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How is forest management influencing carbon storage in sub-boreal forests?

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Abstract

A major question for Kyoto signatory nations such as Canada is what role our forests might play in meeting our greenhouse gas emission reduction commitments. The most important greenhouse gas affected by human activity is carbon dioxide (CO_2). Forests contain high amounts of carbon, which reflect the net balance between photosynthetic fixation of CO_2 into tree products - primarily cellulose - and the return of this carbon back to the atmosphere through respiration and fire. In this paper I integrate two aspects of my sub-boreal forest carbon research program, both conducted at the Aleza Lake Research Forest (ALRF) 60 km east of Prince George, BC. Clearcuts are sources of carbon for two reasons. First, primary forests contain > 250 tonnes per hectare while new clearcuts contain <150 tonnes per hectare; loss of tree carbon is immediate and large. However, even after accounting for harvesting, clearcuts are net carbon sources (input CO_2 into the atmosphere) for > 8 years after harvesting while belowground respiration exceeds photosynthesis. These carbon losses total 33 tonnes per hectare over 8 years, despite gains of 1 to 1.2 tonnes per hectare per year by the regrowing forest. Partial cut harvesting conserves the greatest amount of carbon. In balance, and after taking into account different forest management types, the entire upland region of the ALRF (6,035 hectares) has been essentially neutral with respect to carbon over the past 10 years. Thus, current forest practices and harvest levels at the ALRF appear to be sustainable with respect to carbon.

Introduction

Forest harvesting, fire, and insects are the major disturbance agents that result in old forests being converted to young forests across Canada. In many cases, and particularly in the aftermath of the mountain pine bark beetle epidemic, insect mortality followed by forest harvesting are the current disturbance agents in central British Columbia. With respect to harvesting, recent figures show that 40% of the wood volume harvested in Canada comes from British Columbia, with nearly 16% of this coming from the Prince George Forest District alone (NRCAN 2004).

Global warming and climate change are growing environmental concerns that are resulting from the accumulation of greenhouse gases such as carbon dioxide (CO_2) in our atmosphere. Management of forests can cause both increases and decreases in greenhouse gas accumulation in the atmosphere. A forest that *decreases* CO_2 in the atmosphere is termed a carbon sink, while one that *increases* it is termed a carbon source.

On the carbon source side, deforestation explains about one third of the rise of CO_2 in the industrialized period (1850 to present), mostly because mature and particularly old forests contain large stores of carbon that gets locked up in live and dead wood for long periods of time (IPCC 2000). This carbon is released to the atmosphere when short-lived forest products are decomposed in land-fills. In balance, forests (because of net deforestation globally) still contribute 20% of the increase in CO_2 concentrations globally, though much of this is occuring in the tropics and not in the boreal forests to the north. Finally, clearcuts are a source of CO_2 for some period of time following harvest, when losses of CO_2 due to respiration exceed that gained through photosynthesis. The timing of this transition from carbon source to carbon sink for clearcuts has until recently been largely unknown.

On the carbon sink side, regrowing forests (reforestation) can potentially recapture all of this lost forest carbon through photosynthesis (fixation of CO_2) if harvest rotations are long enough to permit full recovery of forest carbon stocks. Afforestation, the growth of trees on land that did not previously contain trees, is of greater significance, in that genuine gains in carbon can be made over non-forested land surfaces. However, afforestation is of limited applicability to landscapes already dominated by forests such as those in central British Columbia.

In this paper, I summarize two different experimental approaches that I and collaborators have taken to understand how forest carbon storage is influenced by forest management in central British Columbia. First, I examine the net uptake of CO_2 in a sub-boreal clearcut over multiple years to understand when re-planted clearcuts become net sinks for CO_2 after harvesting (Pypker and Fredeen 2002a, 2002b; Fredeen *et al.* 2006). Second, I examine how much forest carbon occurs both aboveground in the trees, woody debris and litter, and below ground in the roots and soil across ecosystem, age-class and management boundaries in sub-boreal forests similar to the clearcut-study site (Fredeen *et al.* 2005, Janzen 2006). Taken together, these experimental approaches have helped to quantify the way in which forest management activities have affected carbon storage in sub-boreal forests of British Columbia.

