Indicators of sustainable forest management: Review of potential indicators

Criterion 4: Role of forests in global ecological cycles

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Executive Summary

This document is intended to serve as a reference document for use in the choice of indicators of sustainable forest management. It provides details, where available, of approximately 200 indicators that have been selected from a broader range of over 3000 indicators that have been proposed or put into practice.

The relationship of each indicator to the criteria and indicators scheme used by the Canadian Council of Forest Ministers (CCFM) is given, and this scheme is used as the framework for the current document. Not all CCFM indicators have been used, and a number of supplementary indicators, more appropriate to the questions being asked about the nature and extent of sustainable forest management in British Columbia are given.

Under each indicator, the rationale and a brief description of the indicator (where available) is given. Much of this material has been taken directly from the source material to avoid the risk of interpretative bias in this reference document. Examples are provided of the use of indicators, and also of where they have been actually reported. Any outstanding research questions or uncertainties related to the indicators are provided, as well examples of the scientific literature related to each indicator (this last section is still incomplete).

Following recommendations at a (non-representative) stakeholder workshop in February 2005, particular emphasis in this document has been placed on social and economic indicators. This is because in work on criteria and indicators to date, it is the social and economic indicators that have caused the greatest difficulty.

This working draft will be supplemented with comments received during a broader stakeholder review. Identified gaps will be filled through further research and through interviews with a number of forest managers with experience of the use of indicators of sustainable forest management.

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[1] Each report contains introductory material for context, plus a single chapter for review.
[2] References are also available as a separate file for information and review.

Introduction

Since the 1992 United Nations Conference on Environment and Development, there has been increasing interest in the practice of sustainable forest management. Although by 1992 the International Tropical Timber Organization had already begun to develop criteria and indicators (ITTO 1992, 1993) and have subsequently done extensive work in this area (ITTO, 1998, 2003, 2005), it was the Forest Principles document[3] that set the scene for the development of a number of different international and national sets of criteria and indicators of sustainable forest management. While many continue to argue that the definition of sustainable forest management is elusive, it is the generally agreed criteria that define sustainable forest management. Canada is a member of the Montreal Process, and in the Santiago Declaration of 1995, agreed to a set of seven criteria that would define the environmental, economic and social values that in turn define sustainable forest management. Each criterion was accompanied by a suite of indicators that would enable reporting of progress towards sustainable forest management at an international level (Montreal Process, 1999).

While most signatory states of the Montreal Process follow and use the criteria and indicators as the basis for national reporting, Canada has adopted a slightly different approach. Through the Canadian Council of Forest Ministers, the provinces have developed a revised set of criteria and indicators, loosely based upon, but subtly different from, the Montreal Process criteria and indicators (Canadian Council of Forest Ministers 2003). Following direction from the steering group of the Common Ground project, this report is structured around the Canadian Council of Forest Ministers revised suite of criteria and indicators.

The international level (Montreal Process) and national level (Canadian Council of Forest Ministers) criteria and indicators provide a basis for reporting at the international and national scales. Reports to date have encountered considerable difficulties due to lack or unavailability of the necessary data, throwing into question the practical value of some of the indicators. In addition, reports at these scales cannot report on whether or not management of individual forestry operations is sustainable (Canadian Council of Forest Ministers, 2003). However, it is at the scale of the management unit that forest managers are facing increasing pressure from major customers, and this pressure is making forest managers re-evaluate their information collection and reporting processes. In addition, it is becoming increasingly recognized that for forest managers to continue to practice forestry, a ‘social license’ is required, whereby there is broad acceptance of forest practices by forest stakeholders. These stakeholders are asking for evidence that good (sustainable) forest management practices are being adopted.

When faced with the challenge to demonstrate that their forest management practices are sustainable, managers are faced with a number of options. They can seek third-party certification through one or more of the systems currently in use (the main ones in

[3] Non-legally binding authoritative statement of principles for a global consensus on the management, conservation and sustainable development of all types of forests. The full document can be accessed at: http://www.un.org/documents/ga/conf151/aconf15126-3annex3.htm .

Canada are the Canadian Z809 Standard, the Sustainable Forestry Initiative and the Forest Stewardship Council), but such certifications have been questioned as demonstrating sustainable forest management. They can rely on Government legislation, assuming that this legislation will ensure that they are within the boundaries of sustainable forest management. However, the current legislation in British Columbia is clearly inadequate in addressing the full range of values generally associated with sustainable forest management. They can produce a management plan, and argue that such plans demonstrate their commitment to sustainable forest management. However, these are plans only, and do not necessarily reflect what will happen, nor do they provide any guarantee that the values associated with sustainable forest management will be met.

