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Impact of Precommercial Thinning on Soil Respiration, Temperature, and Moisture in Western Newfoundland Balsam Fir

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Abstract

surface (R_s) respiration was measured over a diurnal cycle in precommercially thinned and unthinned western Newfoundland balsam fir (Abies balsamea (L.) Mill.) on 15-16 July 2002. Soil temperatures (T_s), soil moisture potentials (Ψ_s) , and R_s were recorded hourly. Average hourly R_s in the thinned stand was significantly lower than in the unthinned stand. Differences in R_s between thinned and unthinned stands changed with time. Only thinned stand hourly R_s was significantly related to T_s and Ψ_s .

Résumé

La respiration totale en surface (R_s) a été mesurée les 15 et 16 juillet 2002 durant un cycle diurne dans des peuplements de sapins baumiers (Abies balsamea (L.) Mill.) de l'Ouest de Terre-Neuve, soit dans un peuplement ayant fait l'objet d'une éclaircie précommerciale et dans un peuplement non éclairci. La température du sol (T_s) , le potentiel hydrique du sol (Ψ_s) et R_s ont été mesurés et consignés toutes les heures. La R_s horaire moyenne était beaucoup plus faible dans le peuplement éclairci que dans le peuplement non éclairci. Les différences de R_s entre le peuplement éclairci et le peuplement non éclairci variaient avec le temps. Une corrélation significative entre la R_s horaire et la T_s et le Ψ_s n'a été établie que dans le peuplement éclairci.

Introduction

Forests exchange significant amounts of greenhouse gases with the atmosphere, and store large amounts of carbon (C) (Kasischke and Stocks 2000). Boreal forests contain about 26% of the world's terrestrial carbon, equivalent to 644 Gt C, of which 80% to 90% is stored in soil (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU) 1998). Surface respiration (R_s) in boreal systems transfers about 322 g C m⁻² year⁻¹ to the atmosphere (Raich and Schlesinger 1992), and is affected by forest management (Price et al. 1996; Londo et al. 1999), e.g., precommercial thinning. It is particularly sensitive to soil temperature (T_s) in environments with low mean annual soil temperature (Morén and Lindroth 2000), such as Newfoundland. Understanding the effect of disturbances on carbon fluxes and stocks is a prerequisite for modeling Canadian boreal forest dynamics (Li and Apps 1995) and for estimating forest carbon stocks and fluxes with the atmosphere (Kurz et al. 1998).

Balsam fir (*Abies balsamea* (L.) Mill.) is the dominant forest cover of western Newfoundland (Wilton and Evans 1974). Balsam fir regeneration following disturbance is often very dense. Stockings of 35 000–148 000 stems/ha have been reported for young balsam fir stands (McArthur 1965, Karsh et al. 1994, Moroni et al. 2005), with an average density of about 50 000 stems/ha in Newfoundland (Corner Brook Pulp and Paper Ltd. 1998). Newfoundland balsam fir regeneration is often precommercially thinned at 10–20 years of age, reducing stem densities to approximately 2000 stems ha⁻¹ (Corner Brook Pulp and Paper Ltd. 1998). Unthinned stands self-thin gradually, decreasing the density of live stems over the life of the stand, a process well described for balsam fir (e.g., Bégin et al. 2001, Pothier 2002). Precommercial thinning (PCT) reduces subsequent self-thinning mortality and accelerates diameter growth of residual trees, shortening the rotation length required to generate merchantable yields (Petersen et al. 1992; Koga et al. 2002). Between 1976 and 2005, ~69 000 ha of Newfoundland balsam fir was precommercially thinned and rates of precommercial thinning are currently about 2650 ha year⁻¹ (Moroni 2006).

Although the effect of commercial thinning on surface respiration has been studied (e.g., Tang et al. 2005; Vesala et al. 2005; Concilio et al. 2006), the impact of precommercial thinning on total surface respiration has received little attention. Most examinations of surface respiration have focused on a small portion of the diurnal cycle, usually examining daytime respiration rates only. Those that have examined surface respiration over diurnal cycles have done so in mature forests (e.g., Moosavi and Crill 1997, Morén and Lindroth 2002, Shibistova et al. 2002). In general, soil temperature and soil moisture regimes are major controls of surface respiration (Schlentner and van Cleve 1985). The aim of this study is to examine surface respiration, soil temperature, and soil moisture potential (Ψ_s) in adjacent thinned and unthinned Newfoundland balsam fir over a diurnal cycle during the growing season.