Methods

All of the following studies were conducted at the Aleza Lake Research forest (ALRF) ~60km north-east of Prince George. (Figure 1).

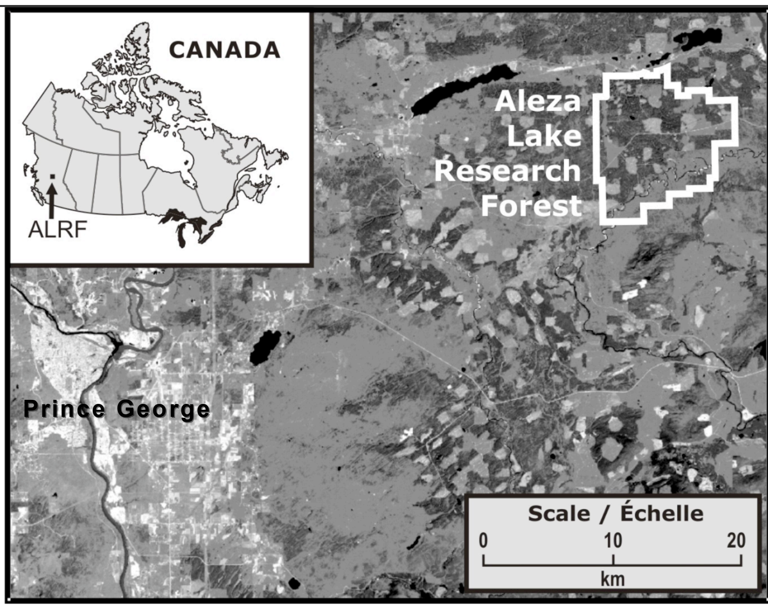

Figure 1. The Aleza Lake Research Forest (ALRF) is the oldest experimental forest in British Columbia.* The ALRF is situated within the central plateau of British Columbia between the northern Rocky Mountains to the east and the coastal mountains to the west. The ALRF is classified as (SBSwk1: wet and cool subzone of the sub-boreal spruce bioegeoclimatic zone) with forests dominated by interior spruce (*Picea glauca x engelmannii)* and subalpine fir (*Abies lasiocarpa*). Mean annual precipitation at the ALRF is 930 mm (one third as snow) and the mean annual temperature is 3°C.

* Figure courtesy of D. Janzen, M.Sc. thesis.

<u>Measurement of total carbon dioxide (CO_2) exchange from a clearcut</u>

To determine when a clearcut becomes a carbon sink, a combination of two basic approaches to measure clearcut CO_2 exchange were used: 1) component CO_2-exchanges (respiration and photosynthesis) in the clearcut were measured using a portable gas-exchange instrument (Li6200) and then multiple regression models were created relating CO_2-exchange to microclimate variables to determine the overall CO_2 exchange for the clearcut, and 2) total CO_2 exchange for an entire clearcut were determined in an integrated measurement using either Bowen-ratio Energy Balance (BREB) or Eddy Covariance (EC) approaches. These methods, approaches and equipment are more fully described elsewhere (Pypker and Fredeen 2002a, 2002b; Fredeen *et al.* 2006). The 84.15 ha clearcut (harvested in 1994) is located in the southwest corner of the ALRF and its CO_2 fluxes measured in 1999 (year 5 after harvest), 2000 (year 6), 2002 (year 8) and 2004 (year 10).

Measurement of total forest carbon stocks for the ALRF

To quantify all of the important forest carbon stocks within the upland conifer-dominated regions of the ALRF, we randomly located and intensively sampled carbon in 147 x 400 m^2 plots across 6,035 hectares of the ALRF from 2003 to 2005, excluding all riparian and flood plain associated with the Bowron river, lakes, streams, roadways, and bogs. All plot-level tree, shrub, herb, woody debris, litter, and soil carbon to 1 meter in depth were sampled and their carbon determined either directly using a carbon analyzer or indirectly by using published carbon contents and relationships between dimensional properties such as length, height and diameter and mass.

