forests in Canada may grow in areas classified as peatlands (peat depth greater than 50 cm), but only some peatlands are forested. The national forest biomass inventory contains no classifiers that identify peatlands, and the national peatland inventory (National Wetlands Working Group 1986) is not spatially referenced to the CFRDS database. Therefore, some spatial overlap (of unknown extent) exists in the areas covered by the two inventories. The current C budget model ignores the spatial overlap and separately accounts for peat accumulation, forest biomass, and soil C dynamics.

Carbon seepage into aquatic systems

Although recent reports indicate that this pathway may be important, the lack of quantitative data prevents the inclusion of estimates of its contribution in the first phase of the model. The analytical structure is present in the Phase I model, but requires calibration data. It should be noted that the budget presented in Phase I may be affected if (1) there is a significant pool (e.g., sediment) associated with the aquatic pathway, and (2) this pool undergoes significant changes resulting from the disturbance of forest ecosystems.

Forest product sector

For the purpose of the C budget, it is necessary to follow wood products throughout their entire history: from the time when timber is cut and removed from the logging site until the time when the C it contains is released into the atmosphere or otherwise deposited in permanent storage.

Forest product trade

The Canadian forest product industry is heavily export-oriented. In 1987 Canada exported 41.7 million m^3 of lumber while importing 1.6 million m^3. To ensure a consistent C accounting system, all forest products generated from timber harvested in Canada are considered part of the Canadian forest sector, regardless of their ultimate end-use location. Forest products generated from biomass originating outside

Canada are not considered part of the Canadian forest sector and are not included in the budget.

All forest products that are part of the Canadian forest sector have been assigned C retention profiles, with no attempt made to account for possible differences between geographic regions of product end use. This approach ensures that all C sequestered in Canadian forests is being tracked until it is released back into the atmosphere.

Design Criteria

Research projects worldwide are investigating questions of global change, and it is anticipated that new scientific understanding will continue to emerge in the foreseeable future. This C budget model was therefore designed as a series of model components that make use of the best available data and understanding. Should either the data improve, the scientific paradigms change, or alternative scientific hypotheses be proposed, it will only be necessary to modify model components to accommodate the new information.

In addition, all data used in the model are provided in external data files. This facilitates the sensitivity analyses used to explore the scientific uncertainties about data, model algorithms, and scenarios of future conditions.

The Phase I model was implemented on a desktop computer system to be able to take advantage of sophisticated user interfaces and programming language compilers. This decision imposed a number of data structure design constraints, particularly on computer memory management. The national forest biomass inventory, one of the primary sources of data, resides on a mainframe computer with large data storage capacity. The inventory, therefore, had to be aggregated before it was moved to the desktop environment.

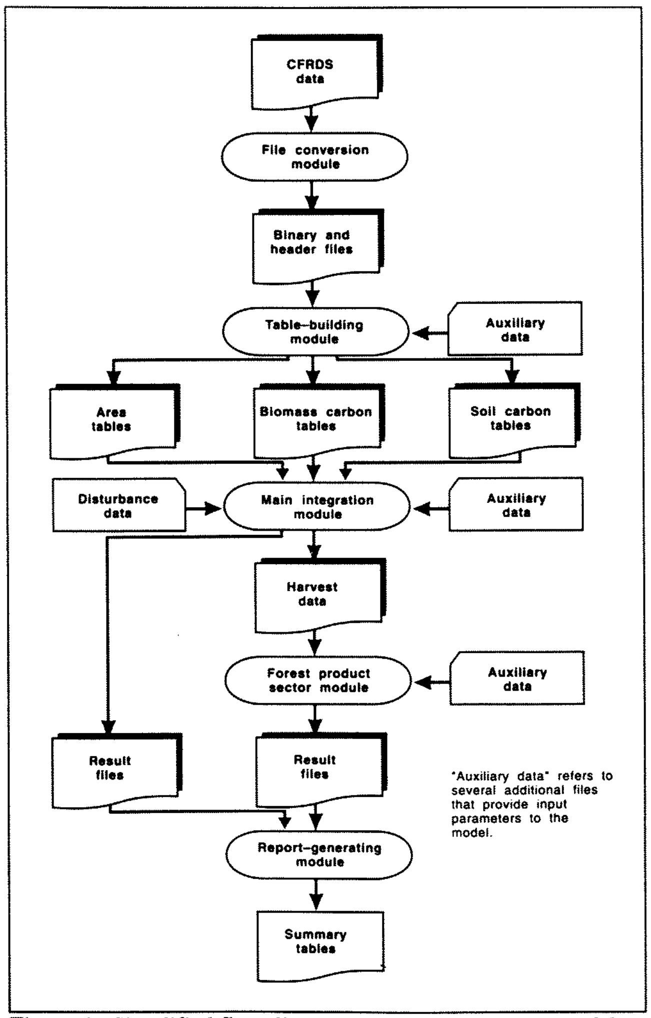

Figure 2. Simplified flow diagram of the carbon budget model, presenting the five main program modules and the major data files.

