FOREST CARBON SEQUESTRATION AND AVOIDED EMISSIONS

a background paper for the
Canadian Boreal Initiative/Ivey Foundation
Forests and Climate Change Forum
October 15th to 17th, 2007

Kananaskis, Alberta

IVEY foundation

CANADIAN BOREAL INITIATIVE

FOREST CARBON SEQUESTRATION AND AVOIDED EMISSIONS

Prepared by Chris Henschel and Tim Gray

Chris Henschel is the National Manager, Domestic and International Policy, Conservation and Climate Change for the Canadian Parks and Wilderness Society.

Tim Gray is Program Director for the Ivey Foundation.

The Ivey Foundation is a private charitable foundation located in Toronto, Canada. The Foundation supports forest conservation in Canada through its *Conserving Canada's Forests* program. The goals of the program are twofold:
1. Increasing the amount of protected forest ecosystem in Canada.
2. Expanding the adoption of sustainable forest practices in Canada.

11 Church Street, Suite 400
Toronto, Ontario M5E 1W1
(416) 867 9229
www.ivey.org

Based in Ottawa, the Canadian Boreal Initiative brings together diverse partners to create new solutions for Boreal Forest conservation and acts as a catalyst by supporting a variety of on-the-ground efforts across the Boreal by governments, industry, First Nations, conservation groups, major retailers, financial institutions and scientists.

249 McLeod Street
Ottawa, Ontario K2P 1A1
Tel: (613) 230-4739
www.borealcanada.ca

Cover photo: Bruce Petersen
Back cover photo: Lori Labatt

INTRODUCTION Canada is a country of forests. We have the world's largest intact forest area in our northern boreal and our temperate and mountain forests contain biodiversity, climate control and economic values that are globally significant.

Climate change will, and is, having a profound impact on these forest ecosystems. Many impacts, such as increases in average temperature and seasonal shifts, are happening in a more compressed timeframe than originally projected by climate scientists. Insect outbreaks, such as the mountain pine beetle, are occurring at a scale that was unimagined ten years ago and some scientists are beginning to warn that many ecosystems may have a "tipping point" beyond which their resilience will be overcome and completely new ecosystems will replace them. Clearly climate strategies in Canada must include those that address the role of this massive and globally significant forest asset.

In parallel to these changes in the natural world, society is rapidly accelerating its discussions concerning how to mitigate against rising carbon emissions and climate change impacts. As a result governments, business and civil society are accelerating discussions concerning how to develop an effective mechanism to reduce carbon emissions. Strategies under development include an abundance of voluntary, and a few regulatory, frameworks. While none are identical, many of them contain carbon trading measures that would enable transfers of money from emitters to entities that could sequester or reduce the net rate of carbon emissions. Most of these systems include forests.

In Canada there is a need to grapple with this emerging market and determine how it can be influenced and directed in a manner that supports the carbon storage and sequestration capacity of forests and conserves forest biodiversity, while helping to reduces our total country-wide carbon emissions (not just those of forests). How to do this involves a strategic discussion among leading advocates for policy reform. It is only in this way that we can arrive at a consensus on the key elements of a carbon reduction strategy that includes forests and a plan to secure the outcomes we seek.

We hope that this Forum will achieve that goal.

In preparing for the Forum we felt there was a need to prepare background material in several key areas that are particularly information rich and/or technical with the hope that it could help to inform more effective participation by Forum attendees.

The material that follows has been prepared to:

1. increase our understanding of the science surrounding estimation of carbon storage and sequestration in Canadian forests
2. Examine the issues of verifiability, additionality, leakage, and permanence as they apply to forests and;
3. Examine the Canadian forest tenure system and its relation to forest carbon trading projects.

Carbon in Canada's boreal ecosystems

This section summarizes the carbon storage and the carbon balance of Canada's terrestrial ecosystems, with an emphasis on the boreal region. The following considerations are important when considering the policy implications of this information:

- *The size of a carbon pool is an indication of the amount of carbon that could be emitted to the atmosphere if the pool is disturbed. Decreasing the size of a carbon pool may result in net emissions to the atmosphere.*
- *The carbon balance of a system indicates whether an overall emission of carbon or removal from the atmosphere occurs on a yearly basis and also the potential for growing (or replacing) the carbon pool.*

- *The residence time of carbon varies between pools. Residence time is an indication of the stability of carbon in that pool (i.e. how long is it expected to remain there?). Moving carbon from one pool (e.g. forest) to another (e.g. wood product) will affect the residence time of the stored carbon.*

Carbon Storage:

Canada's forests cover an estimated area of 303 million hectares and store an estimated 95 Gt of carbon (C).[1] The declared 'managed forest,' for which Canada reports a greenhouse gas balance, covers 230 million hectares and stores an estimated 78 Gt C. Canada's peatlands (64% of which are boreal; 33% are sub-arctic) store an estimated 154Gt C.[2] Table 1 compares some Canadian and global ecosystem carbon stores.

Table 1: Comparison of Canadian and global carbon stores in selected terrestrial ecosystems

Ecosystem	Area (million ha)	Carbon storage (Gt C)
Canada's Forests	303	95[3]
Canada's Peatlands	1136	154[4]
World's Boreal Forests		300 (88 plant biomass; 212 soil and litter)[5]
World's Peatlands		455 (6.9 plant biomass, 448.1 peat)[6] (30% of total global soil pool)[7]

In total, boreal forests store more carbon than any other forest type. Table 2 shows the Canadian Forest Service's estimate of the amount of carbon stored per hectare in Canada's various forest regions.[8]

Table 2: CFS Estimate of carbon storage per hectare in Canada's forest regions

Forest Region	Area	Carbon storage (Mg ha-1)
Total Canadian Forest	404.2	212.4
Boreal West	97.6	170.7
Boreal East	120.2	164.8
Sub-Arctic	85.2	266.1
Cool Temperate	25.8	220.0
Moderate Temperate	0.2	339.8
Grassland	2.6	128.1
Cordilleran	47.3	255.7
Interior Cordilleran	14.6	323.9
Pacific cordilleran	9.1	374.6
Sub-arctic cordilleran	0.9	237.2
Arctic	0.6	265.4

Older boreal, temperate and tropical forests generally all store more carbon than younger forests.[9] Total carbon in a forest ecosystem is stored across several pools: living biomass, coarse woody debris, organic soil horizons, and mineral soil.[10] The majority of boreal forest carbon is stored in soils (including organic).

Carbon Balance:

The overall carbon balance of Canada's forests is equal to the Net Primary Productivity of all forests (NPP = carbon uptake due to photosynthesis - carbon loss due to plant and soil respiration) minus the loss of carbon due to disturbances such as fire and insects. In peatlands, the carbon balance results from emissions of methane balanced by removal of carbon from the atmosphere.

Two major, independent modelling exercises of Canada's forest carbon balance demonstrate that the source/sink balance of Canada's managed forests and Canada's entire forest landbase fluctuates over time. The CFS-CBM3 model used by the Canadian Forest Service estimates that Canada's managed forest has been a sink for most of the past 70 years.[11] However, the model estimates that it has been a source for at least four of the fifteen years between 1990 and 2005 and also estimates a 90% chance that Canada's managed forest will be a net source during the first Kyoto commitment period (2008-2012). The source/sink balance of Canada's forests is driven largely by forces beyond practical human control: natural disturbances and the current age class structure. The recent trend towards a more negative carbon balance is thought to be the result of a recent surge in fire and insect disturbance rates combined with increased temperatures.

The independently developed Integrated Terrestrial Ecosystem C-budget (InTEC) model also shows that Canada's forests have intermittently been a source, but it also estimates a more positive carbon balance for the forest and also that on the whole they are a net carbon sink. At this point in cannot be said which model is a more accurate reflection of reality.