These difficulties have led to increasing interest in a new approach that defines a locally-applicable set of indicators applicable at the level of the management unit and which can be used to measure progress towards sustainable forest management. The definition of such a set of indicators is extremely complex, as the indicators must be both meaningful, and practical.

This report builds on an earlier paper (Hickey and Innes, 2005) that examined the indicators that have been applied in various parts of the world. A total of over 3000 indicators were identified through a survey of the different criteria and indicators schemes in use around the world, combined with assessments of the indicators developed for certification schemes, planning exercises and best management practices. Using the Canadian Council of Forest Ministers framework to identify the questions that need to be asked to determine whether the elements within the Canadian Council of Forest Ministers criteria and indicators are being met, the set of 3000 indicators was reduced to a more manageable suite of 200 indicators. All 200 indicators were considered to be potentially appropriate for British Columbia, but there was clearly some overlap between indicators, and some appeared more relevant than others. At the same time, forest licensees in British Columbia indicated that the final indicator set should be very much reduced in order to make data collection economically feasible.

The Canadian Council of Forest Ministers, in their 2003 revision, adopted six criteria and 46 indicators. Some criteria were sufficiently complex to identify a number of sub-headings, these were termed elements. Thus, the criterion ‘Biological diversity’ contains three elements (‘Ecosystem diversity’, ‘Species diversity’ and ‘Genetic diversity’), and the element ‘Ecosystem diversity’ contains two indicators ‘Area of forest, by type and age class, and wetlands in each ecozone’ and ‘Area of forest, by type and age class, wetlands, soil types and geomorphological feature types in protected areas in each ecozone’.

In this report, we assess each of the 200 indicators, looking at the rationale behind the indicator, the methods used to collect the information, examples of who is currently using the indicator and who is reporting on it, and uncertainties related to the collection of the data or their interpretation, and its relevance to the Forest Resources Evaluation Programme. We have also completed a standardized literature search for each indicator, utilizing keyword searches in the CABI and Web of Science literature databases. The

Natural Resources Information Network database was also searched, but this was found to less helpful, and much of the material indexed here is incomplete or without scientific review. The information provided is intended to provide a state-of-the-art assessment of our knowledge concerning each of the indicators. This knowledge can then be used to reduce the number of indicators being used in an assessment and to help define research priorities.

The work is not being undertaken in isolation. In Canada, the government of Newfoundland and Labrador is taking a strong interest in the work, as are a number of non-BC based forest companies. The project has received recognition from the Montreal Process as one of the most significant developments in work on criteria and indicators in recent years. Both the New Zealand and Australian regional governments have expressed interest in the work, with the latter now suggesting that they might be able to contribute financially to ensure continuation of the work. The European Commission has also expressed interest, particularly in collaboration over the next stages of the report.

The report is a planned stage in the development of a rational set of indicators to define sustainable forest management. Our next report will look at selected licensees to determine which, if any, of the indicators they are already collecting information for. It will include interviews with forest managers to determine the feasibility of collecting further information related to each of the indicators.

The next stage of this process is to determine how we use the information collected from the indicators to determine whether sustainable forest management is actually being achieved. This will involve a major research project on the thresholds for the indicators, and how these thresholds can be adjusted to ensure that an appropriate balance is achieved between environmental, economic and social values. The study, if funded by the Sustainable Forest Management Network of Centres of Excellence, will involve a series of locations across Canada, with current plans including one site each in British Columbia, Alberta, Ontario, and Newfoundland and Labrador. A letter of intent submitted to the BC Forest Sciences Programme, which would have increased the number of sites being studied in British Columbia and more closely tied the project to the BC Forest Resources Evaluation Programme and BC Forest Investment Account, did not generate an invitation to submit a full proposal.

Structure of the report

The report follows the criteria developed by the Canadian Council of Forest Ministers. A standardized format has been adopted which should make it easier to locate particular criteria and elements from the Canadian Council of Forest Ministers framework.

The selected indicators consist of a subset of a much larger group of indicators identified as having been used or proposed in assessments of sustainable forest management. The key to reducing this larger set was to identify the questions behind the indicators being used by the Canadian Council of Forest Ministers. The full process is described by Hickey and Innes (2005).

Two types of indicators are distinguished. They are the current revised indicators adopted by the Canadian Council of Forest Ministers and potential additional or replacement indicators. The latter are labeled as potential indicators. The rationale for each indicator is given, as is a basic description of the indicator, and the question that it might contribute to answering. With both the rationale and the description, we have, where possible, directly quoted from published reports. This is because the document is intended to be a reference only, and the use of direct quotes minimizes any bias or subjectivity that might be introduced by us. In some cases, the rationale for using a particular indicator varies between users – we have simply included the differing rationales without including any value judgment as to which may be the more appropriate.

