92 Extension Note

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Forests in a Carbon-constrained World

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Mitigating Climate Change

Global climate change is one of the most important environmental challenges facing society today. The burning of fossil fuels and to a lesser extent, changes in land use patterns have led to increased concentrations of greenhouse gases in the atmosphere, which are affecting the earth's climate. Not all of the greenhouse gases that we produce stay in the atmosphere—almost half are taken up by the ocean and land ecosystems.[1] Carbon uptake in forests is an ecological service that is becoming one of the values managed by the British Columbia Ministry of Forests and Range. This extension note provides an overview of why carbon uptake and storage in forests are important, some management considerations, and a discussion on how climate change may affect the forest carbon balance.

What Does Carbon Have to Do with Global Warming?

In 2007, the Intergovernmental Panel on Climate Change (IPCC)—representing the most respected climate and natural resource experts worldwide—issued a report with four key conclusions:

- Our climate is changing, including an increase in global average temperatures since the mid-20th century.
- This change is caused by human activities creating greenhouse gases.
- The effects of this change will worsen if no action is taken to reduce our overall greenhouse gas emissions.
- These climate changes will have significant and damaging impacts on human society, industry, and our natural environment.[2]

Millions of people across Canada believe they are already seeing the effects of climate change in their lives. For some people, climate change means the warmer winter temperatures that allowed the mountain pine beetle to expand and spread—killing trees in cities and affecting forestry workers across British Columbia. For others, climate change is the ice roads melting early and cutting off isolated northern communities or access to timber. Yet other people experience climate change in the form of earlier leaf-out of trees and the earlier return of migrating birds. The best explanation we have of these changes is the

[1] IPCC (2007b), p. 26, Table TS.1.
[2] IPCC (2007a).

climate response to the accumulation of human-created greenhouse gases over the last 150 years.

A greenhouse gas (GHG) is any gas that absorbs infrared radiation in the atmosphere. Carbon dioxide (CO_2) is the most important human-created GHG. Its annual emission into the atmosphere grew by about 80% between 1970 and 2004 and now far exceeds the natural range over the last 650 000 years.[3] Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land use change providing a secondary contribution. Other human-created GHGS include methane, carbon monoxide, and nitrous oxide, all of which are produced during the burning of wood and fossil fuels. Additional human-created GHG emissions that are not associated with forestry are hydrofluorocarbons (refrigerant), perfluorocarbons, and sulphur hexafluoride (used in manufacturing).[4]

We convert other GHGS into a common basis of units—carbon dioxide equivalents (CO_2e)—to indicate the global warming potential of each gas. For example, methane has 21 times the impact on global warming as CO_2 over 100 years.[5] Nitrous oxide is even higher at 310 times.

Globally, human activities produced 49 billion t of CO_2e in 2004[6] (15.6 t CO_2e per person in British Columbia in 2007[7]) and these emissions are increasing annually. The forests, land, and oceans have been absorbing our CO_2 emissions for centuries. By the 1890s, these natural carbon sinks were unable to take up all of the human-created emissions and GHGS started accumulating in the atmosphere. We still rely on these natural sinks to take up almost half of our emissions from fossil fuel use and changing land use.

Carbon has become synonymous with the words "greenhouse gas" when people refer to carbon-footprint or low-carbon economy. However, carbon is not identical to carbon dioxide and 1 g of carbon is the equivalent of 3.67 g of CO_2.[8] In forestry, we measure or model the mass of carbon stored in the soil and in the living or dead biomass. The amounts of gaseous emissions or uptake are based on changes in the mass. For example, we can measure the amount of trees, deadwood, and debris before and after a forest fire. The change in mass is assumed to be consumed in the fire and released as gases. However, we have to account for the loss of some of the carbon as methane rather than carbon dioxide and the release of other GHGS.

In the forest ecosystem, carbon cycles from the atmosphere into the forests as trees grow (**Figure 1**). It moves between different components of the ecosystem, including standing