Both models show significant regional variation in carbon balance. Forest areas in the Prairie Provinces are now a large source due to recent fire disturbances and there is a large forest sink in eastern Ontario/western Quebec due to a mid-aged forest.[12] Large areas of British Columbia's forests are carbon neutral.

The average annual carbon flux (net flow of carbon) of Canada's forests is an order of magnitude greater than the long term average carbon flux of peatlands (-0.2 g C yr-1 vs. -0.03 C yr-1)[13], but rates of peatland carbon flux can vary dramatically over shorter time periods (from small source to massive sink).[14] Although average flux rates are much higher for forests than peatlands, the forest sink (i.e. the generally uninterrupted carbon uptake) is transient relative to the peatland sink (50 years vs. 1000 + years).[15] In other words, the residence time of carbon stored in forests (notably living biomass) is short compared to carbon stored in peatlands.

Productivity (NPP) of the forest varies with age. After disturbance (e.g. fire or harvest), forest NPP is initially negative as dead organic materials decompose. As the forest ages the balance becomes positive, carbon sequestration peaks and then declines. For boreal forests, the peak is estimated to occur in the 70-120 year age class,[16] but sequestration continues well beyond this peak.

Conclusions:

1. *Peatlands contain Canada's largest terrestrial carbon stock, but relatively low carbon fluxes. Attention should therefore be focused on overall changes in carbon stores as opposed to increases or decreases in flux.*
2. *The relatively high productivity of forests and the transient nature of forest sinks means that it is relevant to focus on changes in forest carbon balance (flux) as well as total carbon storage.*

3. *It is impractical for management activities to influence the overall nature of Canada's forest carbon balance. Attention should therefore be focused on the effects of management activities.*
4. *Forests remain productive and continue to sequester carbon as they age.*

Effects of forest management on Canada's boreal forest carbon storage and carbon balance

This section summarizes the effects of forest management on forest carbon storage and also discusses the effects of considering carbon stored in forest products, product substitution and secondary emissions associated with forest management. The emphasis is on the boreal forest. The impact of development on peatland carbon stores is also discussed. The following considerations are important when considering the policy implications of this information:

- *Current Kyoto rules only count ecosystem carbon pools, not forest product carbon pool.*
- *How does forest management affect the ecosystem carbon pool?*
- *How is the effect of forest management on the ecosystem carbon pool mitigated by consideration of carbon stored in the forest product pool?*
- *What is the relative sensitivity of forests and peatlands to disturbance?*

Carbon stored in forest products and the effects of product substitution are not included in forest accounting under current Kyoto rules. Doing so would make accounting far more complex and would introduce greater uncertainty into estimates and greater complexity and costs into tracking. The current Kyoto accounting rules for forests avoid these difficulties by excluding forest products: the assumption is that additions to the forest product carbon pool are equal to emissions from decomposition. There is however a movement to include them for several reasons:

- The forest product pool is real and probably growing and we should account for it in order to have a more accurate picture.
- Accounting for the forest product pool would provide incentive for better management of this pool (e.g. encouraging use of recycled wood and discouraging incineration without energy production).
- Accounting for the forest product pool would assist producer countries like Canada, who could count stored carbon in their overall inventory.
- Forest management aimed at increasing production could be subsidized by the carbon market.

The main reasons not to account for forest products are:

- It is too technically difficult and would involve too many uncertainties.
- Consumer countries like the US and the members of the EU would have to account for emissions from products as they decompose.
- It would create an incentive for increased forest management and erode the incentive for forest protection.

Although there is no possibility of Kyoto rules being changed to include forest products for the first commitment period (2008-2012), this could be done for subsequent commitment periods. Policies, markets and offsetting frameworks could also include forest products before this time, but it may be more likely that they will follow Kyoto accounting rules, which treat forest harvest as a direct emission to the atmosphere.

Ecosystem carbon storage

The scientific literature clearly demonstrates that managed forests store less carbon than natural forests.[17] One important reason for this difference is that managed forests contain less old forests. This fact results from the replacement of natural disturbance with harvest disturbance. Harvest rotation ages are generally shorter than the natural disturbance interval. This means that forest stands are not allowed to reach as old an age before they are disturbed, which represents an interruption in the process of forest stands accumulating carbon over time.

The difference in carbon storage between managed and natural forests could be reduced if rotation ages were changed to match natural disturbance intervals but natural forests would still possess more old forest in systems where fire is the dominant natural disturbance because fires do not target mature stands as forest harvest does; fire is relatively age-independent, and burns stands of all ages, resulting in a proportion of the natural forest that ages well beyond the natural disturbance interval.[18] The magnitude of the carbon loss due to conversion depends on the maximum storage capacity of the system (e.g. boreal vs. temperate) and the difference between the age of the old growth state in that system.[19] Conversion of natural to managed forests in regions with shorter fire return interval will result in less carbon loss.

The second important reason that managed landscapes store less carbon than natural landscapes is that forest harvest removes stemwood biomass carbon. This biomass is transferred to the detritus and soil carbon pools after natural disturbance.[20]

Forest management also leads to carbon storage loss from deforestation from the creation of logging roads and landings. The Canadian Forest Service estimates the total amount of annual deforestation in Canada to be about 50,000 ha,[21] a relatively small impact compared to effects on forest age.

A meta-analysis of 26 studies of the impacts of forest harvest on soil carbon suggests that there is no significant overall impact when all harvest types and forest types are taken together. However, the analysis does show a small impact on both soil carbon and nitrogen of full-tree logging, the most common practice in Canadian boreal forestry.[22]

The Canadian Forest Service has estimated the carbon budget implications of converting natural forests to managed forests. The result for the boreal forest was a 12.1% loss of carbon over a 200-year modelling period.[23] Carbon losses are greatest in the first decades of the simulation.

Generally speaking, once the transition from a natural forest to a managed forest has occurred, forest management should not result in significant losses from the ecosystem carbon pool. An important exception to this is sensitive forest areas where harvest could cause hydrological impacts or decreased productivity. Significant losses of ecosystem carbon and nitrogen can also occur under intensive forest management practices (e.g. whole tree harvesting) and extremely short rotation ages.[24]

Forest products

Adding consideration of carbon stored in forest products affects the overall carbon balance of forest management. One estimate for the U.S. is that since 1910, 2.7 Gt of carbon has accumulated in wood and paper products that are still in use or buried in landfills, about 20% of the carbon contained in all living trees in that country.[25] In Canada, forest products were estimated to be less than 1% of the total carbon inventory.

The effectiveness of forest products for carbon storage depends on the efficiency of production, the lifespan of the product and its ultimate disposal (i.e. incinerated, recycled or landfilled). Less than 50% of harvested logs are converted into dimensional lumber;[26] the harvested wood-to-product ratio is higher for pulp and paper (e.g. assumed to be 85% in the CFS-CBM model).[27]

Wood products are deemed to have a relatively long lifespan (5 – 100 years), whereas the lifespan of paper is quite short. However, both these product types can also have significant residence times in landfills. A study in the U.S. suggests that only 0-3% of the carbon in wood is ever emitted as landfill gas and maximally only 30% of the carbon from paper.[28] If this is true, wood carbon stored in landfills has a much larger residence time than tree biomass in a forest.