The basic information about each indicator is followed by a description of the methods used to collect the data, followed by some examples (where known) of who is actually using the indicator and where it has been reported. Finally, examples of reports that use or describe the indicator are cited. These are not intended to be exhaustive; rather the examples given are intended to be illustrative of the use of an indicator. There are quite a number of gaps in these sections, reflecting the fact that while many indicators are recommended, rather fewer are actually put into practice and reported upon.

References

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Hickey, G.M. and Innes, J.L. (2005) Scientific review and gap analysis of sustainable forest management criteria and indicators initiatives. FORREX Series 17. FORREX, Kamloops.

ITTO (International Tropical Timber Organization) (1992) ITTO guidelines for the sustainable management of natural tropical forests. ITTO, Yokohama.

ITTO (International Tropical Timber Organization) (1993) ITTO guidelines for the establishment and sustainable management planted tropical forests. ITTO, Yokohama.

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Criterion 4. Role of Forests in Global Ecological Cycles

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Element 4.1 Carbon cycle

Indicator	4.1.1 Net change in forest ecosystem carbon • Mean Annual Increment (MAI) by forest type and age class • Tree biomass volumes • Non-tree biomass volumes • Soil carbon pools • Removals (fire and harvesting)
Rationale	"Canada's forests play an important role in the global carbon cycle. Forest fires release carbon into the atmosphere while young growing forests take up carbon from the atmosphere and store it. Forest managers, in turn, can have a significant impact on the carbon budget in the way that they manage forests." *Prince Albert Model Forest (2005c)* "Canada's forests store a considerable amount of carbon, and the ability of the forest to take up carbon may factor prominently in Canada's attempts to mitigate climate change. This indicator measures the rate of change in the total forest ecosystem carbon pool over time. In other words, it indicates whether Canada's forests are a sink for or a source of atmospheric carbon." *Canadian Council of Forest Ministers (2003)* "Although the main goal of the Kyoto Protocol is to secure agreement on reducing emissions of greenhouse gases at source, it also recognises that carbon sequestration in forest ecosystems contributes to a reduction in the concentration of greenhouse gases in the atmosphere. Carbon is retained for long periods in the forest biomass and soils, and later in wood products." *Ministerial Conference on the Protection of Forests in Europe (2003)*
Basic Description	This indicator measures the carbon stored in trees, vegetation, litter, dead wood and organic matter "This indicator measures the inputs of carbon to forests from the atmosphere minus losses from forests to forest products and losses to the atmosphere... Interpretation of this indicator should consider not only the total carbon emissions, but also what types of fuels the emissions are coming from. The 2000 report was able to demonstrate that emissions from cleaner energy sources is on the rise while emissions from dirtier fuels is declining. Emissions from fossil fuels, where "new" carbon is being introduced into the atmosphere have different implications for climate change than do emissions from biofuels." *Canadian Council of Forest Ministers (2003)*

Methods Used **A)** **B)** **C)**	 Canadian Forest Service carbon tool Canadian Forest Service Carbon budget model: CBM-CFS2 Net Primary Productivity
Being Used By	Canadian Council of Forest Ministers Lake Abitibi Model Forest, Natural Resources Canada Local Level Indicators Pan-European Forest Process
Examples of Reporting	Canadian Council of Forest Ministers: National Status 2000 The State of Europe's Forests 2003 Australia's State of the Forests Report 2003
Uncertainties and Research Needs	"Considerable information necessary for incorporation into a management-unit scale model of carbon flux exists. Also existing models can be adapted to function at this scale. However, considerable work needs to be done in order to make such calculations using the existing, or modified tools. A detailed discussion of the requirements and outputs of such an exercise is provided. Simulation modeling is the only practical way of undertaking measurement of this indicator. Considerable work needs to be taken on in order to make predictions." *Lake Abitibi Model Forest (1999), Natural Resources Canada Local Level Indicators (2000)*
References	Canadian Council of Forest Ministers (CCFM). 2000. Criteria and Indicators of Sustainable Forest Management in Canada: National Status Criteria and Indicators 2000. Canadian Council of Forest Ministers, Ottawa, Canada. URL: www.ccfm.org/ci/2000_e.html Canadian Council of Forest Ministers (CCFM). 2003. Defining Sustainable Forest Management in Canada: Criteria and Indicators 2003. Technical Supplement 1: Detailed Indicator Descriptions. Canadian Council of Forest Ministers, Ottawa, Ont. URL: www.ccfm.org/review_e.html Commonwealth of Australia. 2003. Australia's State of the Forests Report 2003. National Forest Inventory, Bureau of Rural Sciences, Canberra, Australia. Ministerial Conference On The Protection of Forests In Europe (MCPFE). 2003b. State of Europe's Forests 2003. The MCPFE Report on Sustainable Forest Management n Europe. 4th Ministerial Conference on the Protection of Forests in Europe; 2003 April 28-30;

Vienna, Austria.