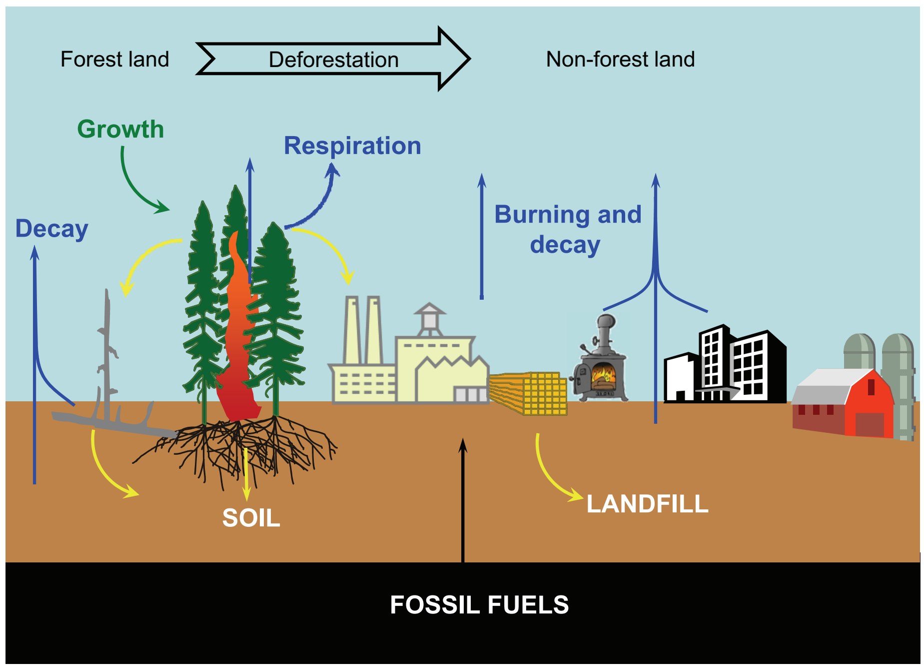

FIGURE 1 *Carbon is taken up from the atmosphere as plants grow (green arrow). From there, carbon may be released back to the atmosphere (blue arrows) or transferred within the ecosystem or to the forest products industry (yellow arrows). Forest carbon also returns to the atmosphere through the burning and decay of wood and decomposition of soils in deforested land. (Image credit: C. Dymond and M. Apps)*

[3] IPCC (2007a), p. 5.

[4] UNFCCC (2009).

[5] British Columbia Ministry of Environment (2009), p. 5.

[6] IPCC (2007a), p. 5, Figure SPM.3.

[7] British Columbia Ministry of Environment (2009), p. 14.

[8] The value 3.67 is estimated from dividing the mass of a mole of carbon dioxide (44.0 grams) by the mass of a mole of carbon (12.0 grams). A mole of chemical substance is, by definition, the number in grams corresponding to the atomic or molecular mass (in atomic mass units). For example, since carbon-12 has atomic mass of 12, a mole of carbon is 12 grams. http://scienceworld.wolfram.com/chemistry/Mole.html

dead snags, leaf litter, fallen branches, stumps, the humus or duff component of the forest floor, and mineral soil. Carbon returns to the atmosphere primarily through respiration of the living vegetation and decay of the dead biomass. Burning of the forest transfers carbon from the living biomass to the atmosphere, deadwood, and soils.

Carbon is taken out of the ecosystem through harvesting or fuelwood collection (Figure 1). The harvested biomass may be used for long-lived products such as construction material, short-lived products like energy or paper, or products that decompose gradually in a landfill. Recycling and reusing forest products slow the return of carbon to the atmosphere. Replacing buildings, disposing of furniture, and burning can accelerate carbon cycling. Additional GHGS are added to the atmosphere from fossil fuel use in transportation and manufacturing by the forest sector.

When we convert forest land to other types of land use, the release of carbon to the atmosphere due to decay is greater than the uptake of carbon by any plants and trees that are part of the new land use. The net result is that these deforested sites are net carbon sources to the atmosphere for at least 10 years. In contrast, land converted into forests tends to be a net carbon sink.

British Columbia Forest Sector Greenhouse Gas Emissions and Uptake

British Columbia's forests are currently a net source of carbon dioxide and other GHGS to the atmosphere. This is the result of harvesting, fires, and the effect of the mountain pine beetle infestation decreasing the amount of tree growth and increasing the amount of decay. Greenhouse gas emissions increased and sinks decreased in British Columbia's forest from 1990 to 2007[9] (Figure 2). The upward trend was mostly due to insect attack and wildfires. In 2006, B.C. Ministry of Forests and Range surveys detected 9.2 million ha of forest attacked by the mountain pine beetle.

An increase in harvesting from 1990 to 2007 resulted in a greater transfer of carbon from forests to harvested wood products. In accordance with international rules, this is reported as a loss of carbon to the atmosphere. In reality, about 40% of the carbon removed from the forest is turned into long-lived forest products like lumber and panels. However, the carbon in wood harvested over the last 100 years is gradually returning to the atmosphere. Provincially, nationally, and internationally, the rules around estimating and reporting GHG emissions from forest products are being revised to better represent what is received by the atmosphere. We can reduce the emission of GHGS from forest products by reducing our consumption, increasing recycling, and using longer-lived products. We can also reduce our overall GHG footprint by using forest products instead of those with a larger footprint such as concrete and steel in construction.

The forest industry in British Columbia consumes fossil fuels in processing and manufacturing facilities and through transportation. Greenhouse gas emissions were estimated at approximately 4 Mt CO_2e for 2006.[10] However, the fossil fuel used in the fighting of wildland fires is not included in these estimates. The trend since 1990 is an overall decrease in emissions as facilities and vehicles have become more efficient, and more