Aboveground and belowground carbon stocks were summed for each plot and extrapolated to the landscape level using satellite imagery of the ALRF (Landsat) from 1992 to 2003, forest inventory data and Geographic Information Systems (GIS). For more details on carbon stock sampling and modeling procedures, see Fredeen *et al.* (2005), Janzen (2006), and Janzen *et al.* (2006).

Results

When does a sub-boreal clearcut become a carbon sink?

There was a considerable amount of year-to-year variation of annual losses and gains of CO_2 from the spruce-planted clearcut at the ALRF. Never-the-less, the linear regression relationship between net CO_2 exchange and time since clearcutting was relatively strong (R^2=0.67) suggesting that the clearcut appears to transition from CO_2 source to CO_2 sink at between 8 and 10 years (8.3 y) after clearcut harvesting (Figure 2). The clearcut contributed an average of 3.2 tonnes of carbon per hectare per year in years 5 and 6, and removed an average of 1.2 tonnes of carbon per hectare per year in years 8 and 10 after harvesting (Figure 2). Immediately after harvest, the clearcut would be expected to be a source for carbon equivalent to the belowground respiration rate. The mean belowground respiration rates for clearcuts at the ALRF in a previous study were found to be relatively consistent from between 0 and 10 years after clearcutting with a mean of 8.7 tonnes of carbon per hectare per year (Fredeen *et al.* 2006), a value close to the 'y'-intercept of -8.1 tonnes of carbon per hectare per year (Figure 2). These data provide tangible support for the general principle that clearcuts are initially carbon sources after harvesting and only later become net carbon sinks when photosynthesis by the vegetation exceeds belowground respiration. The total carbon lost after clearcutting, again using the simple linear relationship shown in Figure 2, would be 33 tonnes of carbon per hectare, which means that the clearcut would not regain these initial net losses of carbon until year 16.

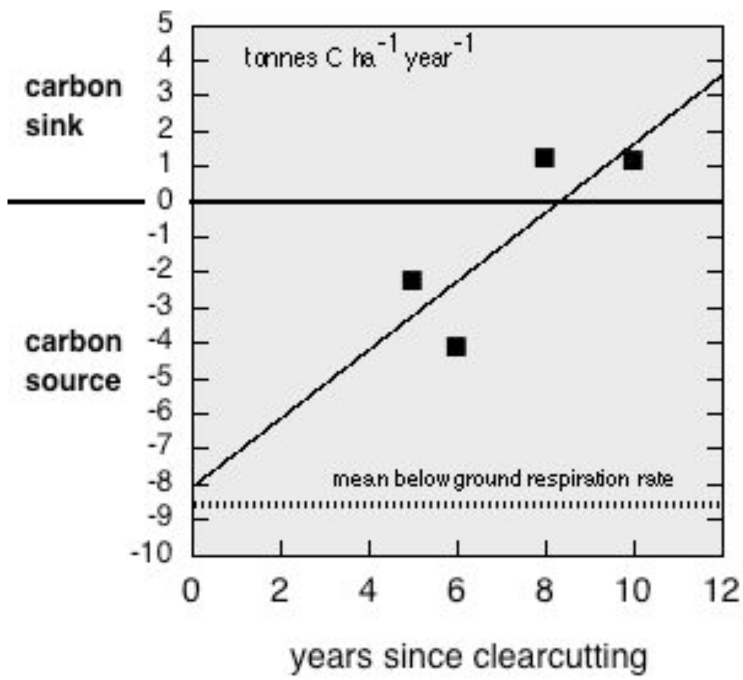

Figure 2. Transtion from carbon source to carbon sink in a clearcut at the Aleza Lake Research Forest 60 km east of Prince George, British Columbia.

Data are indicated for years 5,6, 8, and 10 after clearcut harvesting.