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Polglase, P.J., Keryn, I., Partap, P., Khanna, K., Gwinyai Nyakuengama, J., O'Connell, A.M., Grove, T.S., and M. Battaglia. 2000. Change in soil carbon following afforestation or reforestation: review of experimental evidence and development of a conceptual framework. Australian Greenhouse Office, Canberra, Australia. National Carbon Accounting System technical report; no. 20.

Trofymow, J. A. **,** Porter, G. L. **,** Blackwell, B. A. **,** Arksey, R. **,** Marshall, V. **,** and D. Pollard. 1997 Chronosequences for research into the effects of converting coastal British Columbia old-growth forests to managed forests: an establishment report. Information Report - Pacific Forestry Centre, Canadian Forest Service. No. BC-X-374**,** pp. ix + 137.

Indicator	4.1.2 Forest ecosystem carbon storage by forest type and age class
Rationale	"This indicator measures the total amount of carbon stored by Canada's forest ecosystems. The indicator provides valuable information to Canadians, helping to inform the debate on the impacts and mitigations for climate change." *Canadian Council of Forest Ministers (2003)* "Forests are an important component of the global carbon cycle, and forest carbon stocks are a key indicator of sustainable forest management at the national level. Forests account for almost 60 per cent of the carbon that exists in the vegetation and soils of the earth's land surface. International concern about the effects on climate of increased atmospheric concentrations of greenhouse gases such as carbon dioxide has focused policy attention on the dynamics of carbon in terrestrial vegetation and soils. Forests absorb carbon dioxide (CO_2) from the atmosphere during photosynthesis and release it during respiration and the decay of dead plant material. Forests remove CO_2 from the atmosphere and store the carbon in woody tissue when actively growing. The rate of carbon absorption and hence the magnitude of the carbon sink, is greatest in the earliest stages of regeneration and declines as forests mature. The amount of carbon stored in forests can change over time because of: • natural variation in climatic factors such as temperature and rainfall; • the natural developmental or successional dynamics of vegetation; or • disturbances such as fires, storms, or pest and disease outbreaks. Forest management activities such as timber harvesting, site preparation and fire management also influence the uptake and release of greenhouse gases." *Commonwealth of Australia (2003)* "Net Primary Productivity (NPP) is a measure of the amount of carbon that is stored by plants during the process of photosynthesis. By measuring changes in the amount of carbon that is stored at the landscape level, it is believed that we could determine how productive our forests are and whether or not changes in the global environment are having an impact on our forests." *Lake Abitibi Model Forest (2000), Natural Resources Canada (2000)*
Basic Description	"This indicator identifies the relative size of the carbon pools. Any interpretation will have to take into account factors such as the age class distribution of the forest, fires, insect disturbance, etc. Also, it is important to note that carbon budget (storage) results depend

	on scale of model used." *Canadian Council of Forest Ministers (2003)* "Estimates of total forest biomass allow changes in total carbon pool over time to be assessed. Estimation by forest type and age class allows better understanding of these changes." *Commonwealth of Australia (2003)*
Methods Used **A)** **B)**	 Canadian Forest Service carbon tool Canadian Forest Service Carbon budget model: CBM-CFS2
Being Used By	Montreal Process[1] Canadian Council of Forest Ministers Slocan Forest Products Ltd. United States Department of Agriculture Forest Service: National Report on Sustainable Forests 2003 Commonwealth of Australia Pan-European Forest Process
Examples of Reporting	Canadian Council of Forest Ministers: National Status 2000 United States Department of Agriculture Forest Service Data Report: A Supplement to the National Report on Sustainable Forests (2003) Australia's State of the Forest Report 2003 State of Europe's Forests 2003
Uncertainties and Research Needs	While there is a limited amount of information available for some forest ecosystems, the carbon storage in many forest ecosystems remains imperfectly understood.
References	Canadian Council of Forest Ministers (CCFM). 2000. Criteria and Indicators of Sustainable Forest Management in Canada: National Status Criteria and Indicators 2000. Canadian Council of Forest Ministers, Ottawa, Canada. URL: www.ccfm.org/ci/2000_e.html Canadian Council of Forest Ministers (CCFM). 2003. Defining Sustainable Forest Management in Canada: Criteria and Indicators 2003. Technical Supplement 1: Detailed Indicator Descriptions. Canadian Council of Forest Ministers, Ottawa, Ont. URL: www.ccfm.org/review_e.html