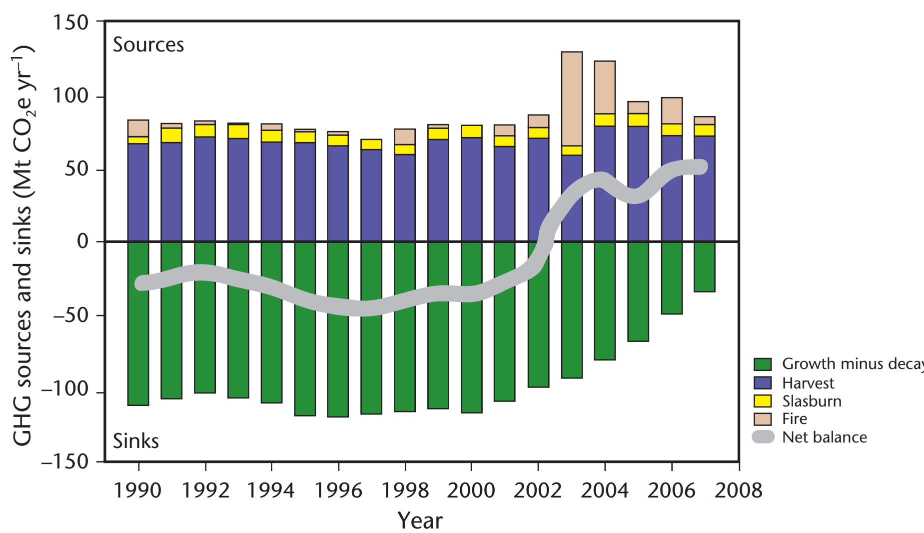

FIGURE 2 *Greenhouse gas sources and sinks in the forest ecosystem of British Columbia (approximately 64 million ha). The sum of growth and decay was a net sink, although recently this sink has decreased due to the mountain pine beetle killing trees. Harvesting, wildfires, and slashburning caused emissions. Consequently, the ecosystem was a net sink from 1990 to 2002 and a net source to the atmosphere in recent years.*

[9]British Columbia Ministry of Environment (2009), Chapter 9.

[10]Data from British Columbia Ministry of Environment and Environment Canada.

recently, due to the closing of mills and reduced industrial activity. The forest sector contributed about 6% to the total provincial fossil fuel and land use change emissions in 2006. This percentage has been decreasing since 1990 as the amount of emissions from the forest industry has decreased and the amount from other sectors has increased.

The losses of forests to other land uses also contribute to GHG emissions. (Note that harvesting followed by regeneration is not considered deforestation.) It is important to monitor this loss because it contributes to 10–30% of global fossil fuel and land use change emissions, and represents about 4% of British Columbia's emissions.[11] The general trend in deforestation activity has been declining since the 1970s when there was considerable hydroelectric and agricultural development. Since 2000, the annual rate was approximately 6200 ha/yr (Figure 3). GHG emissions from deforestation are related to the harvesting and burning during land clearing and decomposition of the forest floor and soil for 20 years following the land clearing activities. Most of the current emissions come from forestland converted to settlements and industrial development. Changes in land use through urban development (e.g., roads and settlements) impact not only biodiversity and water quality but also carbon storage. In British Columbia, communities are becoming increasingly aware of this impact and factoring it into their planning and decision-making. Reducing deforestation can be achieved by avoiding or reducing the permanent loss of forest. Ways to achieve this include narrowing rights-of-way, lowering road density, or reducing urban sprawl.

Afforestation is the planting of trees on land that has not been forested since 1989. In British Columbia, the afforestation rate was approximately 500–2000 ha/yr from 1990 to 2007. The trees were planted primarily on abandoned farmland and increase the amount of carbon dioxide taken up and stored on those sites.

Carbon Cycling in Forest Stands

In an example of a natural, lodgepole pine stand, total carbon stored in biomass increases as the stand grows, and the proportion of biomass in merchantable stemwood also increases (Figure 4). The annual change in the various carbon stock pools is used to determine if an undisturbed stand is a net carbon sink or source. The annual growth represents the uptake of carbon by the stand; the decay causes an annual carbon emission to the atmosphere. The loss or accumulation of net ecosystem carbon stocks is the balance between the two (Figure 4). Young stands after a fire or harvesting are net carbon sources (negative net ecosystem carbon balance) because the decay of woody debris and soil dead organic matter is greater than the uptake in growing biomass. Stands that are mature and vigorously growing are usually net carbon sinks. Old stands with a predominantly single-age cohort may be small sinks or small sources (carbon neutral). Old stands with multi-age stand structure may be substantial carbon sinks.[12]

Forest management can influence the gains and losses of carbon from the forest ecosystem. Therefore, forest management could potentially increase the uptake of carbon dioxide and help mitigate the climate change impacts caused by fossil fuel and land use change emissions. The science of carbon dynamics in response to management activities is still relatively young, and research is ongoing. Below are some examples with the caveat that these results are preliminary.

