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Distinguishing and mapping permanent and reversible paludified landscapes in Canadian black spruce forests

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ABSTRACT

Northern Canadian boreal forest is characterised by accumulation of a thick organic soil layer (paludification). Two types of paludification are recognised on the basis of topography and time since the last fire, viz., permanent paludification that dominates in natural depressions within the landscape, and reversible paludification that occurs on flat or sloping terrain over time following fire or mechanical site preparation. Accurate information about the occurrence of permanent or reversible paludification is required for land resource management. Such information is useful for the identification of locations of existing paludified areas where investment after harvesting should help to achieve greater productivity. This study investigated the potential for using a semi-automated method that was based on geomorphological analysis to map and differentiate between the two paludification types at the landscape scale within the Canadian Clay Belt region. For the purposes of this study, slope, topographic position index (TPI), and topographic wetness index (TWI) were generated from a LiDAR digital terrain model. TPI and TWI are, respectively, predictors of surface morphology (i.e., depressions vs flat areas) and moisture conditions (i.e., wet vs dry), and were used to explain paludification occurrence. A semi-automated classification method based on TPI and slope was firstly used to create six initial topographic position classes: deep-depressions, lower-slope depressions, flat surfaces, mid-slopes, upper-slopes, and hilltops. Each of these six classes was then combined with TWI classes (representing moisture conditions: wet, moderately wet, and dry) and this combination assisted in assigning each resulting class to one of the two paludification types. Slope and TWI values were used in sub-dividing the lower slope depression class, based on slope, into significantly different sub-classes, namely open and closed depressions (Tukey's HSD, $P < 0.001$). The distribution of field data (e.g., tree basal area, organic layer and fibric horizon thicknesses) within each position class provided additional information for corroborating the assignment of each class to a defined paludification type. The proposed semi-automated classification provided a relatively simple and practical tool for distinguishing and mapping permanent and reversible paludification types with an overall accuracy of 74%. The tool would be particularly useful for implementing strategies of sustainable management in remote boreal areas where field survey information is limited.

1. Introduction

Gradual accumulation of thick organic soil layers characterises boreal forest floors of the Hudson Bay–James Bay lowlands (Canada). Accumulations are attributed mainly to paludification, which generally creates wetter conditions that decrease soil temperature, decomposition rates, microbial activity, nutrient availability, and increase canopy openings (Crawford et al., 2003; Lavoie et al., 2005). Paludification can cause substantial productivity losses in the boreal forest and, consequently, potential sources of wood fibre. Paludification is especially problematic in the forested landscapes of the Clay Belt (Fig. 1A), a region within the Hudson Bay–James Bay lowlands, where it has facilitated the transformation of productive forests into unproductive forested peatlands. Within the Clay Belt, ground surface topography and time-since-last fire are two major drivers of paludification (Fenton et al., 2009). Consequently, two types of paludification (i.e., permanent and reversible) are recognised on the basis of these two factors. Theoretically, these two types occur in different locations across the landscape. Permanent paludification dominates in natural depressions, which have wetter soil conditions favouring organic layer build-up. Reversible paludification occurs on flat or sloping terrain, where feather moss-dominated ground cover is replaced by *Sphagnum* spp. (Fenton and Bergeron, 2006), after about 100 years following fire (Simard et al., 2007). Reversible paludification may be reversed through natural severe fire or a combination of silvicultural practices and site preparation,

