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Hydrology, greenhouse gases and forestry implications

Highlights

- Canada's forests play a role in the storage of carbon and emission of CO_2 and other greenhouse gases.
- Tradable carbon credits related to timber production and forestry operations are calculated by identifying carbon sequestration on forest lands after accounting for direct and indirect emissions of CO_2 and other greenhouse gases resulting from forest management activities.
- Emissions of two important greenhouse gases, CH_4 and N_2O, are highest in water-logged soils, so forest management strategies should minimize actions that might increase the extent of saturated soils.
- Watershed classification can aid forest managers in identifying key opportunities and vulnerabilities for forest carbon management strategies.

Forest management and carbon

Carbon cycle processes have long been recognized as an important component of sustainable forest management, especially in relation to maintaining soil organic matter as a key aspect of soil fertility. With carbon content typically representing 50-60% of soil organic matter for surface soils, efforts to maintain or enhance soil organic matter are among the most common elements of forest carbon management. As a result of new carbon trading initiatives, carbon sequestration is becoming a potential revenue source and an objective of forest management. Carbon trading and climate treaties such as the Kyoto Protocol and the Western Climate Initiative are based on carbon storage and fluxes of greenhouse gases (GHGs) including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Assessing the carbon balance for Canada's managed forests involves the measurement of numerous processes, including carbon uptake via photosynthesis and carbon losses through respiration and decomposition. The net carbon remaining within the forest ecosystem is subject to disturbance losses due to wildfire and insect damage, and is also affected by forest management practices. Management decisions must consider these dynamics. For example, recent studies have shown that old-growth forests continue to sequester additional carbon beyond previous estimates (see for example Black et al., 2008). However, increased vulnerabilities to natural disturbance and the effects of changing climatic conditions on forest growth may reduce the potential of forests to store carbon (Black et al., 2008).

Forest management activities have the potential to alter hydrologic flowpaths, thereby affecting carbon and nitrogen cycling and greenhouse gas uptake and release. More rapid hydrologic responses in a watershed following harvest indicate altered hydrologic flowpaths. These tend to be associated with enhanced carbon loss via stream water export. Burning of slash can lead to soil water repellency (e.g. hydrophobicity), linking a secondary hydrologic effect to the direct emissions of GHGs from burning.

Compaction from heavy equipment can lead to water-logging in equipment tracks and adjacent areas. Reduced transpiration can result in higher water tables and enhanced water-logging, which negatively impact carbon sequestration because saturated soils emit significant amounts of CH_4 and N_2O.

Forest fertilization is often employed as a strategy to increase both timber production and thus the amount of carbon sequestered in forest ecosystems. However, fertilizer application and other forest management activities also result in emissions of CO_2, CH_4 and N_2O. This may occur through use of machinery and helicopter fuel, and processes including denitrification of fertilizer following application. As a result, the net GHG emission from forest fertilization, harvest operations and other management practices, as well as hydrologic alterations such as water-logging of soils must be considered when calculating the carbon balance of forest management strategies.

Life cycle analysis of greenhouse gas emissions

To calculate an accurate carbon balance of managed forests, a framework must consider all direct and indirect or associated processes involving the emissions of GHGs. The "life cycle analysis" framework summarizes the cumulative impacts of bringing a product to market (e.g. from extraction and processing of a raw material to manufacture, transport and disposal of a finished good). Life cycle analysis of GHG emissions typically uses a "common currency" of CO_2 equivalents (CO_2e), to which all GHGs can be referenced. These include methane (CH_4), with a global warming potential 25 times that of CO_2 (e.g., 25 CO_2e), and nitrous oxide (N_2O) equivalent to 298 CO_2e.

Sonne (2006) used life cycle analysis to determine the GHG emissions from a range of typical forestry activities in coastal Douglas-fir forests from seed to forest product. The calculations addressed direct GHG emissions from site preparation, seedling production, thinning, harvest, and log transportation, as well as indirect GHG emissions from the manufacture and transport of fertilizer and other chemical inputs. The study found that harvesting activities contributed the most to GHG emissions, followed by site preparation and fertilization. Average GHG emissions across all management scenarios were 1.6 tons CO_2e per hectare for each 100 m^3 harvested.

Large differences in emissions were identified among forest management alternatives, indicating the need for strategic planning of management activities to maximize carbon sequestration and minimize GHG emissions. Of the 408 Douglas-fir forest management strategies that Sonne (2006) analyzed, the management strategy with the lowest GHG emissions (4,200 kg CO_2e ha^{-1}) consisted of a 50 year rotation, planted with small plug seedlings (1,235 trees ha^{-1}), chemical site preparation, an initial planting, with pre-commercial and commercial thinnings. The management strategy with the highest GHG emissions consisted of a 50 year rotation, planted with large plug seedlings (1,729 trees ha^{-1}), pile and burn site preparation, with commercial thinnings, herbicide and fertilizer use (11,600 kg CO_2e ha^{-1}). In the latter case, pile and burn site preparation contributed approximately one third of total direct emissions, and harvesting (including thinnings) contributed approximately half of total direct emissions. N_2O emissions from fertilizer application exceeded the emissions from pile and burn site preparation in coastal Douglas-fir forests (as measured in CO_2e).