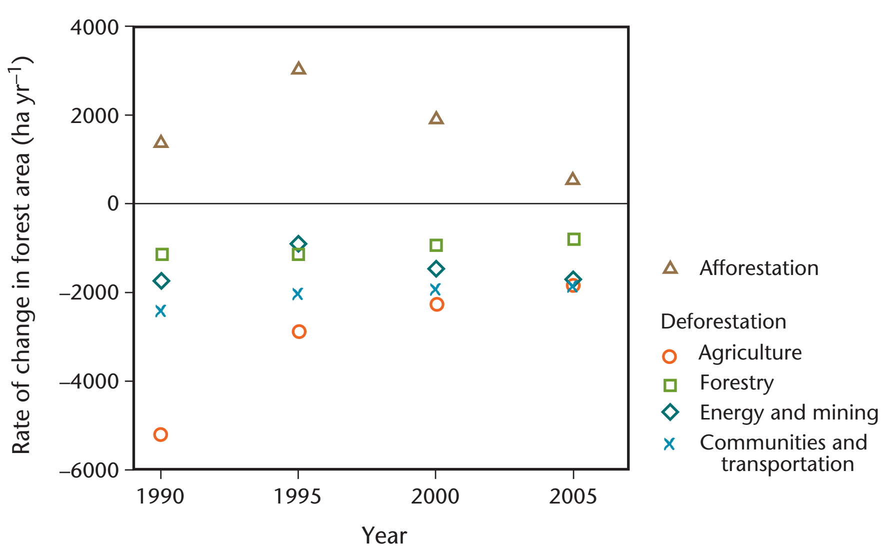

FIGURE 3 *Area affected by afforestation (increasing forest area) and deforestation (decreasing forest area) for British Columbia.*

[11] British Columbia Ministry of Environment (2009), p. 7.

[12] For example, a 500-year-old Douglas-fir stand in Washington State has been a carbon sink 7 out of 8 years that it has been monitored. Luyssaert et al. (2007).

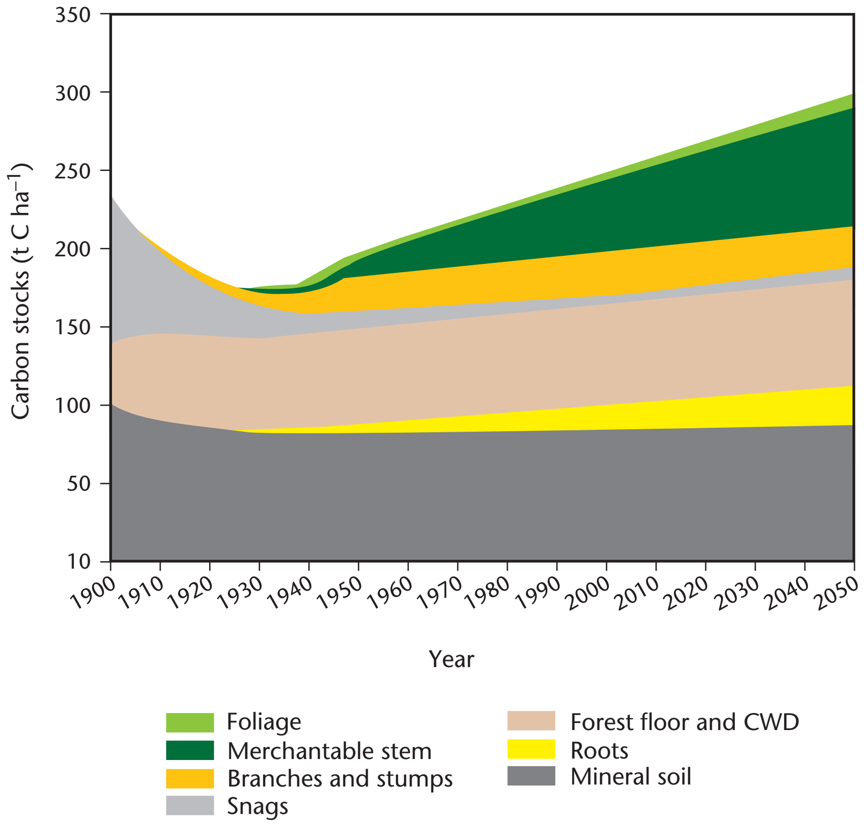

FIGURE 4 *An example of carbon stocks for a lodgepole pine stand using a yield table-driven model of carbon dynamics.*[13] *This is an example for illustration purposes only.*

Harvesting

Harvesting as soon as possible after a stand passes its maximum annual increment or increasing rotation length are proposed as ways to help in mitigating climate change. Harvesting a stand with a low or zero yield increment and replacing it with a young vigorous stand will probably increase the annual uptake of carbon over the next 50–100 years. However, clearcut sites tend to be net carbon sources to the atmosphere for at least 10 years, until the trees grow large enough that their carbon uptake through growth is greater than the decay in the stand. The key to carbon storage through longer rotations is not via the rate of uptake; it is simply the maintenance of storage in the biomass and relative balance of the annual turnover (litter fall) with the decomposition of deadwood and soil carbon. If a stand that historically was disturbed every 350 years is converted to a 30-year rotation, there will be a lot of CO_2 released from the soil. There will not be as much carbon being transferred from the living biomass to the deadwood and soil to maintain the carbon stocks on the site. On the other hand, if a site has already been harvested and is part of a short-rotation system, it might be better to maintain the short rotation and have the carbon stored as forest products.

Fuel Management

Fuel management involves thinning stands and removing deadwood to reduce the severity of wildland fires. These treatments are usually done around communities and infrastructure. It has been suggested that fuel management will reduce the GHG emissions from wildfire. Certainly, thinning a stand means there is less carbon available to burn; however, the likelihood of a severe wildfire must be factored into this argument. There is considerable debate in the fire science community on the effect of stand structure on fire risk and severity because they also depend on the geographic location of the stand, and the vegetation, climate, and ignition sources. For example, many forest types in British Columbia are dry during summer drought periods, but some, such as those on the north coast, never dry out sufficiently to support a large wildfire. If we assume that severe wildfires will occur, the fire and emissions due to the treatment must also be included in carbon calculations. For example, if stands are thinned and the biomass is burned for energy production, then the treatment still created emissions.