A linear regression line was fit to the relationship of annual forest-level net CO_2 exchange: NCE (tonnes C ha^{-1} y^{-1}) versus clearcut age (years):

NCE = 0.972 * (clearcut age) - 8.047
R^2 = 0.67

The question of how much carbon is taken up by sub-boreal clearcuts was also addressed by another method whereby the change in total permanent (biomass) carbon stocks in clearcuts of various ages were examined through a combination of remote sensing and carbon-stock measurements (Janzen 2006, Janzen *et al.* 2006). These measurements indicate that 10 to 20 year-old clearcuts in the ALRF accumulate carbon at a rate of approximately 1.1 tonnes of carbon per hectare per year, a value nearly identical to either the average carbon sink for years 8 and 10 (1.2 tonnes of carbon per hectare per year; Figure 2) or the slope of the linear regression line for annual carbon fluxes (1.0 tonnes of carbon per hectare per year; Figure 2).

<u>Where is carbon stored in a sub-boreal forest?</u>

The greatest stores of carbon in sub-boreal forests, and in fact most forest types, are found in the oldest stands. This was the case with sub-boreal forests at the ALRF (Figure 3). We consistently observed increases in total forest carbon with age even between the oldest age classes. Not surprising was that tree carbon, along with lesser contributions from forest floor and woody debris, was the main contributor to the increase in forest carbon with age (Figure 3). By contrast, soil carbon was relatively stable with increasing forest age, representing over half of the carbon in young stands (0 to 20 years old) and around one third of total ecosystem carbon in the oldest stands (> 175 years old).

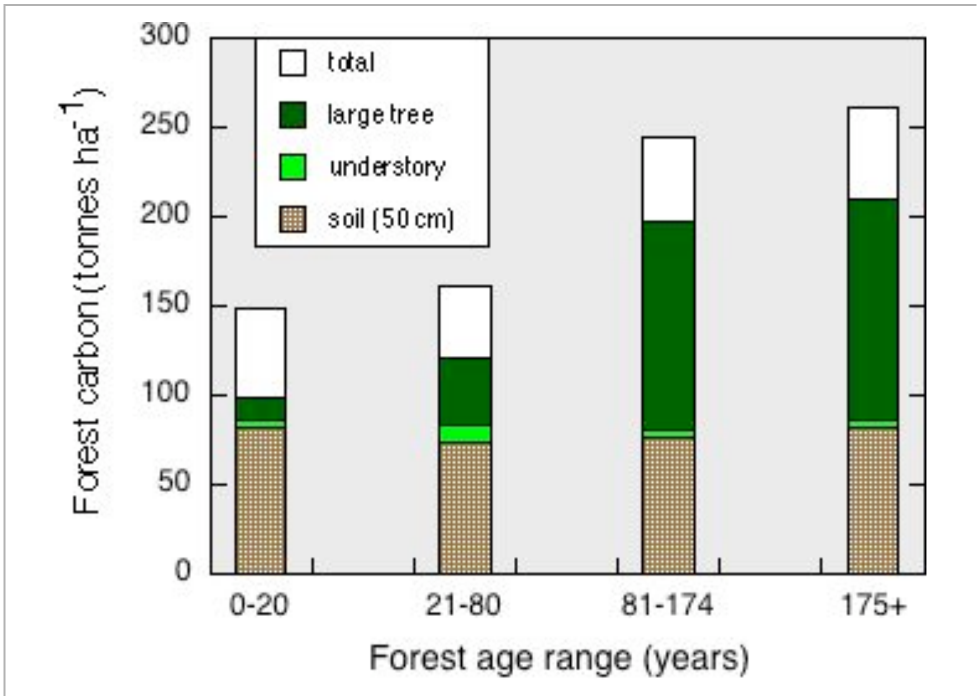

Figure 3. Quantities of measured carbon (tonnes of carbon per hectare) contained in large tree, understory vegetation and soil to a depth of 50 cm within forest stands of different age ranges across the Aleza Lake Research Forest.

<u>How does management influence forest carbon?</u>

A particular problem encountered in assessing the way in which forest management influences forest carbon was that forest management, including things such as: harvesting method, site preparation following harvesting, regeneration approach (e.g. natural versus planting), stocking density, type and species, have all varied considerably over time. This presented some unique challenges to making comparisons between management history types with respect to carbon accumulation because no aspect of management could be directly compared to another at any point in time.