Watershed classification and carbon management

In addition to stand-level issues, forest professionals should consider carbon storage and GHG emissions within a watershed framework. Several aspects of hydrology need to be considered when preparing management plans to increase carbon sequestration. For example, soil erosion resulting from overland flow contributes to carbon loss from the landscape. Water-logging of soils will increase emissions of CH_4 and N_2O through anaerobic decomposition and denitrification that occur under saturated conditions. Watershed classification is one tool for forest professionals to determine appropriate management strategies for specific landscape characteristics and forest conditions to maximize carbon sequestration and minimize GHG emissions.

Watershed classification is a means to identify key attributes of landscapes and streams based on climatic conditions, physical characteristics and hydroecologic processes (Krezek et al., 2008). For example, in humid watersheds where precipitation exceeds potential evapotranspiration (such as the eastern Boreal Shield), carbon fluxes in surface water should be considered as these can represent a significant carbon loss (Figure 1). The physical characteristics of watersheds also impact carbon cycling. For instance, impermeable soils in the humid boreal plains promote overland flow. If not carefully planned, soil disturbance related to harvesting in these areas could have long-term impacts on soil organic matter, and reduce the potential for future carbon sequestration.

Figure 1. Forest streams also transport carbon and nitrogen out of watersheds. Photo courtesy of D. Curran.

Indicators for potential sensitivity of carbon sequestration and GHG emissions differ based on physical and climatic characteristics of the watershed or forest stand. For steeper and more humid areas such as in coastal BC, sensitivities to soil erosion on the landscape and bank erosion within stream channels are of major concern. Areas within watersheds that indicate a risk for rain-on-snow events should also be managed with additional consideration for carbon management because there is a higher risk of erosion and landslides. Rain-on-snow events can also lead to debris flows in streams, increasing the potential impacts on downstream areas. While the value of carbon lost to erosion may appear trivial relative to tremendous impacts of rain-on-snow events, the long-term impacts of eroded carbon include reduced production potential on eroded areas, thus affecting future rotations.

For humid watersheds on the boreal shield, the use of a GIS-derived "depth to water" indicator has proven useful for identifying areas within watersheds that are particularly sensitive to water-logging and possible post-harvest losses of nitrogen and N_2O and CH_4 emissions which are higher in saturated soils (Murphy et al., 2009). Areas for which the "depth to water" indicator is small are more likely to become saturated, and thus prone to emissions of CH_4 and N_2O, particularly if fertilizer is applied.

In the boreal plains, Creed et al. (2008) derived a "probability of wet area formation" indicator, and demonstrated that forestry operations sometimes occurred on areas with the highest potential for hydrological impacts. They proposed using the "probability of wet area formation" indicator to avoid harvest within areas with more than a 25% chance of water-logging. As with the "depth to water" indicator, the "probability of wet area formation" indicator has the added benefit of reducing potential GHG emissions from saturated soils by minimizing the generation of saturated conditions. Harvest activities can increase the risk of saturation by reducing evapotranspiration due to tree removal, increasing snow-water inputs to soil due to lowered canopy snow capture and sublimation, and increasing soil compaction from equipment.

Management considerations for improving net GHG balance

Management strategies directed towards maximizing uptake and storage of forest carbon and/or minimizing cumulative emissions of GHGs as CO_2e needs to consider all carbon pools, including timber produced, harvest residues and soil carbon. They should also take into account carbon and nitrogen transported by hydrologic flowpaths as well as any potential to increase the size of saturated areas. Use of slow-release fertilizer and avoidance of areas prone to water-logging can reduce the N_2O emissions.

Further reading

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Management Implications

- If carbon sequestration is a management consideration, carbon emissions need to be considered during planning of forestry operations to minimize GHG emissions.
- Carbon accounting frameworks should consider all carbon pools, including produced timber, harvest residues and soil carbon.
- GHG gases, including carbon and nitrogen, are transported by surface and ground water. Therefore, forest management activities that affect hydrology (such as water logging) may alter carbon balances.
- Hydrological considerations, such as the relationship between precipitation and evaporation, risk of water-logging, or the types and amounts of surficial materials will influence whether a watershed (or stand or site) stores or produces carbon.

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SFMN Project: Hydroecological landscapes of Canada's forests:
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