Fertilization

Fertilization of forest stands increases the rate of tree growth. Thus, fertilization can effectively increase the merchantable yield and value of established forests. Intuitively then, there could be an increase in carbon uptake and storage. When we compare a representative lodgepole pine stand (site index = 20) with or without fertilization, there is approximately a 15 m^3/ha increase in stand volume.[14] In terms of whole-ecosystem carbon, this translates into approximately

[13]The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) is freely available from Natural Resources Canada.

[14]Brockley (2005).

5.8 t C/ha before harvest, or only a 2% increase, because a lot of carbon is already present on the site. After harvesting and slashburning, the difference in carbon stocks is less than 1% (1.8 t C/ha) (see top panel in Figure 5).[15] After harvesting, the remaining carbon on site will gradually decay and either become part of the soil or return to the atmosphere.

If we consider the annual sources and sinks of GHGs shown in the lower panel of Figure 5, the young stand is a net source to the atmosphere (positive values) because there are greater emissions from decay than uptake through growth. After about age 10, the stand becomes a net sink from the atmosphere as the trees convert CO_2 into wood through photosynthesis. The small impact of fertilization can be seen from age 40 to 50 as a greater annual sink of carbon. When the example stand is harvested at age 60 and the slash is burned, the harvested carbon is shown as a source to the atmosphere of approximately 380 t CO_2e.[16] In reality, 25–50% of the carbon is likely stored in harvested-wood products; however, the research to estimate that storage is still ongoing.

Rehabilitating Underperforming Sites

The Forests for Tomorrow program aims to re-establish young forests on land that would otherwise remain under-productive. The program focusses on land that is primarily within the timber harvesting land base yet outside of forest industry obligations. Lands may be under-productive for a number of reasons, such as insufficient natural regeneration and failure of planted stock. When we look at an example from the area severely affected by the mountain pine beetle, rehabilitating a stand with low natural