Model Overview

The starting point of the C budget model is the national forest biomass inventory. This inventory is considered to have the best available data, with national coverage, on aboveground standing biomass pools and their dynamics. Disturbance data (such as fire, insects, and harvesting) are taken from provincial and federal data bases. The forest product sector is represented by a separate module that uses data on present and past forest harvesting activities.

The C budget model consists of five major computer programs (Fig. 2). The five programs must be run in sequence, because the first four prepare the data files and results that are used by the last program to generate output tables and summary reports. "Auxiliary data" files are identified in three locations in Figure 2. Each of these represents several additional data sources too complex to present in a single diagram.

Several other auxiliary programs have been developed to generate data files that are internally consistent with the requirements of the model. None of these programs modifies the basic input data other than by converting them into the file format required by the model.

The forest product sector module also directs a user-specified proportion of the harvested material toward bioenergy production. The release of C from the burning of biofuels is accounted for, but there is no accounting in the Phase I model for bioenergy substitution of fossil energy sources. This accounting is planned for the next phase of this study.

Results and Discussion

The results of six simulation runs of the C budget model are presented in this Phase I report. Only the first run (referred to as the standard run) is discussed in detail. The additional runs were used to explore some of the uncertainties associated with the current available data and assumptions. A description of the standard run and the five runs for sensitivity analysis follows.

Standard run: The results of a single-year simulation were based on the data for reference year 1986.

Sensitivity analysis: Each of these model runs involved changes to only one main model parameter or process.

1. High biomass run
To investigate the effects of uncertainties in the biomass data, all biomass data in the inventory were increased by 10%.

2. High root-to-shoot ratio run
To investigate the effects of changed assumptions about fine-root inputs to the soil C pools, the simulated input of fine roots into the fast soil C pool was increased by 10%.

3. High fire run
To investigate the effects of altered disturbance regimes, specifically wildfires, the area burned annually was increased by a factor of 3 over that used in the standard run.

4. Stand origins run
To explore the effects of the assumption that all stands in Canada are of fire origin, the alternative assumption was made that all stands originated after clear-cut logging.

5. Slow soil run
To analyze the effects of changes to the partitioning of C leaving the fast and medium soil C pools, the proportion of C entering the slow soil C pool was decreased from 17% to 5% of the C leaving the fast and medium pools.

The full report is available at no charge from Forestry Canada, Northwest Region, Northern Forestry Centre, 5320 122 Street, Edmonton, Alberta, Canada T6H 3S5.

This work was supported in part by the Federal Panel on Energy Research and Development (PERD).

It Came In Out Of The Cold (War)!

Dear John:

Enclosed is a short description of a program that I had written to simulate nuclear missile launches and give students first hand (role-playing) experience with some of the ethical issues involved. I see it as quite fortunate that although a lot of work went into getting it set up several years ago, it is becoming a historical artifact (along with the Cold War).

Best regards,

Craig Summers

Ethical Decision Making
Computer Demonstration on Nuclear Weapons Launching

People who teach in areas related to politics, ethics and defence policy may be interested to know of a computer program that is available for public domain use from a VAX mainframe. This interactive program is a simulation of nuclear missile (ICBM) launch procedures.

It is written in Pascal, and includes a timer program to measure the decision times of participants acting as missile launch operators under different instructional conditions. The program runs from a single account, but is set up for joint operation by partners working at two different terminals. Numerous users can access the program simultaneously, so whole classes can run it if working in groups of two.

Some content on intercontinental ballistic missiles is included, and an explanation of MIRVed warheads (Multiple Independent Re-entry Vehicles). The program allows role playing of nuclear command and control procedures, giving students first-hand experience with issues related to nuclear decision-making. Small experiments can be carried out on the effects of different types of decision information (ethical, rational, superior orders) in political and military applications.

This program was written as a demonstration for a course titled Political Psychology: Explorations in Militarism and Applied Ethics. Through the Telnet system for bitnet/internet sites, the program should be accessible internationally, and as close as the nearest computer terminal. It also works very well as a participatory demonstration after viewing the short National Film Board of Canada's documentary "Push Button Weapons."

For further information, or to obtain the telnet address and account number to access the program, contact:

Craig Summers, Ph.D.
Department of Psychology,
Laurentian University
Ramsey Lake Road
Sudbury, Ontario P3E 2C6
CANADA
E-mail: CSummers@Nickel.Laurentian.Ca.
FAX (705) 675-4823.