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Ecosystem-level CO_2 fluxes from a boreal cutover in eastern Canada before and after scarification

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Abstract

Carbon (C) cycling in the boreal forest is driven by both natural and human disturbances, but there is little information on the impact of forest management practices on ecosystem-level C balance. We evaluated the C balance of a recently harvested boreal site in eastern Canada by measuring CO_2 fluxes with the eddy covariance technique for 1 year before the application of a scarification treatment (mechanical site preparation) and for 1 year after the treatment was applied to approximately 40% of the study area. Net annual exchange indicated a source of 111 g C m^{-2} $year^{-1}$ before scarification that increased to 175 g C m^{-2} $year^{-1}$ after treatment. Annual gross ecosystem productivity (GEP) and net C flux varied between years, but there was no significant difference for ecosystem respiration. Since the differences in climate between years did not explain the changes in the site C balance and daytime net C sequestration under non-limiting environmental conditions was generally lower after the treatment, the large difference in C emissions was most likely due to decreased GEP resulting from the destruction of approximately 60% of the living aboveground vegetation within the scarified areas. Although daily NEP was almost always negative throughout the year, a net daily C sink was observed during a 2-week period in late summer 2003 when air temperatures were approximately 8 °C cooler than preceding weeks. An analysis of the residuals from light–response regressions showed that soil water content and vapor pressure deficit were the second most important variables explaining morning and afternoon net C flux in 2003 and 2004, respectively.

Keywords: Boreal forest; Harvesting; Scarification; Carbon balance; Net ecosystem productivity; Eddy covariance; Black spruce; Jack pine

1. Introduction

The boreal forest covers approximately 15 million km^2 (Schlesinger, 1997), including nearly 3 million km^2 in Canada (Kurz and Apps, 1999). It is the second largest forest biome in the world, contains 49% of all forest carbon (C) (Dixon et al., 1994), and has the potential to play a major role in the global C balance (D'Arrigo et al., 1987; Hall et al., 2004). C cycling in the boreal forest is driven by both natural and human disturbances (Kurz and Apps, 1995, 1999), the most important being fire, insects, diseases, windthrow, and harvesting.

The eddy covariance technique is used to study the C dynamics of ecosystems continuously over multi-year periods. Since the early 1990s, there has been a large increase in the use of this technique to monitor CO_2 exchange at the ecosystem level (Baldocchi, 2003). Numerous eddy covariance studies have focused on mature boreal forests. It has been found that these ecosystems are often C sinks (e.g. Barr et al., 2002; Griffis et al., 2003; Kolari et al., 2004), but they can also be C sources during some years (Goulden et al., 1998; Lindroth et al., 1998). Eddy covariance studies are still fairly rare in younger forests, but increasing attention is

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being directed to them. Natural disturbances that have been studied include fire (e.g. Amiro, 2001; Amiro et al., 2003, 2006) and windthrow (Knohl et al., 2002). Our review of the existing literature indicates that the only direct human disturbance that has been studied so far in boreal forests is clearcut harvesting (e.g. Pypker and Fredeen, 2002; Kolari et al., 2004; Amiro et al., 2006). Although recently disturbed sites can be C sinks during the daylight hours of the growing season (e.g. Knohl et al., 2002; Amiro et al., 2003; Coursolle et al., 2006), they tend to be C sources on an annual basis (e.g. Pypker and Fredeen, 2002; Litvak et al., 2003; Kolari et al., 2004; Amiro et al., 2006).

Since large areas of boreal forest are harvested annually for wood products, including close to 1 million ha per year in Canada (Canadian Forest Service, 2004), harvesting may have a significant impact on the global C balance. Furthermore, the C sink or source status of a forest during the stand regrowth phase is critical to the calculation of regional C balances since the net impact of harvesting at the landscape level is the reduction of average stand age. The various silvicultural treatments used during the initial development of the young stands following logging can also have an impact on C exchange and sequestration. Climate variability has also been shown to have a significant influence on the C balance of boreal ecosystems (e.g. Goulden et al., 1998; Lindroth et al., 1998), although it has been suggested that the effect of disturbance is greater (Thornton et al., 2002; Coursolle et al., 2006). There are currently not enough data available regarding the impact of silvicultural treatments (e.g. thinning, scarification, etc.) on the overall C balance of forests to properly quantify the effect of forest management practices on C cycling. For this reason, we conducted eddy covariance flux measurements on an eastern Canadian cutover that was harvested in 2000. The research site is located in a region of the North American boreal forest having a wetter growing season than regions in the center or western portions of the continent. The study objectives were (1) to evaluate the C balance for 1 year before the application of a scarification treatment and for 1 year after the treatment, and (2) to determine the effect of the major climate forcing variables on the C exchange of this disturbed ecosystem during its initial recovery phase.

2. Material and methods

2.1. Site description

The study area is the Québec 2000 harvested black spruce site (HBS00) of the Fluxnet-Canada Research Network (FCRN). The site is located 75 km southeast of Chibougamau, Québec, Canada (49.267°N, 74.037°W) at an elevation of 400 m above sea level. The region has a large amount of industrial forestry activity, with over 9 million m^3 of wood harvested annually in the 107,952 km^2 region of Saguenay-Lac-Saint-Jean and 2.5 million m^3 in the 32,725 km^2 management unit (St-Félicien) within which our flux tower is located.

The ground is gently rolling with a weak slope (<5%). In mesic areas (designated as well to moderately well drained areas, according to the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey, 1983)), the soil is a ferro-humic to humic podzol covered by an organic layer having an average depth of 26 cm (Fig. 1). In humid areas, the soil is organic (imperfectly to poorly drained) with an average organic layer of 125 cm. Mesic areas accounted for approximately 75% of the total surface area of the footprint and humid areas accounted for 25%.

The original stand was composed of black spruce (*Picea mariana* (Mill.) B.S.P.) and jack pine (*Pinus banksiana* Lamb.). The stand was harvested in autumn 2000 using a method designed to protect the existing natural regeneration and the soil. It is the logging method most commonly used in the region. During the harvest, the operators of the logging equipment were required to limit the movement of the equipment to trails whose area did not exceed one third of the total surface of the cut block, thus protecting natural regeneration and minimizing soil disturbance on the remaining two thirds. All trees of commercial size (DBH > 9 cm) were removed from the 109 ha cut block, except for a 0.3 ha patch located northeast of the

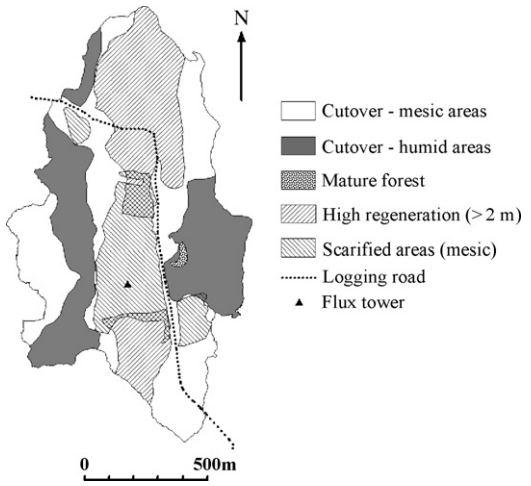

Fig. 1. Map of the microsites within the study area. "High regeneration (>2 m)" refers to areas where some trees were at least 2 m tall.