[1] Refers to Montreal Process Indicator "Total forest ecosystem biomass and carbon pool, and if appropriate, by forest type, age class, and successional stages"

Commonwealth of Australia. 2003. Australia's State of the Forests Report 2003. National Forest Inventory, Bureau of Rural Sciences, Canberra, Australia.

Ministerial Conference On The Protection of Forests In Europe (MCPFE). 2003b. State of Europe's Forests 2003. The MCPFE Report on Sustainable Forest Management n Europe. 4th Ministerial Conference on the Protection of Forests in Europe; 2003 April 28-30; Vienna, Austria.

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Potential Indicator	Available carbon credits in British Columbia's forest sector
Rationale	"Afforestation and wood-ethanol production are excellent opportunities for Canada to reduce its greenhouse gas emissions and help meet its Kyoto commitment while boosting the economy and contributing to rural employment. What is required now is investment to develop the wood-ethanol industry and to address the technology gaps present in wood-ethanol processes." *Saddler (2002)*
Basic Description	
Methods Used **A)** **B)** **C)**	
Being Used By	
Examples of Reporting	
Uncertainties and Research Needs	"It is anticipated that the demand for biomass from afforestation will increase over time, as industrial wood waste supplies become scarce due to increasing efficiency of mills as well as increased competition from other users. The value of carbon based on emerging carbon markets has not been included in the analyses, but if a value can be applied to sequestered or avoided carbon emissions then the potential for afforestation increases." *Saddler (2002)*
References	Saddler, J.D. 2002. The Potential of Short Rotation Forestry on Marginal Farmland in BC and Alberta to Provide a Feedstock for Energy Generation and to Reduce Greenhouse Gas Emissions. Project Report 2002-5 Final Project Report. Sustainable Forest Management Network, Edmonton, Alberta. http://sfm-1.biology.ualberta.ca/english/pubs/PDF/PR_2002-5.pdf **Further Reading:** Cairns, R.D., and P. Lasserre. 2004. Reinforcing economic incentives for carbon credits for forests. Forest Policy and Economics 6(3/4):321-328. Sands, R. 2005. Forestry in a global context. In Sustainable Forest Management. R. Sands, (eds.) University of Canterbury, Christchurch,

	New Zealand pp. 157-185

Indicator	4.1.3 Net change in forest products carbon
Rationale	"While the total amount of carbon stored in forest products is tiny relative to that stored in forests or in the atmosphere, it is, nonetheless, a very important component of the overall carbon cycle. In recent years, the amount of carbon transferred from forest biomass to forest products has exceeded that transferred from forest biomass to soils and the atmosphere." *Canadian Council of Forest Ministers (2003)* "The decay of forest product exports, and the subsequent release of carbon into the atmosphere, depends not only on the type of product, but also the country of export. Products tend to decay faster in tropical countries than they do in temperate countries. Any interpretation of this indicator should address the issue of how exports decay and the assumptions made in the model." *Canadian Council of Forest Ministers (2003)* "Net Carbon Flux or the Carbon Budget of a particular area is of particular concern in the context of climate change. As described in the previous indicator, comparing the amount of carbon stored in a particular area to the amount that is being released to the atmosphere allows us to determine if that area is acting as a source for greenhouse gases or is helping to reduce them. The Model Forest Network and the Canadian Forest Service have cooperated in the development of Carbon Budget models for several areas…Net Primary Productivity (NPP) is a measure of the amount of carbon that is stored by plants during the process of photosynthesis. By measuring changes in the amount of carbon that is stored at the landscape level, it is believed that we could determine how productive our forests are and whether or not changes in the global environment are having an impact on our forests." *Lake Abitibi Model Forest (2000) Natural Resources Canada (2000)*
Basic Description	"Forest products also contribute to the carbon cycle (Indicator 4.3.2 [Fossil carbon products emissions]). Conversion of trees to wood and paper shifts carbon from the standing biomass pool to the forest products pool. Recycling plays an important role in the products pool (Indicator 4.4.1 [Recycling rate of forest wood products manufactured and used in Canada])" *Canadian Council of Forest Ministers (1997a)*
Methods Used **A)** **B)**	 Canadian Forest Service Carbon budget model: CBM-CFS2 Canadian Forest Service carbon tool