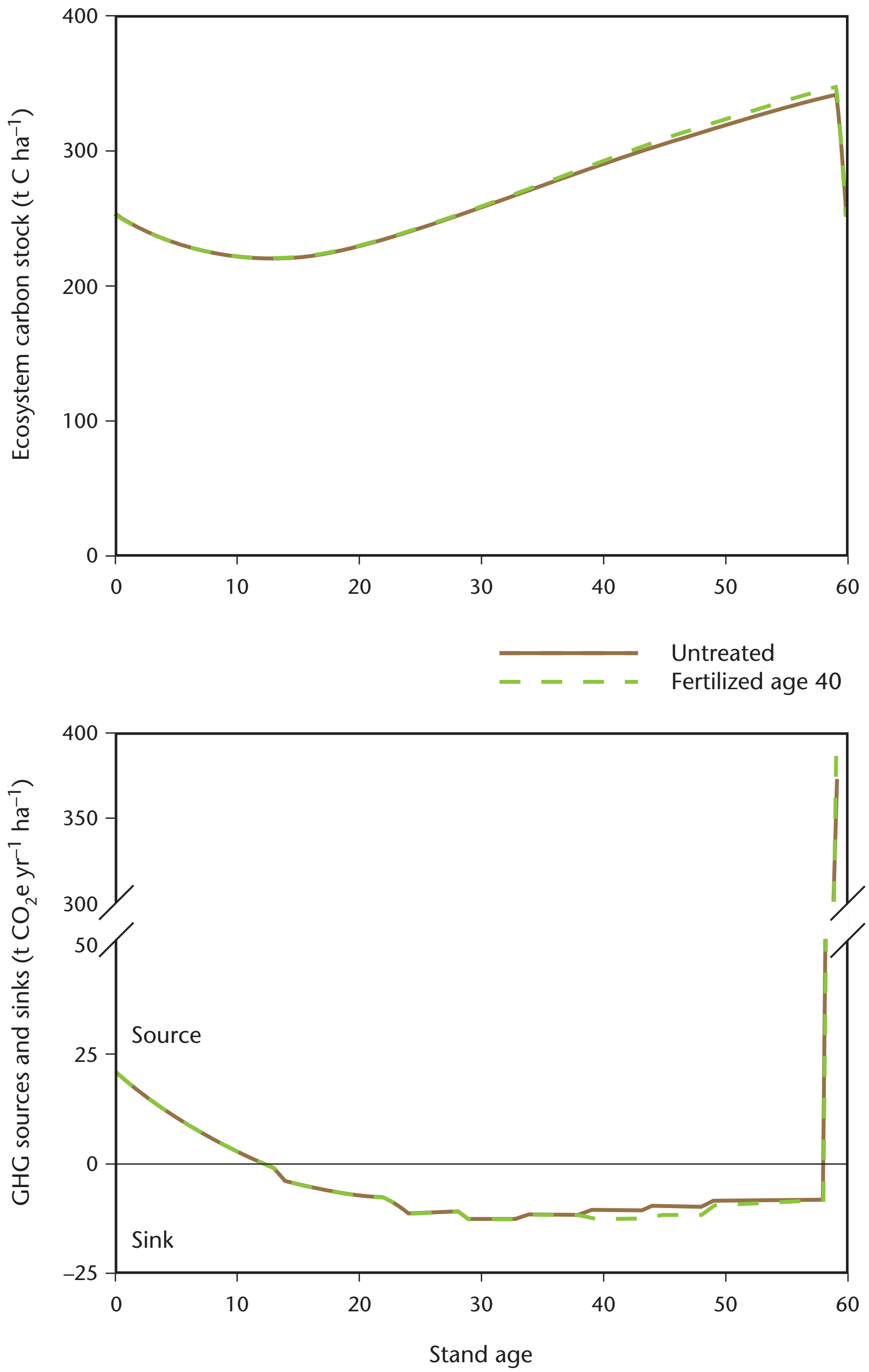

FIGURE 5 *Fertilized and unfertilized lodgepole pine stands (site index = 20) in the Interior of British Columbia. The top graph shows the ecosystem carbon stocks over time, and the bottom graph shows the annual GHG sources and sinks as the stand ages; this includes a harvest event at age 60. This is an example for illustration purposes only.*

[15] Beukema (2009).

[16] Ibid.

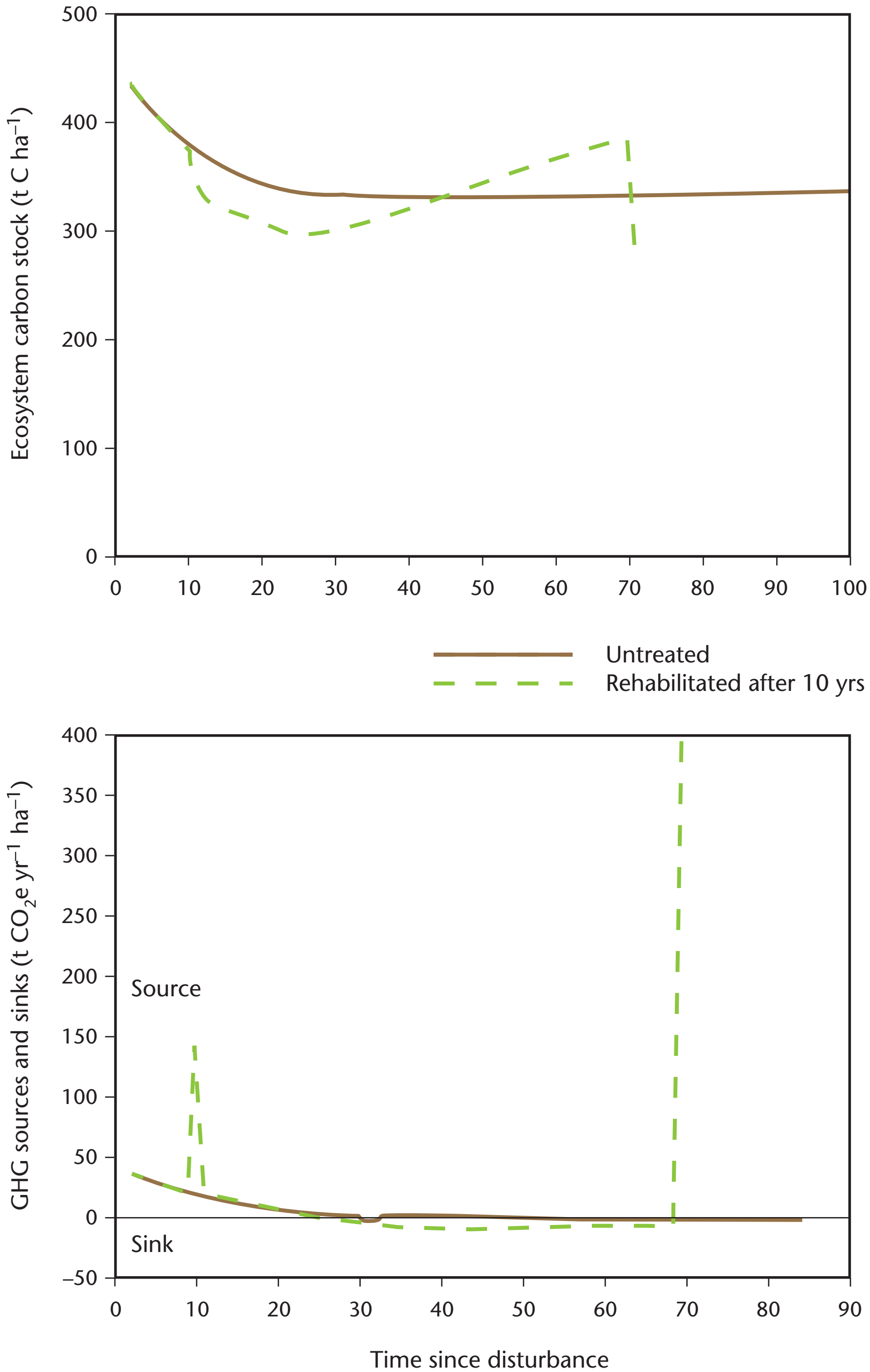

FIGURE 6 *An example rehabilitation simulation for a lodgepole pine stand that naturally regenerated to 325 stems per hectare following 100% mortality caused by the mountain pine beetle. The top graph shows the ecosystem carbon stocks over time, and the bottom graph shows the annual* GHG *sources and sinks. The simulated treatment involved a clearcut, slashburn, and replant at 10 years after being killed by the beetle. The rehabilitation scenario assumed a site index of 20 and included a harvest at age 60. This is an example for illustration purposes only.*

