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The role of mineral soil topography on the spatial distribution of organic layer thickness in a paludified boreal landscape

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ABSTRACT

Mineral soil topography is difficult to describe in boreal regions because of the thick overlying organic layer despite its presumed importance in determining where and at what rate an organic layer will accumulate (paludification). The overall purpose of this study was to examine the relationship between mineral soil topography and OLT at the landscape scale. More specifically, these relationships can be used to map the distribution and spatial variability of paludification across the landscape, thereby exploring the potential to discriminate between the two commonly known paludification types (permanent and reversible). Seven topographic variables (elevation, slope, aspect, mean curvature, plan curvature, profile curvature and topographic wetness index) were generated from a digital elevation model that we developed for the mineral soil surface (MS-DEM). OLT data were collected from field measurements across the landscape by manual probing and values varied from 5 to 150 cm. The MS-DEM was generated by subtracting OLT field values from the corresponding LiDAR-derived elevation values. Most correlations between OLT and individual predictor variables were weak and illustrated that OLT and its landscape-scale distribution cannot be explained by simple bivariate relationships. Consequently, two regression tree-based models were developed using: (1) only the seven mineral soil topographic variables, and (2) all predictor variables (mineral soil topography and surficial deposits). Mineral soil slope was the most important variable for both models and corresponded to the first level of splitting the dataset into homogenous landscape units in terms of organic layer thickness. Surficial deposit, topographic wetness index (TWI) and aspect were also related to OLT and proved to be contributing to the development of the two models.
Model 1 explained 0.34 of the OLT variability and offer simple models with few landscape units that are easy to interpret. Model 1 splitting rules allowed the combination of different maps (slope, TWI and aspect) for producing a landscape units map, on which OLT was determined and related to increasing paludification categories. A good overall accuracy of 74% was achieved for this map. Model 2 was the best model in terms of estimate quality ($R^2_{adj} = 0.52$). Both models were successful in discriminating highly paludified landscape units. Except for one landscape unit that was assigned to permanent paludification type, both models were unable to further subdivide more landscape units into reversible and permanent paludification, suggesting that both of these types interact within the same landscape unit. This study demonstrated that the combination of topographic information from remotely sensed LiDAR data and field OLT measurement data has the potential to be useful for defining both promising and vulnerable areas for forest management.

1. Introduction

Paludification is a natural process where organic material accumulates on the ground surface over time, resulting in higher soil moisture levels and elevated water tables (Crawford et al., 2003; Vygodskaya et al., 2007). These conditions alter dynamic succession and favour the invasion of *Sphagnum* moss species (Fenton and Bergeron, 2006, 2007; Fenton et al., 2005), which can lead to the development of forested peatlands and substantial decreases in forest productivity (Simard et al., 2007, 2009). While essentially a regional process, many parts of the world, including interior Alaska, the western Siberian plain, and the Hudson Bay–James Bay Lowlands of Canada, are prone to paludification. In the black spruce forests of the Clay Belt, a region in the southern portion of the Hudson Bay–James Bay Lowlands (Fig. 1A), time-since-last fire and ground surface topography have been reported as the two main factors that cause paludification. Consequently, two types of paludification can be identified: permanent and reversible, respectively (Fenton et al., 2009; Lavoie et al., 2007; Simard