Still, most of the studies reviewed for this paper show that even when carbon storage in wood products is considered, models project that managed forests still store less carbon than natural forests,[29] though the gap is reduced.[30] A notable exception to this trend is a model projection for the Foothills Model Forest in Alberta. In this case the harvest rotation age was longer than the natural disturbance interval, and overall carbon storage in the forest and product pool increased.[31]

Secondary emissions

The effect of carbon storage in wood products on the overall forest carbon balance is countered by the inclusion of emissions associated with forest management, processing and transport. Several studies have attempted to quantify the effect of secondary emissions. The outcome of the assessment depends on its scope. One study looked at the fossil fuel emissions from increased silvicultural activity and found that they offset the gains in increased production of forest products.[32] Another study found that emissions from forest management were only a fraction of carbon sequestration from tree growth.[33] The most comprehensive assessment paints a very different picture. The Heinz Center, partnered with Stora Enso in North America, CANFOR, Home Depot, Time Magazine and InStyle Magazine, examined the entire supply chain from forest harvest to waste disposal and product decomposition for dimensional lumber and magazines.[34]

Consistent with the previous studies mentioned, they found that forest management operations had a fairly small effect, but this accounted for less than 1% of total greenhouse gas emissions from the supply chain. Ninety-four percent of total greenhouse gas emissions from the dimensional lumber supply chain resulted from transportation and distribution of the product to the consumer. Pulp mill emissions accounted for 61 to 77 % (depending on the mills) of the total greenhouse gas emissions in the magazine supply chain. In total, the study found that the supply chains resulted in the emission of 0.22 tons of carbon per ton of dimensional lumber, 0.32 tons of carbon per ton of Time Magazine and 0.30 tons of carbon per ton of InStyle magazine.

Product Substitution

The carbon benefit of forest products would again be increased when the effect of using wood products in place of more energy-intensive products such as concrete and steel is considered.[35] One study reviewed claims that whereas both the ecosystem carbon pool and the wood product carbon pool can become saturated, the emission reductions through product substitution can be continuous. However, these studies make questionable assumptions about forest management and growth (e.g. do not consider effect of forest conversion) and also have not incorporated a comprehensive life-cycle analysis such as was done by the Heinz Center.

Looking at product substitution from the opposite perspective, virgin forest products could be substituted with alternatives (e.g. recycled inputs). This perspective would tend to worsen the net carbon balance of the forest sector.

We are not aware of any studies or assessments that model or estimate all the trade-offs of forest conversion, carbon stored in wood products, secondary emissions and product substitution.

Development of peatlands

The carbon balance of peatlands is determined by the balance of methane emissions and carbon removal from the atmosphere. The impact of development, therefore, depends on the relative effect on these two processes. Modest drainage of peatlands for forest management as practiced in Finland, for example, would have no or a very small effect on the carbon balance; although peat decomposition would increase, this would be balanced by tree growth and by the cessation of methane emissions. Flooding peatlands for hydrological development and large-scale drainage and peat extraction would have a very large positive effect on net emissions.[36] A life cycle analysis of peat extraction in Canada from 1990 – 2000 showed a large net emission of greenhouse gases, 71% from decomposition of the extracted peat and 15% from the conversion of the peatlands from a carbon sink to a source. The authors of this study estimated that it would take 2000 years for peatlands to replace this carbon.

Conclusions:

1. *Ecosystem pools of carbon are reduced by forest management when natural forests are converted to managed forests. The rate of carbon loss is highest in the first few decades. The magnitude of this loss depends on forest type and the natural disturbance interval.*
2. *It appears that the benefits of carbon stored in wood products alone, without considering product substitution, would not be enough to offset the carbon losses associated with forest conversion.*
3. *It remains unclear if there is an overall carbon increase or loss in carbon as a result of forest conversion, production and product substitution. If there is an overall carbon benefit, it will accrue over time because of the initial carbon losses from the forest and the inefficiencies of production.*
4. *After the transition from natural forest to managed forest has occurred, significant losses should not continue unless management is unsustainable or it causes unintended consequences on sensitive sites such as hydrological changes in forested peatlands. A net benefit will be observed when wood products and product substitution is considered.*
5. *Development of peatlands can result in a very large and long-lived impact on peatland carbon stores.*

Forest carbon management activities

This section discusses possible management activities to reduce carbon emissions and increase carbon removal from the atmosphere. The discussion includes the likely carbon benefit as well as biodiversity impact. The following considerations are important when considering the policy implications of this information:

- *Accounting for forest product carbon and product substitution may affect the choice of management activity.*
- *What is the relative importance of short-term and long-term effects and how could/should they be incorporated into policies, programs and markets?*
- *How should biodiversity impacts be considered in the eligibility of management activities?*

Strategies for affecting the forest carbon balance could include both those that protect carbon stores (reduce emissions) and those that increase sequestration. For the purposes of this discussion, management activities are organized into one of three possible classes: land use changes; activities in unmanaged forests; and activities in managed forests.

Activities related to land use change are currently included under Kyoto rules. Countries must account for the effect of these activities on their overall emissions and these activities are also eligible for carbon credits from tropical countries through the Clean Development Mechanism. The effects of forest management activities are currently optional under Kyoto rules and Canada has elected not to account for them. Forest protection would count as a forest management activity.

Land Use Change

Afforestation and reforestation both result in an increase in the total forest carbon pool. The benefit of this activity will accrue over time as plantations or new forests grow. The overall effect on the climate of carbon sequestration from afforestation and reforestation must be balanced against the warming effects of decreased albedo, an effect that is greatest at northern latitudes.

Around 50,000 ha of land is deforested in Canada every year. The carbon benefit of reducing deforestation would be small but immediate and unequivocal. In a forestry context, this could best be achieved through reducing the area of roads and landings, which would have a positive biodiversity impact. Changes in deforestation could be measured using a national, provincial or territorial baseline.

Activities in Unmanaged Forests

Protection of unmanaged forests avoids the carbon loss associated with converting natural forests to managed forests. The term degradation is already being applied to this practice in international policy discussion, so protecting unmanaged forests could also be usefully referred to as "avoided degradation."

As discussed in the previous section, converting natural forests to managed forests results in a loss of carbon from the forest. Avoiding forest degradation in this sense would therefore represent a real and sizeable reduction in emissions, most of which would be manifest in the short-term. A practical way to measure this activity would be to establish a national (or provincial/territorial) baseline estimating the rate of forest conversion over several base years (e.g. 1990 – 2000). This national baseline approach has been the foundation for the broad support currently enjoyed by proposals to include reductions in tropical deforestation within the Kyoto Protocol, largely because it effectively addresses the problem of leakage at the national level.

Measured on a large scale, the reduced emissions associated with reducing conversion are permanent because the models have incorporated a continuation of natural disturbance into the estimate of avoided emissions (i.e., we don't have to worry about the forest offset burning, because this is factored in).

If the outcome of a comprehensive assessment of the benefits of carbon storage in wood products and product substitution documented an overall carbon benefit, the benefits of avoided conversion would be discounted. Over time, there would be a greater carbon benefit of conversion and production versus natural forest protection. Otherwise, beginning forest management activities in currently unmanaged forests would result in net carbon loss from the system unless it happened within a national context of decreasing forest degradation rates.

Avoided forest conversion would have a large biodiversity benefit, especially for large area-demanding species such as boreal woodland caribou (threatened species).

Activities in Managed Forests

Lengthening rotation ages

Many studies have shown that lengthened rotation ages increases total carbon storage,[37] even when forest products are considered.[38] However, shortening rotation age decreases the chance of forest loss due to fire. Lengthened rotation ages would have a positive biodiversity benefit because it would create a larger and more natural amount of the forest in older age classes. The benefit of lengthened rotation ages would accrue over the long term.

Increased forest retention

Activities aimed at increasing forest retention both at the landscape and stand level (e.g. consistent with FSC standards for residual tree retention and maintenance of old core forests) would also increase ecosystem carbon storage. If these activities were practiced without lowering the overall harvest level, they would have no negative impact on total forest product carbon storage.