regeneration (325 stems per hectare) resulted in a net gain of ecosystem carbon stocks of about 55 t C/ha in the year before harvesting (top panel, Figure 6). Four years after harvesting, the sites had less ecosystem carbon stocks (about 50 t C/ha) because logging removes carbon. The relationship between untreated and rehabilitated sites will vary depending on the level of productivity with and without rehabilitation, and whether there is future harvest.

In the lower panel, the untreated stand is initially a net source of GHGS because of the large amounts of deadwood on site that were decaying. Over time, the amount of deadwood is reduced, but the poor regeneration resulted in a GHG-neutral stand in the simulation. The rehabilitation treatment created a larger source than the untreated site in year 10 of the simulation because of cutting and burning of the regenerated stand. The treated stand created a larger source when harvested because more carbon leaves the ecosystem and is reported here as immediate emissions.

Changing Land Use through Afforestation

As previously discussed, afforestation is the deliberate human action of changing the land use of an area and creating a forest. The amount of GHG uptake due to changes in land use varies greatly between sites depending on the productivity, age, and tree species of the forest. For example, coastal forests can have carbon storage up to three times greater than interior forests. A newly afforested area will not become a net carbon sink for about 2 years on open agricultural land, while it may take 30 years for a site to become a net GHG sink following the clearing and burning of bushes and small trees (e.g., Figure 7).

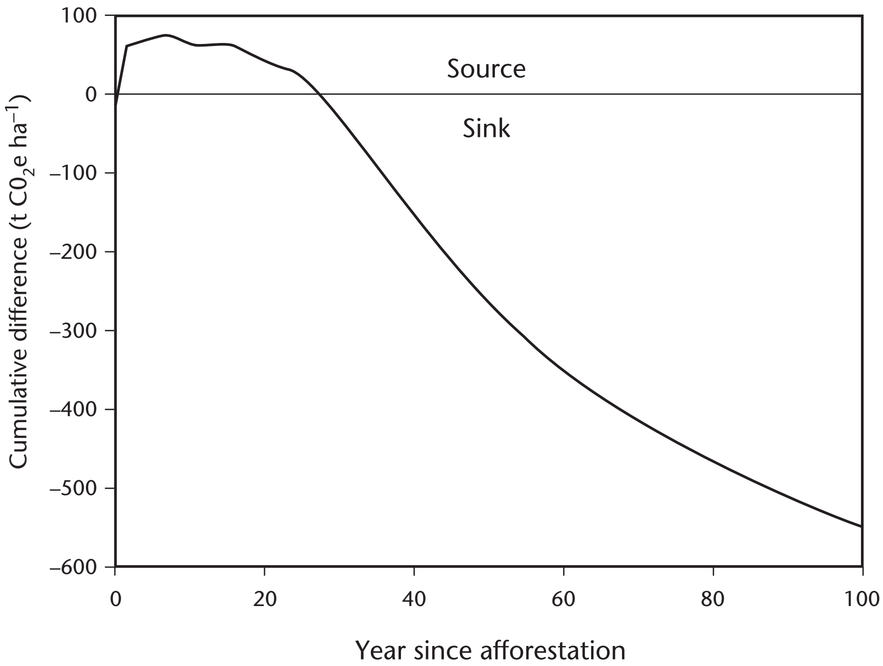

FIGURE 7 *Cumulative difference in CO_2 sinks between the untreated and afforested examples. This is an example for illustration purposes only.*

In the simulation, an example site with some scattered trees and bushes is cleared, burned, and planted in year zero. These activities are reflected in a 1-year increase in GHG emissions. Over time, the ecosystem carbon stocks increase in the afforested site and it becomes a GHG sink (Figure 7). Note that the comparison site is assumed to be GHG neutral.

Offset Carbon Markets

Forests and the forest sector have roles to play in helping mitigate climate change. We can work to reduce sources of GHG emissions and increase the sinks in the forests. As emissions become capped or taxed, a number of opportunities become available for the forest sector in a carbon-constrained world.

A carbon offset is any kind of reduction in GHG emissions or increase in carbon storage that helps you meet your target for mitigating climate change. It was initially envisioned as a last-hope mechanism after reducing consumption and increasing energy efficiency have failed to meet a target. Realistically, offsets have become a least-cost or least-effort mechanism for many. The target may be voluntary or regulated by an authority. Targets may be defined for individuals, companies, industries, sectors, or governments.

The natural process of trees taking up carbon through growth obviously lends itself to carbon sequestration and storage. However, that does not necessarily translate into a carbon offset. To be included in a regulated system, a carbon offset project must be "additional to" or "incremental to" current management—that usually means a project deliberately implemented to increase carbon uptake or reduce emissions to meet climate change goals. In the example afforestation project described in the previous section, the initial treatment of the site creates a net carbon source that over time is compensated for by tree growth. Figure 7 shows the cumulative difference between the afforestation simulation and the baseline (GHG neutral) simulation. In this example, the site became a net carbon sink after about 30 years, and after 100 years had stored about 550 t CO_2e.