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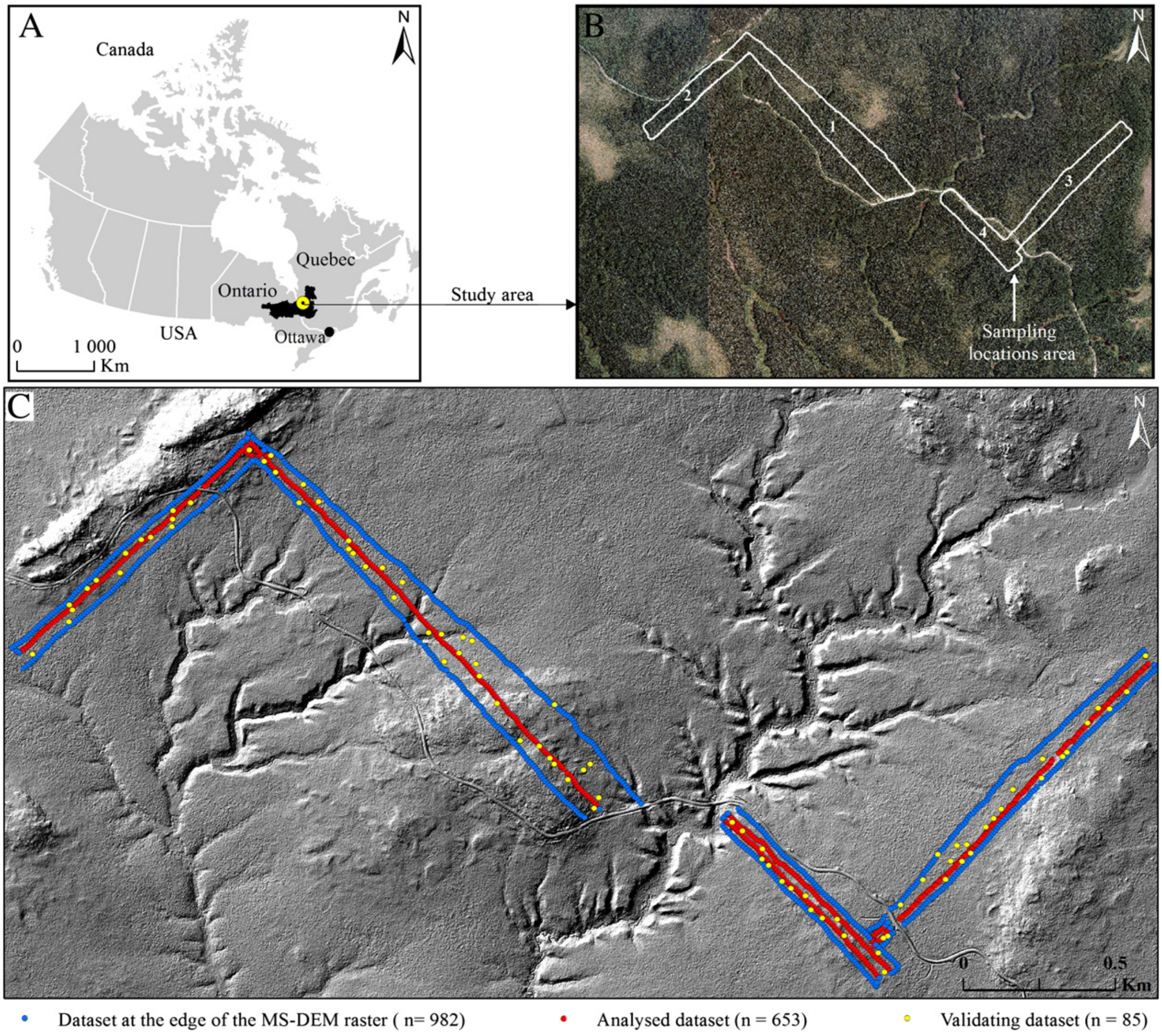

Fig. 1. Study area within the Clay Belt of Ontario and Quebec (A). Sampling locations along transects within four sectors (1, 2, 3, and 4) and delimitation of the mineral soil digital elevation model area (B). Landscape map of the study area showing the field organic layer thickness sampling points locations (C). The analysed dataset ($n = 653$) was formed by summing the original dataset along the central transects ($n = 568$) and independent validation datasets along the same transects ($n = 85$).

et al., 2007). Within the landscape, permanent paludification dominates in natural depressions, which have wetter soil conditions that favour organic layer build-up. Reversible paludification occurs on flat or sloping terrain, where a feather moss-dominated bryophyte layer is replaced over time by Sphagnum species, starting about 100 years following fire (Fenton and Bergeron, 2006; Simard et al., 2007).

Numerous studies have been conducted to characterise the influence of topography on the accumulation and spatial variability of the organic layer across the Clay Belt (i.e., Giroux et al., 2001; Lavoie et al., 2005, 2007; Simard et al., 2009); however, these studies have largely been restricted to investigations of the ground surface topography at the plot-scale. In a recent extensive study at the landscape scale, Laamrani et al. (2013b) found weak correlations between organic layer thickness (OLT) and topographic surface variables, suggesting that OLT may be controlled by other factors, such as the mineral soil topography, i.e., the contours of the surface beneath the organic layer.

Mineral soil topography affects the accumulation of organic layer mainly through its control of water movement at the landscape scale (Emili et al., 2006). This topography has been difficult to describe in boreal regions because it is masked by the thick overlying organic material. Despite the presumed importance of mineral soil topography in determining where and to what degree paludification will occur in the Clay Belt, no attempt has been made in this region until now to measure and link mineral soil topography to OLT and to the two paludification types (permanent and reversible) at the landscape scale. In this context, the overall purpose of this study was to examine the relationship between mineral soil topography and OLT at the landscape scale. More specifically, these relationships can be used to map the distribution and spatial variability of paludification across the landscape, thereby exploring the potential to discriminate between permanent and reversible paludification. To do so, we correlated field organic layer measurements that were obtained by manual probing with topographic variables that were derived from a digital elevation model (DEM), which was generated at the mineral soil surface. The mineral soil DEM was generated using LiDAR (Light Detection And Ranging) data together with field OLT measurements.

2. Methods and materials

2.1. Study area

The study was located in the James Bay Lowlands physiographic region of Quebec, Canada (Fig. 1A). It was centred (49°27′30″ N, 78°31′5″ W) on a 72 ha site within the Clay Belt region, which is dominated by black spruce (*Picea mariana* [Mill.] BSP) forest (Fig. 1B). The forest floor was composed of *Sphagnum* spp., feather mosses (principally