Fire and insect protection

In the short-term, both fire and insect suppression can have a large impact on reducing forest carbon emissions. However, it is possible that, in the long term, fire suppression results in the build-up of fuels and results in old forests that are more susceptible to both fire and insect attack. Fire and insects are both a natural part of the boreal ecosystem and there are likely negative biodiversity impacts associated with suppressing them. The inclusion of forest products and product substitution would have no effect on this strategy.

Salvage logging

The proportion of fire-killed and pest-killed stands harvested varies between provinces, but in some provinces (Alberta, Newfoundland, Ontario, Saskatchewan) it is negligible.[39] Overall emissions would be significantly lower if a larger proportion of burned and insect-damaged forests were harvested to satisfy a given forest product demand. This would constitute a sustained carbon benefit. However, it is probably impractical to harvest much of this area due to limited access. Increased road access and a decreased extent of naturally disturbed forest would have negative biodiversity impacts. The inclusion of forest products and product substitution would increase the benefit of this strategy. Salvage logging is the possible exception to the conclusion that converting natural forests to managed forests has the net effect of diminishing stored carbon.

Improved regeneration

Assisting regeneration by increased planting and competition management (e.g. herbicides) can have an effect on the carbon uptake in the long-term and also decrease the period of time for which cutovers are net sources of carbon to the atmosphere (short-term benefit). The impacts of increased planting on biodiversity are unclear, but could include the benefit of returning species-appropriate forest to sites that are difficult to regenerate. It could also, however, accelerate replacement of natural mixed age and species forests with single-age and single-species plantings. The biggest documented impact of herbicide use is habitat alteration.[40] Other possible impacts include toxicological effects on fish, killing of non-target insects, and aquatic impacts. Including forest products and product substitution would increase the benefit of this strategy.

Planting improved tree stock

Planting of seedlings that are genetically improved through tree breeding and selection for vigour is already a common practice. However, the extent of use of improved nursery stock could be increased resulting in greater rates of carbon sequestration. This carbon benefit would accrue over the length of the rotation. The biodiversity impact of this practice is unknown. Genetically modified trees do not have regulatory approval for use in Canada and have not been widely field tested.[41] Including forest products and product substitution would increase the carbon benefit of this strategy.

Fertilization

Fertilization has the potential to greatly improve tree growth; studies in Sweden have shown 100% -200% increases in stem volume. However, field studies in Canada have not yielded similar results. The effectiveness of fertilization varies with species, tree density, stage of development, nutrient status of the site, etc. The benefit of fertilization would accrue over the rotation. If inorganic fertilizer is used, the carbon benefit of increased growth will be at least partially offset by the energy costs of producing and transporting the fertilizer.[42] Including forest products and product substitution would increase the carbon benefit of this strategy.

Thinning

Thinning refers to one or more partial harvests of the stand designed to reduce density and result in increased growth in the remaining trees. Thinning does not generally result in an increase of total volume on the site, but may result in a shortened rotation and can also be used to create larger, higher quality wood. The production of higher quality wood could be significant if products and product substitution are considered. Thinning can have biodiversity benefits because it results in greater ground vegetation diversity;[43] the biggest negative impact on biodiversity results from the greater need for road access for multiple entries to the stand.

Conclusions:

1. *Activities adding to the forest land base (afforestation) and decreasing loss (deforestation) have clear benefits. The benefits of reducing deforestation are immediate.*

2. *In unmanaged forests, avoiding conversion of natural to managed forests is the best strategy. If wood products and product substitution are considered, the effects of this activity could be discounted over time.*
3. *In managed forests, lengthening harvest rotation is an effective activity for increasing total carbon storage, even when storage in forest products is considered.*
4. *In managed forests, various activities aimed at increasing forest growth can be an effective strategy for increasing total carbon storage as long as they are demonstrated not to reduce site productivity. Very intensive management would likely result in productivity declines.*

The above discussion provides insight into which forest management practices would be likely to provide the greatest carbon and biodiversity benefits if they were applied in the managed forest. However, which of these practices are most likely to be selected will be strongly influenced by the existing economic structures and policy environments that predominate in Canada's managed forests.

All of these managed forests are managed with a primary objective of producing timber for use in a variety of forest products facilities. These mills require a fixed (and generally increasing) volume of timber to maintain their competitive place in the market and to make a return on investment for the very considerable capital infrastructure in place across the country. Provincial government resource management bureaucracies are also structured in a manner to provide licensing, management support and revenue collection services to this industry. Finally, many politicians, especially those from areas where forest industry dependent communities dominate, respond favourably to forest industry policy demands.

It is therefore probable that there will be a strong institutional and economic bias in the Canadian forest policy and business establishment to select carbon positive forest management practices that also increase the rate of production of wood fibre. Carbon positive practices that do not result in increased short-term fibre production (even if they are cheaper and give relatively larger carbon and biodiversity benefit) are likely to receive lower priority (partly because longer term benefits will be discounted economically).

Therefore it is advisable that strong consideration be given to taking priority action on the establishment of binding protocols that specify acceptable forest carbon practices. These protocols should be in place in advance of the creation of a carbon offset trading regime that includes publicly owned forests.

Carbon Accounting and Offset Measurement Systems

Policy responses to climate change can include setting emission reduction targets, regulating reductions in emissions, providing financial incentives or disincentives (taxing carbon), investing in technology and infrastructure (e.g. public transit), conditional transfers of funds between governments, increasing public awareness, improving government operations,[57] and changing land use policy. This section discusses forest carbon offset projects that could be part of voluntary carbon markets or part of a market resulting from regulated emission reductions. This section does not discuss other policy options, such as land use policies, for addressing the carbon balance of forests at a regional or national level.

There are several key concepts that are important to understanding issues surrounding the proper measurement and accounting for carbon within forest carbon projects. This section of the paper answers the following questions:

1. *What must a forestry activity or project demonstrate in order to meet a high standard of credibility for carbon sequestration or avoided emission?*
2. *What level of consistency has been developed around these terms and the rules for addressing their use in various voluntary and regulatory offset systems?*
3. *Are there some examples available to demonstrate how these concepts have been addressed in real projects?*

Key concepts for development of a forest carbon standard or protocol

a) Verification requirements

Verification systems for forest carbon projects resemble those used for forest certification systems. Eligible auditors are usually registered professional foresters[44]. Common elements of carbon offset verification systems include:

i) Purpose: Provide guidance to "approved third party certifiers" to conduct a standardized and accurate assessment of reported GHG data at forest entity and project levels. Third party certification is essential for credibility of reported GHG emissions (biological and non-biological) reductions.
ii) Process: Certifier assesses entity's methodologies, estimations, models and calculations.
iii) Direct Sampling: Certification process usually includes direct sampling of required carbon pools at the beginning and end of certification intervals.
iv) Annual Monitoring Reports: Certifier assesses annual monitoring reports submitted by entity, checks reports against public information.
v) Material misstatements: Reported data must be free of material misstatements (e.g. entity's direct sampling results must be within some percentage range of certifier's results).

b) Baselines

Development of the forest carbon project base case considers how the forest land would likely be managed without the sequestration project. The credits available are the difference between the "with" and "without" project performance. This also requires the establishment of a base year where carbon stock is measured at the beginning of the project and is compared to stock measures at periodic intervals. The difference is the project performance (+ or -). In some cases (generally for smaller projects) a modeled value can be used without measuring actual performance if this is supported by research. Regional averages can also be used in baseline establishment. This would likely be the case in determination of the rate of forest conversion from natural to managed across Canada.

c) Permanence

Forest carbon projects need to demonstrate that carbon offsets are permanent. This means that the carbon in the trees (or soils or peat) is kept out of the atmosphere for the period the project is designed to cover. Some forest carbon projects will have higher rates of failure risk than others (e.g. a project that relies on fire and insect suppression to lengthen harvest rotations in Manitoba will have a relatively higher risk of failure than one that relies on an unmanaged BC costal forest remaining standing). There are several ways in which risk can be addressed. One option is to discount the value of carbon offsets to reflect the probability of project failure. Another is to purchase insurance that would compensate for project failure. Both of these approaches address the financial liability risk and may protect the interests of the carbon offset purchaser and seller, but they do not provide any compensation for the fact that project failure will result in the carbon returning to the atmosphere. A third approach is to issue only temporary credits for forest offset projects, which would ensure that if a project fails, the emission reduction credit would have to be replaced through other emission reduction efforts in short order.