There are risks associated with these opportunities. The permanence of the incremental carbon must be ensured over a defined period of time to be sold as a carbon offset. Since forest stands are susceptible to disturbance or harvest, a risk management plan must be in place. An offset project's efforts may be futile if they cause the same or more emissions somewhere else (e.g., result in deforestation elsewhere). This is called leakage. The importance of the additionality in carbon offsets cannot be understated. How "business as usual" for a project is defined may limit forest sector economic opportunities. More information on regulated offsets in British Columbia can be found on the websites of the British Columbia Ministry of Environment, Pacific Carbon Trust, and Western Climate Initiative.

Climate Change Impacts

Climate change could subject British Columbia's forests to changes in species communities and their geographic distribution. British Columbia's forests may also be subject to more frequent extreme storms and wind damage, droughts, fires, and insects. All of these components of the forest ecosystem affect the carbon balance and will determine whether British Columbia's forests will be a net sink of atmospheric carbon or a net source in the future.

Predicting the future is always difficult, even more so when we cannot rely on past experiences. Although individual trees will likely survive in their current location under a changed climate, growth rates will be affected. In general, we expect an increase in forest productivity in currently cold environments, and decreased productivity in currently warm environments.[17] If a species becomes unsuitable to the changing conditions, there may also be increased competition from other species more suited to the climate. The potential ranges of species will move northward and upward in elevation.[18] However, actual changes in the species occupying an area will depend on natural disturbances, slow natural migration rates, soils suitability, and other habitat factors. In managed areas, human activities such as harvesting and planting will also contribute to species migrations.

The rates and risks of natural disturbances are expected to increase as the climate changes. Wildfires, insects, drought, windstorms, and diseases may have increased impacts on the timber supply and forestry operations. Forestry operations will be impacted directly by changes in productivity, wood quality, and volume and size of logs. Access to timber may be limited especially in winter because of warmer and wetter conditions shortening the season for winter roads or increasing the sensitivity of wet sites. Furthermore, increases in the occurrence of storms will affect logging roads and increase the probability of landslides and debris flows.[19] Both the direct effects of loss of life and property from natural disasters, plus the indirect impacts on the forestry industry, mean that British Columbia's rural communities will directly bear the impacts of climate change.

The combined effects of climate change on the forest carbon balance are currently an active area of research. The forests of British Columbia may become a net sink by 2020; however, it may take much longer if the worst effects of climate change occur.

Literature Cited

Beukema, S. 2009. Interim report on development of forest carbon management options for British Columbia. B.C. Min. For. Range, Victoria, B.C. Consultant's report.

British Columbia Ministry of Environment. 2009. British Columbia greenhouse gas inventory report 2007. Victoria, B.C. www.env.gov.bc.ca/epd/climate/ghg-inventory/pdf/pir-2007-full-report.pdf

Brockley, R.P. 2005. Effects of post-thinning density and repeated fertilization on the growth and development of young lodgepole pine. Can. J. For. Res. 35:1952–1964.

Intergovernmental Panel on Climate Change (IPCC). 2007a. Summary for policy makers of the climate change 2007: Synthesis report. In: Contribution of Working Groups I, II and III to the 4th Assessment Report of the Intergovernmental Panel on Climate Change. R.K. Pachauri and A. Reisinger (editors). Geneva, Switzerland. www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

________. 2007b. Technical summary of working group I. In: Climate change 2007: The physical science basis. Contribution of Working Group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (editors). Cambridge University Press, Cambridge, U.K. and New York, N.Y. www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-ts.pdf

Luyssaert, S. et al. 2007. CO_2 balance of boreal, temperate and tropical forest derived from a global database. Global Change Biol. 13:2509–2537.

United Nations Framework Convention on Climate Change (UNFCCC). 2009. Compilation of new greenhouse gas information. Updated March 2009. http://unfccc.int/national_reports/annex_i_ghg_inventories/items/4624.php (Accessed July 2009).

Walker, I.J. and R. Sydneysmith. 2008. Chapter 8: British Columbia. In: From impacts to adaptation: Canada in a changing climate. D.S. Lemmen, F.J. Warren, J. Lacroix, and E. Bush (editors). Government of Canada, Ottawa, Ont. http://adaptation.nrcan.gc.ca/assess/2007/ch8/3_e.php

Williamson, T.B., S.J. Colombo, P.N. Duinker, P.A. Gray, R.J. Hennessey, D. Houle, M.H. Johnston, A.E. Ogden, and D.L. Spittlehouse. 2009. Climate change and Canada's forests: from impacts to adaptation. Sustainable Forest Management Network and Natural Resources Canada, Edmonton, Alta. www.sfmnetwork.ca/docs/e/SP_ClimateChange_English.pdf

[17] Williamson et al. (2009), p. 33.
[18] Williamson et al. (2009), p. 34.
[19] Walker and Sydneysmith (2008), Chapter 8, Section 3.3.

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