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Carbon dioxide and energy fluxes from a boreal mixedwood forest ecosystem in Ontario, Canada

J.H. McCaughey [a,*], M.R. Pejam [b], M.A. Arain [b], D.A. Cameron [c]

[a] Department of Geography, Queen's University, Kingston, Ontario K7L 3N6, Canada
[b] School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario L8S 4K1, Canada
[c] Great Lakes Forestry Centre, Canadian Forest Service, Natural Resources Canada, Sault Ste. Marie, Ontario P6A 2E5, Canada

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Abstract

A long-term flux measurement station has been established in a 74-year-old mixedwood forest ecosystem, located approximately 80 km west of Timmins in northern Ontario, as part of the Fluxnet-Canada Research Network (FCRN). Measurements of energy, water vapour, and carbon dioxide fluxes have been made continuously since August 2003 using the eddy covariance technique, along with ancillary meteorological variables. The spatial structure of the site was evaluated using a variety of sources and techniques, including remote sensing, showing that this forest is mixed but relatively homogeneous. The canopy top height is remarkably constant at between 30 and 32 m. The basal area varies from 18 to 27 m^2 ha^{-1}, and the aboveground biomass ranges from 82 to 122 Mg ha^{-1}. In this paper, we summarize the diurnal and seasonal patters of carbon dioxide exchange and water loss from September 1, 2003 to August 31, 2004. Net ecosystem productivity (NEP) is strongly related to temperature. Atmospheric vapour pressure deficit (VPD) in this ecosystem exerted strong biophysical control on the daily gross ecosystem productivity (GEP) and evapotranspiration. Seasonal change in shortwave albedo, as a result of the presence of mixed deciduous and coniferous species, was clearly evident. Albedo changes were comparable to the seasonal pattern of NEP. The dormant season lasts more than 6 months of the year at this station. This forest was a moderate sink of carbon over the measurement period. Annual values of GEP, ecosystem respiration (R), and NEP were 1075, 919, and 156 ± 35 g C m^{-2}, respectively.

Keywords: Mixedwood boreal forest; Eddy covariance; Net ecosystem productivity; Net ecosystem exchange; Respiration; Gross ecosystem productivity; Latent heat flux; Albedo; Fluxnet-Canada Research Network

1. Introduction

The boreal forest covers nearly one-fifth of the Earth's vegetated land surface, the second largest area after tropical forests (Landsberg and Gower, 1997) and occupies more than one-third of the Canadian landscape. This forest ecosystem is of particular importance and interest to climate and global change scientists because of its size (estimated to be between 12.0 and 14.7 million km^2) and its huge carbon stores, especially the accumulation of carbon in the soil. During the last decade, there has been extensive discussion about the role of ecosystem respiration in the carbon balance of forest ecosystems, particularly in boreal forests that have accumulated huge amounts of carbon in the soil (Barr et al., 2002; Grace and Rayment, 2000; Griffis et al., 2003; Valentinni et al., 2000). Also, there is uncertainty about how ecosystem respiration will respond to future climate change when global temperature increases will

* Corresponding author. Tel.: +1 613 533 6035; fax: +1 613 533 6122.
E-mail address: mccaughe@post.queensu.ca (J.H. McCaughey).

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affect boreal forests (Janssens et al., 2001; Jarvis et al., 2001; Piovesan and Adams, 2001; Valentinni et al., 2000). Arain et al. (2002) argue that, for a FCRN site of old black spruce in Saskatchewan, the inter-annual differences in net carbon exchange were primarily caused by an increase in respiration and a small reduction in GEP during warmer years. Similar findings have been reported for another FCRN site, a West Coast Douglas-fir forest on Vancouver Island, British Columbia, Canada (Morgenstern et al., 2004).

In central Canada, mixedwood is the dominant forest type in the southern boreal region. Most past studies of energy and carbon exchange from boreal sites have focused on pure, single-species, forest stands (Baldocchi et al., 2000, 2001; Barr et al., 2002; Blanken et al., 1997; Chen et al., 2000; Sellers et al., 1997; Valentinni et al., 2000). As a result, our current understanding of the carbon exchange features for mixedwood forests that contain large amounts of soil organic matter is relatively poor. To enhance our understanding of carbon exchange from mixedwood forests, in autumn 2003 we started year-round measurements of energy, water vapour and carbon dioxide fluxes at one of the FCRN sites: the Groundhog River Flux Station (GRFS) (Fluxnet-Canada Website, 2006). The FCRN is a national network of flux towers distributed across the managed forest zone in southern Canada, designed as an east–west transect from coast to coast, and including both forested and wetland ecosystems. In this paper, we report on the first year of operation of the station and have chosen the measurement period from September 1, 2003 to August 31, 2004. The major themes discussed in this paper are: (i) the diurnal and seasonal dynamics of CO_2 exchange, (ii) the empirical relationships of respiration and photosynthesis with meteorological variables, (iii) the relative contributions of photosynthesis and respiration to the annual net carbon exchange, (iv) the linkages between photosynthetic uptake and water loss from the canopy, and (v) the evaluation whether energy and mass exchanges in this boreal mixedwood forest exhibit properties similar to boreal coniferous or deciduous forests.

2. Site description and analysis of its spatial structure

The study site (48.217°N and 82.156°W) is located in a typical boreal mixedwood forest in northeastern Ontario, Canada, approximately 80 km southwest of Timmins, near the Groundhog River. The forest developed after high-grade logging in the 1930s. The forest is dominated by five species characteristic of Ontario mixedwoods: trembling aspen (*Populus tremuloides* Michx.), black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*Picea glauca* (Moench.) Voss.), white birch (*Betula papyrifera* Marsh.), and balsam fir (*Abies balsamea* (L.) Mill.). In some patches of the forest, eastern white cedar (*Thuja occidentalis* L.) can be found. The degree of spatial structure for the site was evaluated from a variety of sources and with various techniques, including remote sensing data and more traditional cruise line data collection. A cruise of the site was conducted in 2003 to identify the distribution of species and the basal area. Based on the cruise data, the site was divided into four cardinal quadrants (NW, NE, SE, and SW). The summary data on species composition and basal areas are shown in Table 1. In the northwest, the species composition is equally divided between coniferous and deciduous species. The northeast sector has a deciduous: coniferous species ratio of 56:44, and in the SW sector the distribution of species is similar, at 53:47. The SE sector has significantly more deciduous species where the ratio is 65:35.

Table 1
Species occurrence (%) and basal area ($m^2\ ha^{-1}$) in the four cardinal sectors at the GRFS site based on cruise data

Species	NE sector		SE sector		SW sector		NW sector	
	Percent	Basal area	Percent	Basal area	Percent	Basal area	Percent	Basal area
Black spruce	19.69	5.91	13.10	3.57	16.86	4.30	20.84	6.28
Balsam fir	12.46	3.74	9.50	2.59	7.32	1.87	7.31	2.20
White birch	33.52	10.07	34.19	9.32	34.72	8.87	23.52	7.09
White spruce	11.83	3.55	12.07	3.29	7.44	1.90	10.56	3.18
Trembling aspen	21.8	6.55	31.00	8.45	18.20	4.65	26.12	7.87
Black cherry	0.15	0.04	0.11	0.04	0.08	0.02	0.11	0.03
Eastern cedar	0.55	0.16	0	0	15.42	3.94	11.5	3.46
Larch	0	0.01	0	0	0	0	0.04	0.01
Total		30.03		27.26		25.55		30.12
Hardwood–softwood ratio	56:44		65:35		53:47		50:50	