Table 1. Soil characteristics of the study site

	pH in	Total N	Total C	
Horizon	CaCl ₂	(mg g ⁻¹)	(mg g ⁻¹)	C:N
LFH	3.4	6.100	305.6	27.5
Ae	4.5	0.013	5.9	11.4
Bhf/Bf	4.8	0.067	17.2	14.9
ВС	4.9	0.003	3.2	12.3

Materials and Methods

Site description and sampling

A site was selected for study in the vicinity of Deer Lake, western Newfoundland, Canada (N 49°07'19", W 057°18'08"). The site is located within the Boreal Shield Ecozone characterized by a continental climate with a mean annual temperature of 3.3°C (normals 1971–2000), and a mean annual precipitation ranging from 1000 mm to 1200 mm (Environment Canada 2006). The soil is classified as Orthic Humo-Ferric Podzol (Table 1), and is part of the Birchy Ridge Soil Association, characterized by moderately coarse-textured morainal deposits (Kirby et al. 1992).

In 1992, a 60- to 80-year-old Pleurozium–balsam fir forest was clearcut and left to regenerate naturally to balsam fir. In July 2001, a 30 x 30 m plot was precommercially thinned, reducing stem density from 68 000 stems ha⁻¹ to 2778 stems ha⁻¹. An adjacent plot of the same size was left unthinned. Total surface respiration was measured at three random locations, and soil temperature and soil moisture potential were measured at four locations within each plot. Total surface respiration was measured using a portable gas chromatograph (EGM Environmental Gas Monitor; PP Systems, USA) from PVC collars (\emptyset = 0.103 m) inserted 2 cm into the organic layer in May 2002. Surface respiration measurements were taken hourly over a 24-h period on 15–16 July 2002 (Julian days 196–197). Soil temperature and soil moisture potential were measured at the interface of the organic and mineral soil layers (~5 cm depth) every 10 minutes using Type T thermocouple wire and Campbell Scientific Model 253 Soil Moisture Probes, and averaged hourly.

Statistical analysis

Soil moisture potential data required squaring to achieve normal distribution. Differences between stands for all variables were determined using the Independent Samples T-Test. Where correlation analysis was significant (Pearson correlation coefficient), linear and non-linear regression analysis was performed using SPSS version 12.0 (SPSS Inc. 2003). Where applicable, equations of the data transformation and the transformed data regression models were combined to yield the stated regression models.

Results

Soil measurements

Average hourly soil temperature showed a high diurnal variation and peaked around 1500 h at 26.2°C and 25.3°C in the thinned and unthinned stand, respectively (data not shown). In both stands, the lowest hourly soil temperature of 10.5°C was measured around 0500 h. Average soil temperatures between the thinned and unthinned plots were not significantly different (T-Test; P > 0.05; data not shown). The thinned stand had significantly higher average hourly soil temperature than the unthinned stand (*T*-Test; $P \le 0.001$; Fig. 1a). Soil moisture potential was significantly lower in the thinned stand than in the unthinned stand (T-Test; $P \le 0.001$; Fig. 1a).

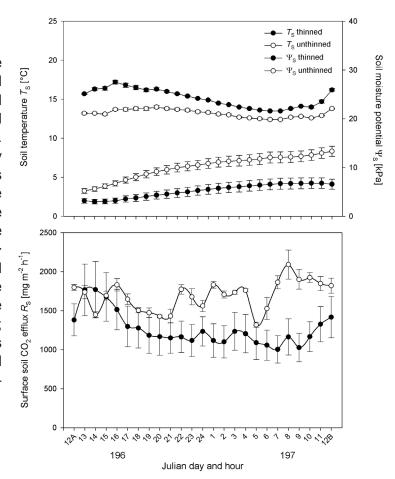


Figure 1. Hourly (A) T_s and Ψ_s (n = 4), and (B) R_s (n = 3) for one diurnal period 15–16 July 2002. \pm Bars denote standard error.

Table 2. Linear and non-linear regression analysis of hourly surface respiration (R_s) and soil temperature (T_s) or soil moisture potential (Ψ_s). Applied regression models are shown with regression coefficients a and b, and $r_{adjusted}^2$. Parentheses contain standard errors of regression coefficients

Stand	Model	а	b	n	r ² adjusted	Р
Thinned	$R_{s} = a + b * T_{s}$	-726.28 (404.36)	131.45 (26.63)	25	0.493	< 0.001
	$R_s = a + b^* \log 10 \Psi_s$	1569.07 (78.29)	-10.54 (2.45)	25	0.421	< 0.001

Note: Values used in the analyses were the means of each stand.