C)	"This indicator is measured as inputs of carbon from forest biomass to forest products plus inputs from imports minus the losses from products to the atmosphere and losses due products exported." *Canadian Council of Forest Ministers (2003)*
D)	Net Primary Productivity (NPP)
Being Used By	Canadian Council of Forest Ministers Lake Abitibi Model Forest, Natural Resources Canada
Examples of Reporting	Canadian Council of Forest Ministers: National Status 2000 Lake Abitibi Model Forest Assessment of Indicators of Sustainable Forest Management (1999), Natural Resources Canada, Local Level Indicators (2000) Australia's Forests at a Glance 2005
Uncertainties and Research Needs	"Ideally, we would like to measure the NPP at the LAMF level. However, at this time, NPP is measured only at the regional level using complex models. A component of the ongoing research at the LAMF could be to develop a way of determining NPP at the local level so that it can feed into the regional and provincial levels and provide a better understanding of the sustainability of our forests." *Lake Abitibi Model Forest (2000), Natural Resources Canada (2000)*
References	Canadian Council of Forest Ministers (CCFM). 1997*a*. Criteria and indicators of sustainable forest management in Canada: Progress to date. Canadian Council of Forest Ministers, Ottawa, Canada. URL: www.ccfm.org/ci/tech_e.html Canadian Council of Forest Ministers (CCFM). 2000. Criteria and Indicators of Sustainable Forest Management in Canada: National Status Criteria and Indicators 2000. Canadian Council of Forest Ministers, Ottawa, Canada. URL: www.ccfm.org/ci/2000_e.html Canadian Council of Forest Ministers (CCFM). 2003. Defining Sustainable Forest Management in Canada: Criteria and Indicators 2003. Technical Supplement 1: Detailed Indicator Descriptions. Canadian Council of Forest Ministers, Ottawa, Ont. URL: www.ccfm.org/review_e.html Commonwealth of Australia. 2005. Australia's forests at a glance 2005. Australian Bureau of Rural Sciences. Department of Agriculture, Fisheries and Forestry, Canberra, Australia Natural Resources Canada (NRC). 2000. A user's guide to local level indicators of sustainable forest management. Natural Resources Canada, Ottawa, Ont.

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Potential Indicator	Report separate subtotals for emissions of CO2, CH4, N2O, HFCs, PFCs, SF6 in tonnes and tonnes of CO2
Rationale	"Many trace atmospheric constituents affect the radioactive budget of the atmosphere. The Kyoto Protocol includes carbon dioxide (CO2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulphur hexafluoride (SF_6) (http://www.unfccc.de/resource/docs/convkp/kpeng.pdf). Some studies suggest that potential carbon sinks and opportunities to limit emissions of other greenhouse gases may reduce the cost of control." *Reilly et al. (1999)* "The efficiency of processing is another important factor related to fuel consumption and the release of greenhouse gases. Ideally, the amount of energy required for production of a given volume of final product would be quite low. If production efficiency is continually improving, then it is likely that greenhouse gas emissions are declining or remaining stable. If efficiency is declining this could be a warning sign that a facility may not be performing sustainably and that improvements may be required to ensure that carbon budget objectives are met. Admittedly, this could be construed as an indicator of competitiveness, but the focus should be on energy efficiency. An inefficient facility could be contributing significantly more greenhouse gases than an efficient one. " *Lake Abitibi Model Forest (2000) Natural Resources Canada (2000)*
Basic Description	This indicator reports on the gases included in the Kyoto Protocol.
Methods Used **A)** **B)** **C)**	Carbon Budget Model
Being Used By	Southern Rocky Mountain Management Plan Global Reporting Initiative
Examples of Reporting	Roadmap for Sustainability: Weyerhaeuser Company 2004 Citizenship and Environment Report. British American Tobacco. Social Report 2004/2005.
Uncertainties and Research Needs	