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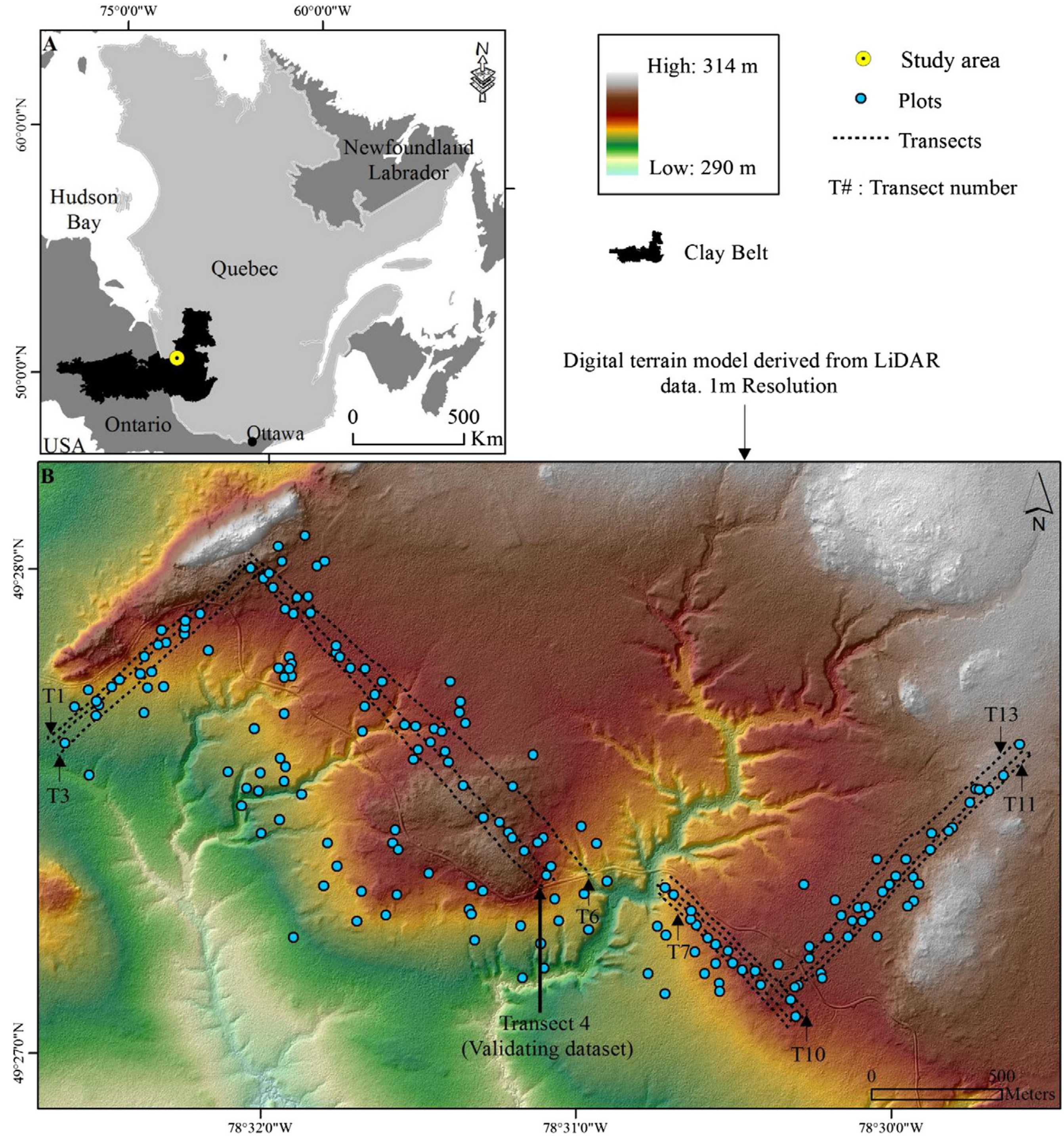

Fig. 1. Study location within the Clay Belt region of Ontario and Quebec (A). Topographic overview of the study area showing field sampling points along transects and plots (B).

as detailed by Fenton et al. (2009). In contrast, permanent paludification is not reversible, as its name suggests.

Several studies have dealt with either one or the other paludification type within Clay Belt black spruce (*Picea mariana* [Miller] BSP) forests (Fenton et al., 2005; Lavoie et al., 2005; Simard et al., 2009). Yet research examining spatial distributions of these two paludification types across larger areas is rare (Laamrani et al., 2014b,c; Lavoie et al., 2007). Mapping their occurrence at the landscape scale is critically important for land managers and decision-makers, if they are to implement appropriate management practices. To effectively manage black spruce forests in the Clay Belt, accurate spatial maps that can identify the two paludification types are required. Such maps could be used to delineate areas where efforts and investments should be made to achieve higher productivity after logging or to identify retention areas that maintain structural attributes and habitats. Finding the terrain attribute that can most easily differentiate between paludification types could be considered and addressed within the context of landscape classification.

Light Detection and Ranging (LIDAR, remote sensing system) is a practical technology for landscape analysis (Southee et al., 2012) and captures topographic features with high vertical and horizontal precision, making it suitable for this study. Also, LiDAR potentially provides information on surface morphology (e.g., flat areas vs depressions) and wetness conditions (e.g., wet vs dry), which are intuitively important in discriminating between reversible and permanent paludifications