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Can spatial patterns be used to investigate aboveground-belowground links in reclaimed forests?

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ABSTRACT

In forests undergoing reclamation, monitoring spatial patterns and relationships may be one way to decide if reclamation goals have been met. As a first attempt, linkages between soil nutrients and the canopy were assessed based on spatial patterns of trees, forest floor biomass, and seasonal nutrient availability in reclaimed forest sites in northern Alberta, Canada using a spatially explicit protocol (0.5 minimum resolution). Three different stand types, including aspen (*Populus tremuloides* Michx.), jack pine (*Pinus banksiana* Lamb.), and white spruce (*Picea glauca* (Moench) Voss) were assessed. Nutrient supply rate patterns were spatially dependent at scales of 3–20 m and varied among seasons suggesting that controls shift seasonally between aboveground and belowground processes. Increased canopy cover and forest floor mass led to increased soil nutrient supply rates for all macronutrients in the aspen stand. Only forest floor mass was associated with increased sulfur and calcium in the pine stand, and canopy cover with increased potassium in the spruce stand. Linkages between aboveground and belowground processes appear to be reestablishing, however further investigation is needed to determine missing parameters controlling nutrient supply, to explicitly compare with natural background sites and account variation in reclamation material.

1. Introduction

Ecological processes in terrestrial ecosystems often operate at multiple scales, potentially influencing a variety of variables simultaneously (McIntire and Fajardo, 2009). These different processes can be difficult to separate with conventional statistical analyses. In particular, their spatial variability is often regarded as random noise. However, investigating the spatial patterns of ecosystem variables can provide valuable insight into ecological processes operating at different scales (see Ettema and Wardle, 2002 for a short review). Spatial variability can be explicitly incorporated into statistical models as a function that accounts for unmeasured or unknown variables, such as soil moisture, temperature, and topography (McIntire and Fajardo, 2009). Information about the interactions between aboveground and belowground processes, including nutrient uptake or litterfall and decomposition, can then be inferred from the spatial patterns developed by these other related variables. Given that surface mining removes all of these interactions and land reclamation attempts to re-connect them, having a system that does not require the examination of every single variable, which is not possible, would be beneficial.

The main goal of reclamation in the Athabasca Oil Sands Region (AOSR) is to create functioning and self-sustaining ecosystems after surface mining (see Quideau et al., 2013 for a review). Land reclamation in the AOSR builds sites with an organic rich horizon (peat mineral mix, 20–30 cm thick) placed over a mineral subsoil (80–100 cm thick). The placement of these substrates by heavy equipment generates relatively uniform patterns of soil moisture and nutrient availability relative to an undisturbed forest soil. Previous studies have shown that the spatial heterogeneity of available soil nitrogen in young reclaimed mine sites was lower than that in undisturbed forest soils (Boerner et al., 1998; Fraterrigo et al., 2005; Nyamadzawo et al., 2008). Therefore, successful land reclamation might be evaluated with spatial statistics, because natural forests are characterized by small scale spatial patterns, whereas newly reclaimed landscapes are typically more homogenous, with coarser scale spatial patterns. Increasing heterogeneity in soil processes can be expected as a forest canopy develops and the ecosystem recovers following disturbance (Das Gupta, 2015). Finally, the analysis of soil-plant relations via spatially explicit techniques can be very informative, as soil is spatially connected to vegetation by a number of ecological processes, including, for example, carbon quality, nutrient availability, and uptake (Bengston et al., 2006; Saetre,

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1999). Spatial statistics do not assume independence between samples, in fact it explicitly models the dependence between samples that is typical with environmental variables. Finally, spatial statistics can remove non-causal correlations allowing us to focus on mechanistic relationships (MacKenzie et al., 2008).

Reclaimed sites provide an opportunity to investigate the nature and spatial pattern of soil-plant relations in developing ecosystems. Natural forests in the area exhibited increasing spatial heterogeneity in both above and belowground properties following recovery from wildfire (Das Gupta, 2015). Similar relationships should exist if reclaimed forests are following a developmental trajectory parallel to forests recovering from natural disturbance. Specifically, aboveground processes (i.e.: canopy cover, stem location, and forest floor mass) have been observed to drive the associated spatial patterns in nutrient supply and relationships between observed aboveground vegetation and belowground soil processes (Binkley and Valentine, 1991; Prescott, 2002; Sorenson et al., 2011). The composition of canopy trees has a substantial impact on soil nutrient cycling by influencing forest floor quality, quantity, and decomposition rates (Binkley and Valentine, 1991; Prescott, 2002; Sorenson et al., 2011). Specifically, Sorenson et al. (2011) suggested that aspen captures reclamation sites more rapidly through canopy closure and forest floor development. Aspen can also improve site fertility relative to coniferous stands because of higher nitrogen mineralization (Flanagan and van Cleve, 1983), faster nitrate turnover, and nitrogen accumulation (Ste-Marie and Paré, 1999).

This study evaluated soil-plant interactions, particularly the influence of tree canopy on soil nutrients, in the AOSR. The objectives of this study were to quantify the spatial dependence of stand characteristics and soil nutrient availability on reclamation sites with different types of tree canopies. Additionally, we were interested in investigating if patterns in spatial dependence can be used to assess if nutrient availability was being driven by the aboveground characteristics of the different sites. Seasonal variation was of also interest, as the dominant canopy processes (i.e.; litterfall, nutrient uptake, stem flow, and throughfall) affecting soil nutrients were expected to vary seasonally (MacKenzie and DeLuca, 2006). We hypothesized that this would affect patchiness in soil nutrient supply rates and that differences in seasonal nutrient supply rate patterns would exist among aspen, pine and spruce reclaimed sites. Therefore, relationships between canopy cover, stem location and soil nutrient supply rates were investigated after accounting for the residual spatial pattern to determine if seasonal controls existed in different stand types.

2. Materials and methods

2.1. Study sites

The three study sites were located in the Athabasca oil sands region north of Ft. McMurray, Alberta (56°43′N 111°21′W, Fig. 1). The deciduous site was reclaimed 15 years before the time of the study and the two coniferous sites were reclaimed 26 years before the time of the study. A younger stand was selected for the deciduous stand as Sorenson et al. (2011) identified that the establishment of canopy cover is a critical factor for forest floor and soil development in these reclaimed forests and that deciduous stands reach canopy closure earlier than coniferous stands. The three sites from

Fig. 1. Location of Aspen, Pine, and Spruce reclaimed study sites within the Athabaca Oil Sands Region.
Source: Google Earth, TerraMetrics © 2017.