It may also be possible in the Canadian context (where large forest areas are the norm) to protect against individual project failure through development of projects that operate over large areas. For example, if it was decided to extend the rotation of a 5 million ha. managed forest area as a way to increase carbon sequestration, the project would only fail if a natural disturbance event was large enough to erase the gains for the whole area. Similarly, a large number of smaller projects could be pooled to spread the risk of individual project failure. It is likely that the smaller the project, the more deeply discounted carbon credits would need to be (especially in the boreal forest) to account for a high risk of failure.

d) Additionality

It must be demonstrated that the emission reduction (or CO_2 removal) resulting from an offset project would not have happened in the absence of a carbon market (i.e., someone to buy the value of the CO_2 reduction). A useful way to think about this is that Company A wants to reduce its emissions but decides that it is not in a position to take direct steps to reduce its own emissions and must find another company through which to act vicariously -- "We will reduce our emissions through Company B." Therefore, even though Company A has not reduced its own emissions, its action of purchasing an offset has resulted in a decrease in emissions. The key, however, is that these credits are only valid if the sale of credits was necessary to make Company B's project viable and it would not have proceeded without credits.

The problem with additionality is that it can be very difficult to demonstrate. Furthermore, despite the fact that the methodology developed for use within the Kyoto Protocol is deemed to be rigorous, a recent study indicates that 30-50% of projects developed under Kyoto's Clean Development Mechanism are likely non-additional.[45]

e) Leakage

Leakage occurs when the project causes activity within the project boundary to be displaced to another area outside the boundary, or when the project has market effects, such as causing a change in demand, supply or prices[46]. For example, a reduction in harvest levels in a forest would cause an increase in harvest elsewhere if overall demand did not drop. This problem would not be addressed even if harvest levels were reduced across a wide area (such as a province) because the demand could then "leak" to other regions. However, leakage in forest projects could be avoided by increasing forest area (afforestation), maintaining overall harvest levels, or increasing the use of recycled inputs, for example.

2. Current Protocol Development Situation

Currently there are a number of programs that include forest carbon offsets that are being formulated, operated, and tested. These include the proposed Federal Regulatory Framework for Air Emissions, the Chicago Climate Exchange, National Carbon Offset Coalition, California Climate Action Registry, Zerofootprint, CarbonZero, etc.. There are no absolute international or national guidelines to guide the development of forest protocols under these systems. Some authors have indicated that there may be no "right way" to develop these protocols and that it may be best to develop them on an "as needed" basis[47]. However, the development of significantly different systems will reduce transparency and credibility of systems and may greatly increase transaction costs as project participants are required to learn multiple rules for project design.

To date most approaches have been developed by policy experts with very little or no public input. There is, therefore, little indication of how different approaches may be received by stakeholders. If forest-carbon offset programs become more widespread and begin to be implemented on public lands, the need for greater public consultation and buy-in will increase.

Sample Project

Perhaps the most relevant sample forest carbon project for Canada is one that has been developed in Saskatchewan. The Saskatchewan Forest Carbon Sequestration Project (2002) became the first forest carbon sequestration project to be formally reviewed and approved in Canada under the Greenhouse Gas Emission Trading (GERT) Pilot. GERT concluded that the project will result in real, measurable, verifiable and surplus net sequestration, calculated as carbon stock changes in the with-project case less stock changes in the baseline case. The project is a 50-year agreement (2000–2050) in which Saskatchewan Environment sells net carbon sequestration to the provincial electrical utility, Saskatchewan Power Corporation. Net sequestration of 1.6 Mt C is expected to result from the establishment of white spruce plantations on 3300 ha. of not-sufficiently restocked (NSR) Crown forest land and from forest protection through creation of 206,000 ha of Forest Carbon Reserves (FCR).

Issues that arose in the review included leakage, the permanence of the sequestered carbon and risk of losses, establishment of the reference case, methodologies for projections of impacts, approaches for sampling and measurements, and accounting methods[48].

Issues of leakage were discussed by GERT and it was decided that there were no leakage issues with NSR lands because regeneration on these sites was not displacing agriculture or other uses. There was thought given to a possibility of leakage from the reduction of AAC as a result of the protection of the FCRs, but the impact was too small to measure. This would not be the case on larger projects. NSR lands were eligible because there is no legal or policy requirement in Saskatchewan to regenerate harvested sites (so this project is above baseline). FSR lands were eligible because it was demonstrable that these forest areas would have otherwise been logged in the near term (they were mature).

Permanence issues were addressed by: providing a discount factor on carbon sequestration; protection efforts whereby the NSR lands will receive intensive fire and insect protection and; risk diversification whereby the NSR and FCR lands (12 individual parcels) are dispersed across a large area, therefore reducing the chances of them being burned or destroyed by insects.

On the accounting method side, GERT decided to approve storage of carbon in long-lived forest products (OSB and dimensional lumber) while recognizing this approach conflicted with Kyoto accounting rules. GERT also required that registration of carbon sequestration gains be done on an as-demonstrated basis. Other systems exist that allow registration of benefits based on modeling projections of sequestration. GERT established a number of reporting and other conditions to be fulfilled when estimates of actual net sequestration are registered.

GERT identified several policy issues that require address by government. They include:

1. The acceptability of specific carbon accounting methodologies for forestry sequestration projects.
2. The appropriate minimum lifetime for projects, requirements that carbon stores be maintained for minimum periods, and where responsibility lies for net emissions occurring after a project ends.
3. The appropriate method to use for accounting for harvested wood products.

Additional issues forest conservationists should consider about the Saskatchewan project include the validity of baselines where there is no legal or policy requirement to reforest previously harvested lands, and the ecological criteria used to select FCR lands for protection.

Tenure and Forest Carbon Projects in Canada

In addition to technical issues concerning the ability of Canada's forests to act as sources or sinks for carbon, there are also issues related to how the dominant ownership pattern of Canadian forests impacts possible forest carbon offset projects. In this section the following questions are addressed:

1. How does the public forest ownership system in Canada relate to potential forest carbon offset projects?
2. What policy options exist to enable projects?

Only afforestation, reforestation and avoided deforestation projects could contribute to meeting our Kyoto commitments pre-2012 because Canada has elected not to account for the effects of forest management in the first commitment period. Other forest management activities and projects (including protection) could be eligible in subsequent commitment periods. Meanwhile, ownership of offset credits will still need to be determined for the voluntary market as well as any regulatory markets that develop outside of the Kyoto framework (e.g., the proposed Federal Framework for Air Emissions).

Canadian Forest Tenure and Carbon Projects

Canadian forests are largely public forests. While there is considerable variation by province, 93% of Canadian forest lands are publicly owned and management authority is overwhelmingly provincial, comprising 77% of the total[49]. The 7% of lands that are privately held increases proportionately as one moves from west to east. In the northern territories the federal government retains management control, although forestry management has been devolved to the territorial government in Yukon.

This tenure summary only shows part of the picture. Increasingly, Canadian governments have been ordered by our courts to meaningfully consult on resource and land allocation decisions with Aboriginal peoples. While progress to achieve this reality on the ground has been spotty at best, the ownership and land tenure system for these public forest lands can be seen to be shifting towards greater rights for Aboriginal people and increasingly any new dispositions of land or resource rights (including carbon rights) must address their interests.