One such comparison that I had hoped to be able to make was between partial cutting and clearcutting, since both types of harvesting have occurred at the ALRF, and both are harvesting systems still in use today. However, most of the partial cutting was done pre-1980 and, in operational terms, it varied considerably, from strip-cutting to various forms of diameter-limit logging. Even clearcutting and the subsequent post-harvest activities have varied tremendously over the last few decades. Thus, while detailed comparisons were not possible, we were able to contrast the way in which broad classes of forest management from 1992 to 2003 affected carbon storage today by way of remote sensing and modeling of C stocks using Landsat imagery spanning this 11 year period (Table 1).

Table 1. Land area (hectares) and changes in biomass + woody debris carbon stocks from 1992 to 2003 for 4 forest management classes within the Aleza Lake Research Forest: (1) new clearcuts (NCC: harvested between 1992 and 2003) (2) old clearcuts (OCC: harvested before 1992), 3) old partial-cuts (OPC: harvested prior to 1992), and 4) undisturbed primary forest (UPF). Positive values indicate a gain in carbon from 1992 to 2003.*

		Average change in carbon from 1992 to 2003 (tonnes ha^{-1})			Total change in carbon from 1992 to 2003 (kilotonnes)
Class	**Area (hectares)**	**Biomass**	**Woody Debris**	**Biomass + Woody Debris**	**Biomass + Woody Debris**
NCC	323	-121.2 ± 7.5	-2.2 ± 2.5	-123.5 ± 8.0	-39.9 ± 2.6
OCC	1507	12.1 ± 2.8	-1.4 ± 0.9	10.7 ± 2.9	16.1 ± 4.4
OPC	1411	-0.2 ± 3.7	0.6 ± 1.2	0.4 ± 3.9	0.6 ± 5.5
UHF	2794	4.6 ± 2.5	0.6 ± 0.8	5.2 ± 2.7	14.5 ± 7.5
Total	6,035				-8.7 ± 10.6

*Adapted from D. Janzen, 2006. M.Sc. thesis, UNBC.

Over the past 11 years, the ALRF study area has contained approximately 670 kilotonnes of biomass and woody debris carbon (Janzen 2006). The ALRF is essentially neutral with respect to carbon accumulation between 1992 and 2003, registering a small loss (not significant) of carbon over this 11 year interval (-8.7 ±10.6 kilotonnes of carbon) after weighting the four management classes by their respective areal extent in the ALRF (Table 1). However, many forest management types are combined into this forest-level carbon change, all with different carbon outcomes. First, both new and old clearcuts combined represented net losses of carbon. New clearcuts (NCC), here defined as those less than 11 years since harvest, registered large carbon losses (Table 1), primarily because of the accounting procedures used whereby losses of primary forest carbon resulting from harvesting were attributed solely to new clearcuts. By contrast, 'old' clearcuts (OCC: greater than 11 years old) accumulated carbon at between 1.0 and 1.2 tonnes of carbon per hectare per year (see Table 1 and Figure 2). Second, older forest stands recovering form partial-cutting (OPC) have high carbon stocks, in some cases as high as unharvested primary forest (Janzen 2006), but they appear to be relatively neutral with respect to present day carbon uptake (Table 1). This result was unexpected given the accumulation of carbon observed for unharvested forests (UHF: ~ 0.5 tonnes of carbon per hectare per year), which were essentially primary, mature to old-growth forest stands. It is not surprising that older partial cuts would be carbon neutral relative to clearcuts, since they are of greater age than clearcuts in the ALRF, and even after harvest, would have had a high composition of already mature trees. However, it is puzzling that by contrast, unharvested stands were accumulating carbon when they might have been expected to be more stable with respect to carbon than old partial cuts.

Conclusions

There is no question that clearcuts result in enormous carbon losses, particularly in the first 8 to 10 years after harvest, and that these losses could be minimized by partial-cutting. However, it remains to be determined how carbon stocks are affected by these different harvesting methods over the longer term. A move to shorter forest harvesting rotation ages will reduce forest carbon storage but greater longevity of forest products, for example, could at least partially offset lower spatially-averaged carbon stocks. While carbon storage is only one forest stewardship concern, it may well be an important one, particularly in boreal nations such as Canada where climate change (warming) is occurring at twice the rate of the global average.

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Further Readings or Resources

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