References	British American Tobacco. 2005. Social Report 2004/2005. URL:http://www.bat.com/OneWeb/sites/uk__3mnfen.nsf/vwPagesWebLive/C1256E3C003D3339C12570200047DBF2?opendocument&SID=&DTC= [Accessed on 15 October 2005] British Columbia Ministry of Sustainable Resource Management, Kootenay Region. 2003. Southern Rocky Mountains management plan (SRMMP). B.C. Ministry of Sustainable Resource Management, Victoria, B.C. Global Reporting Initiative. 2002. Sustainability Reporting Guidelines. Global Reporting Initiative, Boston, Mass. URL: http://www.globalreporting.org/guidelines/2002/gri_2002_guidelines.pdf [Accessed on 16 October 05] Natural Resources Canada (NRC). 2000. A user's guide to local level indicators of sustainable forest management. Natural Resources Canada, Ottawa, Ont. Reilly, J., Prinn, R., Harnisch, J., Fitzmaurice, J., Jacoby, H., Kicklighter, D., Melillo, J., Stone, P., Sokolov, A., and C. Wang. 1999. Multi-gas assessment of the Kyoto Protocol. Nature (401):549-555. Weyerhaeuser Company. 2005. Roadmap for Sustainability: Weyerhaeuser Company 2004 Citizenship and Environment Report. Weyerhaeuser Company, Federal Way, WA. URL:http://www.weyerhaeuser.com/environment/sustainability/webreport/pdf/2004RoadmapForSustainability.pdf. [6 November 2005].

Potential Indicator	Fuel consumption (per m3 of product)
Rationale	"The amount of fuel consumed in forest management activities and in processing the wood provides an indication of the amount of carbon that is being released and may provide some direction in terms of how the forest should be managed for sustainability from the perspective of global climate change… "Another important aspect of the carbon cycle in the LAMF is the amount of carbon that is released as a result of forest management operations. This is not usually considered to be an aspect of sustainable forest management, but from the perspective of lowering emissions of greenhouse gases, all activities that contribute to the release of these gases are a concern. Thus, if harvesting operations contribute a significant amount of greenhouse gases to the atmosphere, these activities may need to be modified because they may not be sustainable from a global perspective." *Lake Abitibi Model Forest (2000) Natural Resources Canada (2000)*
Basic Description	"Fuel usage per cubic meter of harvest represents a fossil-carbon-released to renewable carbon harvested ratio" *Western Forest Products Inc. (2003)*
Methods Used **A)** **B)** **C)**	Track the amount of fossil fuels consumed
Being Used By	Western Forest Products Inc. Lake Abitibi Model Forest, Natural Resources Canada
Examples of Reporting	Western Forest Products Tree Farm License 6, 2003 Annual Report
Uncertainties and Research Needs	"The information required to measure this indicator may be considered proprietary by the forest industry because divulging it could affect the competitiveness of their operations. It is also potentially a difficult indicator to track, given the way that forest management operations are conducted within the LAMF. There are a number of different companies operating in the forest, each with a different tracking system and with various sub-contractors who may or may not be tracking the amount of fossil fuels consumed. Therefore, more research will be required to determine how this indicator can be measured and to gauge

	the contributions of forest management and processing activities in terms of their contributions to climate change." *Lake Abitibi Model Forest (2000), Natural Resources Canada (2000)*
References	Natural Resources Canada (NRC). 2000. A user's guide to local level indicators of sustainable forest management. Natural Resources Canada, Ottawa, Ont. Western Forest Products Inc. 2001. Tree Farm License 6 Sustainable Forest Management Plan. Western Forest Products Inc. Duncan, B.C. URL: www.westernforest.com/fstew/tfl6.html Western Forest Products Inc.. 2003. Tree Farm License 6 2003 Annual Report. Western Forest Products Ltd. Duncan, B.C. www.westernforest.com/fstew/monitoring.html

Potential Indicator	Use and emissions of ozone-depleting substances (in tonnes of chlorofluorocarbon-11 (CFC-11) equivalents)
Rationale	"Substances that deplete the ozone layer are scheduled to be phased out by developed countries by 2005 in accordance with the Montreal Protocol. The forest products industry uses one such substance, methyl bromide, to kill insects, weeds and other disease-causing organisms in tree- seedling nursery beds and to disinfect some export products. The industry believes use of this chemical is critical to produce cost-effective, healthy seedlings and to prevent the spread of insects and disease. Weyerhaeuser has been actively seeking alternatives since 1979." *Weyerhaeuser (2005)*
Basic Description	Certain ozone-depleting substances are still being used and this indicator tracks the overall use and emission level of these substances.
Methods Used **A)** **B)** **C)**	
Being Used By	Global Reporting Initiative
Examples of Reporting	Roadmap for Sustainability: Weyerhaeuser Company 2004 Citizenship and Environment Report
Uncertainties and Research Needs	
References	Weyerhaeuser Company. 2005. Roadmap for Sustainability: Weyerhaeuser Company 2004 Citizenship and Environment Report. http://www.weyerhaeuser.com/environment/sustainability/webreport/pdf/2004RoadmapForSustainability.pdf. [Accessed on 6 November 2005] Global Reporting Initiative. 2002. Sustainability Reporting Guidelines. Global Reporting Initiative, Boston, Mass. URL: http://www.globalreporting.org/guidelines/2002/gri_2002_guidelines.pdf [Accessed on 16 October 05]