Given this ownership structure, any forest-carbon offset program that is to be a significant contributor to atmospheric carbon reduction must be operable in a public tenure environment. This situation presents a different set of challenges and opportunities from projects that have been developed in forest landscapes that are dominated by private holdings.

Currently there are two very different forest land-allocation environments where carbon offsetting may interact with forests. The first is the largely intact, sparsely allocated (to industrial interests) northern forest where conservation opportunities remain very high and the more fragmented, fully-allocated southerly forest where conservation opportunities are less but still significant and important.

The two most likely forest-carbon projects that could be developed in these landscapes are those that use carbon offset monies to:

a) avoid conversion of natural forests to managed forest (including peatland forests where the highest stored carbon value may be in the peat rather than the trees); and
b) increase the sequestration of carbon in managed forests through modifications to forest management practices.

On balance there are more opportunities for avoided conservation of natural forests in the northern unallocated parts of the provinces and territories (where forest tenures are absent)[50]. However, there remain significant opportunities in portions of forest management licences that have only recently been allocated or accessed (e.g .Trout Lake FMA in Ontario, Al-Pac FMA in Alberta). The opportunities for forest management related projects are the reverse, with generally greater possibilities in the more southerly licensed forests.

However, for both types of projects there will be common tenure issues to be addressed if carbon-offsetting projects are to be developed in a public ownership environment. These issues are related to assignment of responsibility and carriage of risk in the development of contracts in a carbon offset trading environment. The risks and responsibilities themselves are not significantly different than those found for projects that would be developed for private land, but the methods by which they may be addressed and how they influence the feasibility of the projects may be quite different from private land projects.

Ownership-related issues to be addressed in any forest-carbon project include (in addition to those of determining the baseline calculation, permanence, additionality, and leakage that are common to forest-offset projects in private lands and discussed elsewhere in this document):

1) Ownership or title

Since forest lands are seen by provinces and the federal government to be under their title, any contracts concerning ownership of carbon rights (and therefore revenue) would need to be negotiated with them as a full and willing participant. This situation may seem like that with a private land-owner but it is complicated by two significant factors: aboriginal title and the forest industry tenure system.

Of first priority (and of importance in both northern and southern forests) are Aboriginal claims to land rights. These claims exist in a variety of circumstances, from those where modern treaties are completely absent (such as most of British Columbia, much of northeastern Quebec, parts of Labrador and in large portions of the Territories) to the Prairies, Ontario and the Maritimes, where historic treaties are in place but where they have, until recently, been interpreted as only conferring limited rights to Aboriginal peoples.

However, Canadian courts have recently ruled that Aboriginal peoples in both circumstances—either as beneficiaries of treaties or where Aboriginal rights and title issues have not yet been settled--have significant rights to greater degrees of consultation and accommodation than have been historically afforded in land and resource allocation decisions. It is therefore very likely that Canadian courts would see the assignment of major rights over carbon as a new allocation on public lands that would require, at a minimum, consultation and accommodation with affected Aboriginal peoples.

Forest industry tenure presents another complication with different attributes. Forest management tenures were developed in conjunction with the original establishment and early growth of the lumber and pulp and paper industry in the early to mid-20th century. These were part of a social contract between government and industry whereby industry provided investment dollars and government provided commitment to timber supply. Industry generated profits to shareholders and government gained high levels of employment in labour-intensive harvest and processing facilities as well as revenue from income, corporate and property taxes.

Governments saw this approach as a popular and lucrative development tool and, in many cases, fully allocated the forest, often resulting in overlapping tenures. However, governments retained most rights, usually even to the trees until they were felled and paid for. Common attributes of Canadian forest tenures are: harvest yield controls; mill appurtenancy (connection of forest harvest rights to an area or volume with a particular mill); export controls; non-competitive administered stumpages; controls on license divisibility and transferability[51].

Under this tenure system it is not clear that the forest company that has the harvest license to an area (even if they have an area-based rather than volume-based licence) would be the owner of forest carbon rights and therefore be eligible to enter into carbon offset contracts. Despite these realities, however, some forest companies and associations have expressed an interest and willingness to enter into carbon-offsetting programs[52]. Significantly, some Aboriginal peoples have also expressed interest in entering into negotiations with governments to add carbon rights to those that they have negotiated with governments over forest management[53]. They would appear to face similar barriers to implementation that affect industrial forest tenure holders.

2) Liability and Remedies

Issues of rights to carbon offset-generated monies are inherently linked to responsibilities for making sure that this carbon stays sequestered in the manner stipulated by any offset contract. This means that the risk of failure of the project (e.g., because of fire, missed growth-response target, etc.) must be assessed and incorporated into the project. Legal obligations for compensation and payment for failure must be assigned as well as assessments of the probable capacity of the entity selling the carbon credits to collect compensatory monies from a responsible owner if the project fails to meet its carbon sequestration goals[54].

Common approaches to addressing risk of failure include discounting of the carbon credit value based on risk of failure or to have the recipient of the offset monies directly or indirectly hold (through insurance) the financial liability for potential failure[55]. These issues are more easily addressed in private land situations where the forest owner is the manager and a corporate entity. They become more complex when the carbon-project signatory is an aboriginal community or forest company while the land owner remains the provincial or federal government.

3) Property Rights Changes

If large scale forest carbon offset projects were to occur (and these would be needed if forest projects are to be significant contributors to emissions mitigation) then the entities (countries, large corporate emitters etc.) would need to hold some form of ownership (through contracts) over the carbon credits that they have sold to forest projects[56]. This encumbrance on Crown ownership of public forests would need to be addressed in any system that is developed.

Policy Options for Forest Carbon Projects

Northern Forests

In the northern portions of the provinces, and throughout the southern forested portions of the territories, large intact forest areas remain. Most of these areas are dominated by Aboriginal populations and many of these forests are subject to ongoing land-use or resource allocation discussions between Aboriginal peoples and the Crown.

In the areas where sustainable forest management is ecologically possible there remains an opportunity to design a tenure system that could incorporate forest carbon projects.
For example, when a new land-use or forest management plan is developed, the government could assign the carbon rights together with the timber rights to an Aboriginal community under a land management agreement. If the plan conserves a greater portion of the forest land as protected reserves than areas to the south, it could be argued that this difference can be considered "above baseline" for the region and the aboriginal community could receive carbon offset monies equivalent to the amount of carbon conserved by not allocating that portion of the land to timber development.

To illustrate this point, consider a hypothetical million hectare forest area in Quebec north of the industrial forest line. If a new land-use plan was to determine that 50% of the area should be permanently protected for woodland caribou habitat, cultural sites and other values, this level of protection would be much higher than the 8% of the forest that is designated to be protected south of the boundary (the Quebec government's committed-but-not-yet-achieved "business as usual" scenario in this case). Therefore, the northern forest may be eligible to receive carbon offset monies equivalent to the amount of carbon kept out of the atmosphere had the forest been converted from natural to 92% managed (e.g., a 42% "above baseline" credit).

Questions to address in respect to this example, or indeed, for any project design include: the nature of the land management agreement between the Crown and the aboriginal community; how to account for the ownership of future carbon credit liability if the baseline increases in the south (through a government move to increase the provincial protected areas target beyond 8%); and how to accurately account for the long-term difference in carbon stores between the managed forest and the natural one (as the basis for credit calculation).