Units: R_{g} [mg CO₂ m⁻² h⁻¹], T_{g} [°C], Ψ_{g} [kPa]

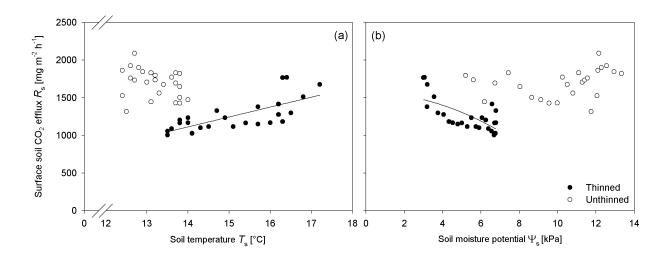


Figure 2. Relationship between hourly R_s and (a) average hourly T_s and (b) Ψ_s during diurnal measurements 15–16 July 2002. Lines depict results of regression analysis (see Table 2): • Thinned (solid line) \circ Unthinned. n.b., different scales of the X-axes.

Surface respiration

Throughout the 24-h period, average hourly surface respiration rates in the thinned stand were significantly lower than in the unthinned stand (T-Test; $P \le 0.001$; Fig. 1b). In the thinned stand, maximum rates occurred between 1300 and 1400 h (1770 mg CO_2 m⁻² h⁻¹), and then decreased to a minimum of 1003 mg m⁻² h⁻¹ at 0700 h (Fig. 1b). In the unthinned stand, maximum rates of surface respiration were measured at 0800 h, shortly after the minimum efflux of 1317 mg CO_2 m⁻² h⁻¹ at 0500 h (Fig. 2b). Throughout the night (2100–0500 h), fluctuations in surface respiration were large in the unthinned stand (Fig. 1b). Surface respiration was significantly positively related to T_s ($P \le 0.001$; Fig. 2a, Table 1) and soil moisture potential ($P \le 0.001$; Fig. 2b, Table 2) only in the thinned stand.

Discussion

Average hourly surface respiration was significantly higher in the unthinned plot than in the thinned plot, which is probably a consequence of reduced overstory root respiration following thinning. Surface respiration also varied significantly with time at both sites, where differences between the thinned and unthinned plots differed temporally (Fig. 1b). Differences between thinned and unthinned plots were largest between 0700 h and 1100 h and least between 1200 h and 2100 h. Differences between treatments transitioned from large to small during "business hours" (~0900 h to 1700 h) when surface respiration is commonly measured (e.g., Striegl and Wickland 1998, Hanson et al. 1993). Thus, extrapolating differences between unthinned and thinned forest surface respiration, measured over a small component of the diurnal cycle, to 24-h periods, potentially introduces errors by not accounting for relative temporal differences between harvested and unharvested surface respiration. As business hours were dominated by the period of least differences between thinned and unthinned plots, surface respiration measurements taken over this time will underestimate the effect of thinning on surface respiration.

Only diurnal surface respiration in the thinned plot was correlated with soil temperature and moisture (Fig. 2a, Table 2). Surface respiration in unthinned balsam fir is dominated by root respiration (Lavigne et al. 2003). The large increase in unthinned surface respiration after sunrise (0500 h to 0800 h) is probably increasing root respiration associated with increasing tree metabolic activity as the sun rises, as respiration is driven by current photosynthesis (Högberg et al. 2001). Microbial respiration is positively correlated with soil temperature (Alexander 1961) and negatively correlated with soil moisture potential (Orchard and Cook 1983). Thinning removed 98% of live trees and associated root respiration, increasing the proportion of microbial respiration in surface respiration. Microbial-dominated surface respiration likely explains the positive relationship between surface respiration and soil temperature (Fig. 2a, Table 2) and the negative relationship between surface respiration and soil moisture potential (Fig. 2b, Table 2) in the thinned stand. As forest harvesting also kills overstory tree roots, the impact of harvesting on surface respiration is likely to be similar to that of precommercial thinning.

Diurnal patterns in surface respiration between forested and harvested or thinned sites are likely to differ due to differing proportions of root and microbial respiration. When comparing surface respiration from forested and harvested plots, differences over the entire diurnal cycle require consideration.

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