Indicator Name	4.1.4 Forest sector carbon emissions
Rationale	"Concentrations of greenhouse gases in the atmosphere are increasing as a result of human activities. While the impact is not known with certainty, it is believed that humans are having a discernible influence on the global climate, and that future effects will be potentially more serious. The major source of emissions is the burning of fossil fuels, and the major greenhouse gas in terms of volume emitted is carbon dioxide." *Canadian Council of Forest Ministers (2003)*
Basic Description	"This indicator tracks forest sector's contribution of carbon dioxide to the atmosphere by measuring, over time, the industry's emission of carbon dioxide, include carbon dioxide produced as a result of energy production." *Canadian Council of Forest Ministers (2003)*
Methods Used **A)** **B)**	 Canadian Forest Service Carbon budget model: CBM-CFS2 Canadian Forest Service carbon tool
Being Used By	Commonwealth of Australia Canadian Council of Forest Ministers
Examples of Reporting	Canadian Council of Forest Ministers: National Status 2000 Australia's Forests at a Glance 2005
Uncertainties and Research Needs	Identified indicator research need(s): 1. Life cycle analysis of forest products
References	Canadian Council of Forest Ministers (CCFM). 2000. Criteria and Indicators of Sustainable Forest Management in Canada: National Status Criteria and Indicators 2000. Canadian Council of Forest Ministers, Ottawa, Canada. URL: www.ccfm.org/ci/2000_e.html Canadian Council of Forest Ministers (CCFM). 2003. Defining Sustainable Forest Management in Canada: Criteria and Indicators 2003. Technical Supplement 1: Detailed Indicator Descriptions. Canadian Council of Forest Ministers, Ottawa, Ont. URL: www.ccfm.org/review_e.html Commonwealth of Australia. 2005. Australia's forests at a glance 2005. Australian Bureau of Rural Sciences. Department of Agriculture, Fisheries and Forestry, Canberra, Australia.

	Further Reading: Kijazi M.H., and S. Kant. 2003. Conformance of Ontario's forest management planning with criteria and indicators of sustainable forest management. Forestry Chronicle 79(3):652-658.

Further Reading for Criterion 4: Role in Global Ecological Cycles

Kirschbaum, M. U. F. 2001. The role of forests in the global carbon cycle. In: Criteria and indicators for sustainable forest management. Papers presented at an IUFRO/CIFOR/FAO conference 'Sustainable forest management: fostering stakeholder input to advance development of scientifically based indicators'; 1998 August; Melbourne, Australia, p 311-339.

Trofymow, J. A. **,** Porter, G. L. **,** Blackwell, B. A. **,** Arksey, R. **,** Marshall, V. **,** and D. Pollard. 1997 Chronosequences for research into the effects of converting coastal British Columbia old-growth forests to managed forests: an establishment report. Information Report - Pacific Forestry Centre, Canadian Forest Service. No. BC-X-374**,** pp. ix + 137.

Appendix 1: Questions and associated indicators for Criterion 4

Carbon Cycle (CCFM Element 4.1)

To what extent are British Columbia's forests a sink for, or a source of, atmospheric carbon?

CCFM Indicator:
4.1.1 Net change in forest ecosystem carbon
• Mean Annual Increment (MAI) by forest type and age class
• Tree biomass volumes
• Non-tree biomass volumes
• Soil carbon pools
• Removals (fire and harvesting)

To what extent are British Columbia's forest ecosystems having an impact on climate change?

CCFM Indicator:
4.1.2 Forest ecosystem carbon storage by forest type and age class

Other Potential Indicators:

- Available carbon credits in British Columbia's forest sector

To what extent is the amount of carbon transferred from forest biomass to forest products greater than that transferred from forest biomass to soils and the atmosphere?

CCFM Indicator:
4.1.3 Net change in forest products carbon

Other Potential Indicators:

- Report separate subtotals for CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 in tonnes and tonnes of CO_2
- Fuel consumption (per m3 of product)
- Use and emissions of ozone-depleting substances (in tonnes of chlorofluorocarbon-11 (CFC-11) equivalents)

To what extent is British Columbia's forest product sector contributing carbon dioxide to the atmosphere?

CCFM Indicator:
4.1.4 Forest sector carbon emissions

Identified indicator research need(s):

- Life cycle analysis of forest products