It is also arguable that the actual baseline of activity in this previously unallocated forest is zero development and 100% de facto protection. A possible solution to these divergent baseline scenarios is to develop a national (or provincial/regional) baseline of historical forest conversion rates (say 1960-1990). Increases and decreases from this rate would be considered reductions or increases in emissions generated by this activity. This approach would also be more amenable to national accounting than taking a project-by-project approach. If the overall rate was declining (as the result of project level or policy decisions like those described above) then individual projects could receive carbon offset monies. (As a side note, the same system may also create carbon liabilities for operations which exceed that baseline rate.) This approach would be similar to what is being developed for use with the "avoided deforestation" issue in tropical countries.

Southern Forests

Further south, forest management licences dominate and surround the tenures of private land-owners, mines and hydro projects. This landscape has been described as "fully allocated" where virtually all forest lands are licenced to forestry, reserved as parks, first nation reserves or provided to private interests and individuals. Issues concerning Aboriginal rights also apply here, but the crowded nature of the landscape, and existing investments in forest mill infrastructure and employment -- not to mention legal obligations under existing forest management agreements -- suggest that it will likely be up to governments to develop a carbon tenure regime that will accommodate multiple parties.

Interestingly, the current difficult economic situation facing the forest industry has led to discussions in several jurisdictions concerning the possibility of forest licence tenure reform. Some have called for enhanced forest industry tenure through privatization of a large portion of public forest lands. It has been argued that this would create a mechanism to provide the industry with the long-term certainty of harvest needed to invest in advanced silviculture. This mechanism would also provide a basis for the land-owner and forest manager roles to become one and the same -- and could make the transaction costs of forest carbon projects somewhat lower by being more straightforward to negotiate. However, large-scale privatization of public forests in Canada has few proponents (even in industry) and a considerable list of opponents. It seems to have limited political viability.

Another tenure alternative that has been suggested is to create non-for-profit or for-profit forest management corporations that would operate forest management agreement areas. These corporations would sell timber at market rates (rather than administratively fixed ones as is the practice for most forest lands in the country). This would address industry's request for the end of appurtenancy (although perhaps not in their preferred way), take away a key U.S. complaint in the ongoing softwood lumber wars (that of "subsidized" prices for timber), and turn forest management areas from a cost centre to a potential profit centre. These forest management corporations would also provide a ready vehicle to sell other forest services, including carbon sequestration and storage. They could also be structured to provide management involvement or control to a variety of players, including partial or sole Aboriginal control. Their establishment would also fit with continued provincial government ownership.

Questions to be addressed for such a tenure model include: what would be the likely impacts on industry if timber moved to market prices and flowed freely from producers without government mandated wood supply commitments; and would it be reasonable to expect that the sale of wood, carbon or other products could be done in a manner that produced a viable revenue stream for a typical forest management area?

Summary

1. *The public land ownership system of Canada's forests presents some unique challenges to forest carbon projects. In particular, the responsibility to consult with Aboriginal people and the forest industry tenure system must both be addressed in any forest carbon program.*
2. *New tenure arrangements on public lands will likely be necessary to enable forest-carbon projects. It is possible that such new arrangements could serve other social and economic functions as well.*

References

1 Roulet N.T. 2000. Peatlands, carbon storage, greenhouse gases, and the Kyoto Protocol: prospects and significance for Canada. Wetlands. 20(4): 605-615.

2 There is some degree of overlap between Canada's forest area and Canada's peatlands

3 Roulet N.T. 2000. Peatlands, carbon storage, greenhouse gases, and the Kyoto Protocol: prospects and significance for Canada. Wetlands. 20(4): 605-615.

4 Roulet N.T. 2000. Peatlands, carbon storage, greenhouse gases, and the Kyoto Protocol: prospects and significance for Canada. Wetlands. 20(4): 605-615.

5 Lavoie M., D. Paré, and Y. Bergeron. 2005. Impact of global change and forest management on carbon sequestration in northern forested peatlands. Environ. Rev. 13: 199–240

6 Ibid.

7 Laiho, R. 2006. Decomposition in peatlands: Reconciling seemingly contrasting results on the impacts of lowered water levels Soil Biology & Biochemistry 38 (2006) 2011–2024

8 Kurz W.A. and M.J. Apps. 1999. A 70-year retrospective analysis of carbon fluxes in the Canadian Forest Sector. Ecological Applications 9(2): 526-547.

9 K.S. Pregitzer and E.S. Eukirchen. 2004. Carbon cycling and storage in world forests: biome patterns related to forest age. Global Change Biology (2004) 10, 2052–2077.

10 Ibid.

11 Kurz W.A. and M.J. Apps. 1999. A 70-year retrospective analysis of carbon fluxes in the Canadian Forest Sector. Ecological Applications 9(2): 526-547.

12 Chen, J. Convergence of various estimates of Canada's forest sinks and remaining challenges. Presentation. http://www.davidsuzuki.org/files/Conservation/Conference/Chen.pdf.

13 Roulet N.T. 2000. Peatlands, carbon storage, greenhouse gases, and the Kyoto Protocol: prospects and significance for Canada. Wetlands. 20(4): 605-615.

14 Lavoie M., D. Paré, and Y. Bergeron. 2005. Impact of global change and forest management on carbon sequestration in northern forested peatlands. Environ. Rev. 13: 199–240

15 Roulet N.T. 2000. Peatlands, carbon storage, greenhouse gases, and the Kyoto Protocol: prospects and significance for Canada. Wetlands. 20(4): 605-615.

16 K.S. Pregitzer and E.S. Eukirchen. 2004. Carbon cycling and storage in world forests: biome patterns related to forest age. Global Change Biology (2004) 10, 2052–2077.

17 Kurz, W.A., S.J. Beukema and M.J. Apps. 1998. Carbon budget implications of the transition from natural to managed disturbance regimes in forest landscapes. Mitigation and Adaptation Strategies for Global Change 2: 405-241.

Karjalainen, T. 1996. Dynamics and potentials of carbon sequestration in managed stands and wood products in Finland under changing climatic conditions. Forest Ecology and Management 80: 113-132.

Harmon, M.E., W.K. Ferrell and J.F. Franklin. 1990. Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. Science, New Series: 247 No. 4943.

Cooper, C. 1982. Carbon storage in managed forests. Canadian Journal of Forest Research. 13: 155-166.

18 Kurz, W.A., S.J. Beukema and M.J. Apps. 1998. Carbon budget implications of the transition from natural to managed disturbance regimes in forest landscapes. Mitigation and Adaptation Strategies for Global Change 2: 405-241.

19 Harmon, M.E., W.K. Ferrell and J.F. Franklin. 1990. Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. Science, New Series: 247 No. 4943.

20 Kurz,W.A., S.J. Beukema and M.J.Apps. 1998. Carbon budget implications of the transition from natural to managed disturbance regimes in forest landscapes. Mitigation and Adaptation Strategies for Global Change 2: 405-241.

21 Environment Canada. 2006. National Inventory Report: Greenhouse Gas Sources and Sinks in Canada 1990-2004. April 2006.

22 Johnson, D.W., P.S. Curtis. 2001. Effects of forest management on soil C and N storage: meta analysis. Forest Ecology and Management 140: 227-238.

23 Kurz,W.A., S.J. Beukema and M.J.Apps. 1998. Carbon budget implications of the transition from natural to managed disturbance regimes in forest landscapes. Mitigation and Adaptation Strategies for Global Change 2: 405-241.

24 Peng C., H. Jiang, M. J. Apps and Y. Zhang. 2002. Effects of harvesting regimes on carbon and nitrogen dynamics of boreal forests in central Canada: a process model simulation. Ecological Modeling 155: 177/189

25 Skog and Nicholson 2000.

26 Harmon, M.E., W.K. Ferrell and J.F. Franklin. 1990. Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. Science, New Series: 247 No. 4943.

Kurz, W.A., M.J. Apps, T.M. Webb and P.J. McNamee. 1992. The carbon budget of the Canadian forest sector: Phase I. Northwest Region Information Report NOR-X-326. Forestry Canada.

Gower, S.T., A. McKeon-Ruediger, A. Reitter, M. Bradley, D.J. Refkin, T. Tollefson, F.J. Souba Jr., A. Taup, L. Embury-Williams, S.Schiavone, J. Weinbauer, A.C. Janetos and R. Jarvis. 2006. Following the paper trail: The impact of magazine and dimensional lumber production on greenhouse gas emissions: A case study. The H. John Heinz III Center for Science, Economics and the Environment. www.heinzctr.org.

27 Kurz, W.A., M.J. Apps, T.M. Webb and P.J. McNamee. 1992. The carbon budget of the Canadian forest sector: Phase I. Northwest Region Information Report NOR-X-326. Forestry Canada.

28 Micales J.A. and K.E. Skog. 1997. The decomposition of forest products in landfills. International biodeterioration and biodegradation. Vol 39: 2-3: 145-158.

29 Kurz,W.A., S.J. Beukema and M.J.Apps. 1998. Carbon budget implications of the transition from natural to managed disturbance regimes in forest landscapes. Mitigation and Adaptation Strategies for Global Change 2: 405-241.

Karjalainen, T. 1996. Dynamics and potentials of carbon sequestration in managed stands and wood products in Finland under changing climatic conditions. Forest Ecology and Management 80: 113-132.

Harmon, M.E., W.K. Ferrell and J.F. Franklin. 1990. Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. Science, New Series: 247 No. 4943.

30 Kurz,W.A., S.J. Beukema and M.J.Apps. 1998. Carbon budget implications of the transition from natural to managed disturbance regimes in forest landscapes. Mitigation and Adaptation Strategies for Global Change 2: 405-241.

31 Price, D.T., D.H. Halliwell, M.J. Apps, W.A. Kurz, and S.R. Curry. 1997. Comprehensive assessment of carbon stocks and fluxes in a Boreal–Cordilleran forest management unit . Can. J. For. Res. 27: 2005–2016.

32 D. Markewitz. 2006. Fossil fuel carbon emissions from silviculture: Impacts on net carbon sequestration in forests. Forest Ecology and Management xxx (2006) xxx–xxx.

33 Sonne, E. 2006. Greenhouse Gas Emissions from Forestry Operations: A Life Cycle Assessment. J. Eniron. Qual. 35 JULY–AUGUST: 1439-1450.

34 Gower, S.T., A. McKeon-Ruediger, A. Reitter, M. Bradley, D.J. Refkin, T. Tollefson, F.J. Souba Jr., A. Taup, L. Embury-Williams, S.Schiavone, J. Weinbauer, A.C. Janetos and R. Jarvis. 2006. Following the paper trail: The impact of magazine and dimensional lumber production on greenhouse gas emissions: A case study. The H. John Heinz III Center for Science, Economics and the Environment. www.heinzctr.org.

35 Gustavsson, L., and R. Sathre. 2006. Variability in energy and carbon dioxide balances of wood and concrete building materials. Building and the Environment. 41:940-951.

Garcia, J.P., B. Lippke, J. Comnick, and C. Manriquez. 2005. An assessment of carbon pools, storage, and wood products market substitution using life-cycle analysis results. Wood and Fiber Science.

36 Roulet N.T. 2000. Peatlands, carbon storage, greenhouse gases, and the Kyoto Protocol: prospects and significance for Canada. Wetlands. 20(4): 605-615.

37 Cooper, C. 1982. Carbon storage in managed forests. Canadian Journal of Forest Research. 13: 155-166.

Freeden, A.L., C.H. Bois, D.T. Janzen and P.T. Sanborn. 2005. Comparison of coniferous forest carbon stocks between old-growth and young second-growth forests on two soil types in central British Columbia, Canada. Canadian Journal of Forest Research 35:1411-1421.

Harmon, M.E., W.K. Ferrell and J.F. Franklin. 1990. Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. Science, New Series: 247 No. 4943.

Euskirchen, E.S., J. Chen, L. Harbin, E. J. Gustafson and T. R. Crow. 2002. Modeling landscape net ecosystem productivity (LandNEP).

Peng C., H. Jiang, M. J. Apps and Y. Zhang. 2002. Effects of harvesting regimes on carbon and nitrogen dynamics of boreal forests in central Canada: a process model simulation. Ecological Modeling 155: 177/189 under alternative management regimes Ecological Modelling 154: 75–91

38 Seely, B., C. Welham and H. Kimmins. 2002. Carbon sequestration in a boreal forest ecosystem: results from the ecosystem simulation model, FORECAST. Forest Ecology and Management 169: 123–135.

39 Kurz W.A. and M.J. Apps. 1999. A 70-year retrospective analysis of carbon fluxes in the Canadian Forest Sector. Ecological Applications 9(2): 526-547.

40 Lautenschlager R.A. 1991. Response of wildlife in northern ecosystems to conifer release with herbicides. Cooperative Forestry Research Unit, University of Maine, Maine. Information Report 26. 12pp.

41 Columbo, S.J., W.C. Parker, N. Luckai, Q. Dang and T. Cai. 2005. The effect of forest management on carbon storage in Ontario's forests. Ontario Ministry of Natural Resources. Queen's Printer for Ontario. 126pp.

42 Columbo, S.J., W.C. Parker, N. Luckai, Q. Dang and T. Cai. 2005. The effect of forest management on carbon storage in Ontario's forests. Ontario Ministry of Natural Resources. Queen's Printer for Ontario. 126pp.

43 Kolstrom and Pitkanen. 1999. Effect of forest management on alpha diversity of ground vegetation in boreal forests: A model approach. Boreal Environment Research 4(1): 45-54.

44 Anon 2005. California Climate Action Registry Forest Protocols Overview

45 *Bramley, M. 2007. Forest Carbon Pricing in Canada: A Climate Advocacy Perspective. Presentation to CBI/Ivey Forests and Climate Forum. October 16, 2007. Slide 4 refers to the results of a forthcoming study by the Oko-Institut in Germany.*

46 Brown, S. 2002. Measuring, monitoring, and verification of carbon benefits for forest-based projects. Phil. Trans. R. Soc. Lond. A 1797: 1669–1683.

47 Sampson, R. Neil, 2005. Qualifying Carbon Credits Winrock/CCAR workshop. Berkeley California

48 Lemprière, T.C. et al. 2002. Saskatchewan Forest Carbon Sequestration Project. Forestry Chronicle pgs 843-849 Vol. 78 No. 6

49 NRCAN, 2006. State of the Canada's Forests, 2005-2006

50 Note: If there were no plans to develop these sites at time of the development of carbon offset rules they would not likely be eligible for credits.

51 Haley, David 2006. B.C.'s tenure system in a world context. A presentation for the B.C. Forests Symposium, Nov. 1st 2006.

52 FPAC, 2005. California's Approach to Forest GHG Mitigation – A Canadian Perspective. *Presentation to IETA/ California Climate Action Registry Side Event* Montréal December 8, 2005

53 Webb, J. 2007. Personal communication regarding the Little Red River/Tall Cree First Nations FMA in northern Alberta

54 McCauhey, Hannah, 2005. Trading Forestry Carbon Commodities: Special legal considerations for contracting for sink credits. Presentation to COP 11 2005, 7 December 2005

55 Anon, 2007. California Climate Action Registry Forest Protocols Overview

56 Brown, K and N. Adger, 1993. FORESTS FOR INTERNATIONAL OFFSETS: ECONOMIC AND POLITICAL ISSUES OF CARBON SEQUESTRATION. CSERGE Working Paper GEC 93-15

57 Bramley, M. 2007. An Evaluation of Federal Policy to Combat Climate Change. Pembina Institute. In Draft.

IVEY foundation

CANADIAN
BOREAL
INITIATIVE