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Using spatial ecology to examine above and belowground interactions on a reclaimed aspen stand in northern Alberta

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ABSTRACT

Examining the spatial interactions between above and belowground components of terrestrial ecosystems can give meaningful insight into the ecological processes happening at different scales. Understanding spatial dependence in these processes may help to evaluate reclamation success which is crucial for future management of such areas. The aim of this study was to measure the spatial patterns of soil biogeochemical properties in a young aspen stand reclaimed after oil sands extraction and to evaluate how the patterns were related to nutrient availability. Samples were collected from a 14-year old reclaimed site using a spatially explicit protocol with a minimum resolution of 0.5 m. Field-measured variables included forest floor depth and mass, tree cluster (canopy overlap), distance to nearest tree, and resin available nutrients. Soil microbial properties including microbial biomass C and N, basal respiration, and extracellular enzyme activity were measured during an eight-week laboratory incubation experiment. Geo-statistics were applied to examine the spatial patterns and model the space effect. A fine scale (<10 m) spatial pattern was found for the majority of stand variables, soil microbial properties, and available macronutrients (N, P, S and base cations). Macronutrients such as N, P and S availability had a fine scale cyclic spatial association with soil microbial properties, with an 8–10 m oscillation, which indicated belowground control on these nutrients. Spatial regression models also suggested a stronger microbial influence on the availability of these nutrients when compared to stand characteristics. However, stand characteristics exhibited significant control on base cations and micronutrient availability through the effect of forest floor depth and tree clustering. Although nutrient availability showed strong spatial relationships with belowground processes in the studied reclaimed site, similar relationships with aboveground properties appeared to be weak, and might require further time to develop.

1. Introduction

Heterogeneity in ecosystem processes may arise from interactions between above and belowground components (Kardol and Wardle, 2010). There are both positive and negative feedback loops through which one component influences the other, and sometimes these forces work together under the same spatio-temporal scale to generate specific ecosystem patterns (Wardle et al., 2004). Above and belowground linkages at one level of ecosystem organization can transcend to a higher level of organization; for example the interaction between soil microbes and plant functional traits can directly shape community level biodiversity, which has the potential to affect ecosystem level C and nutrient fluxes (Kardol and Wardle, 2010; Van Der Heijden et al., 2008). Aboveground properties such as tree distribution, tree cluster, and forest floor depth can directly or indirectly affect variability in soil microbes, including composition and function (Wardle, 2002; Weber and Bardgett, 2011). Trees can influence the spatial distribution of under-story species and belowground biota by modifying resources such as light, moisture, and by their variable rate of litter input and nutrient uptake from soil (Saetre, 1999; Wardle, 2002; Weber and Bardgett, 2011; Turner et al., 2011). Belowground organisms can also significantly influence aboveground vegetation dynamics and distribution. Changes in the soil microbial community can favor plant associations of a certain type by directly modifying organic matter decomposition pathways, and altering belowground nutrient dynamics (Bradford et al., 2002; John et al., 2007).

Microbes are very important biogeochemical agents in marginal or heavily disturbed soil, where they are responsible for initiating ecosystem development and creating resource heterogeneity (DeGrood et al., 2005; Smithwick et al., 2012; Van Der Heijden et al., 2008). Stolp (1988) proposed that microbially driven biogeochemical heterogeneity in soils is determined by the availability of microbial resources and abiotic reaction conditions. Soil microbial control on nutrient availability, therefore, could be stronger at the initial stage of stand development in disturbed ecosystems (Wardle, 2002), when the disturbance creates large amounts of labile soil organic matter, as is the case after wildfire (Certini, 2005; Choromanska and DeLuca, 2002; Fernández et al., 1997) and after tillage in agriculture (Marriott and Wander, 2006). Strong microbial influence on vegetation dynamics and nutrient

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biogeochemistry at the stand initiation phase has also been reported in human disturbed ecosystems such as in ecosystems recovering from surface mining and harvesting (Holmes and Zak, 1999; Ingram et al., 2005; Mummey et al., 2002). In nutrient limited northern ecosystems such as the boreal, soil microbial influence on the spatial distribution of nutrients is likely to have similar magnitude as plant contributions since the aboveground and belowground feedback loops in these ecosystems are tightly linked through the accumulation of organic matter (Eskelinen et al., 2009; Van Der Heijden et al., 2008). Disturbance, especially surface mining and reclamation with novel soil substrates, can reshuffle the established spatial structure in the aboveground and belowground processes, and these patterns might take decades to recover as seen in abandoned agricultural fields (Flinn and Marks, 2007).

In this study, we seek to tie patterns of nutrient availability to above and belowground properties with spatially explicit sampling and geostatistics. Fig. 1 and the following outline our specific hypotheses with the objective of: 1) examining spatial predictability of above and belowground properties, 2) isolating the microbial influence on nutrient availability, and 3) examining tree influence on microbial activity.

1.1. Hypothesis 1

Young oil sands reclaimed sites usually have less heterogeneity in terms of geomorphological features, including: micro-topography, slope, and sub-surface materials (Fig. 1). Low heterogeneity in juvenile reclaimed ecosystems has been reported in previous studies (e.g. Nyamadzawo et al., 2008; Shukla et al., 2005). Heterogeneity might develop in such reclaimed ecosystems over time through continuous organic matter input (Boerner et al., 1996, 1998), modification of soil physico-chemical conditions (Shukla et al., 2007), and proliferation of a diverse soil microbial community (Anderson et al., 2008). However, the amount of time it might take for heterogeneity to develop has not been well documented. The most significant aboveground changes in forest ecosystems happen during the canopy closure phase of stand development. Natural fire disturbed aspen ecosystems usually reach canopy closure by 7 to 11 years after initiation (Petersen and Petersen, 1992; Valverde and Silvertown, 1997). During this time forest floor litter and stand structure will develop predictable patterns that may increase with tree gap or cluster formation (Cumming et al., 2000). Development

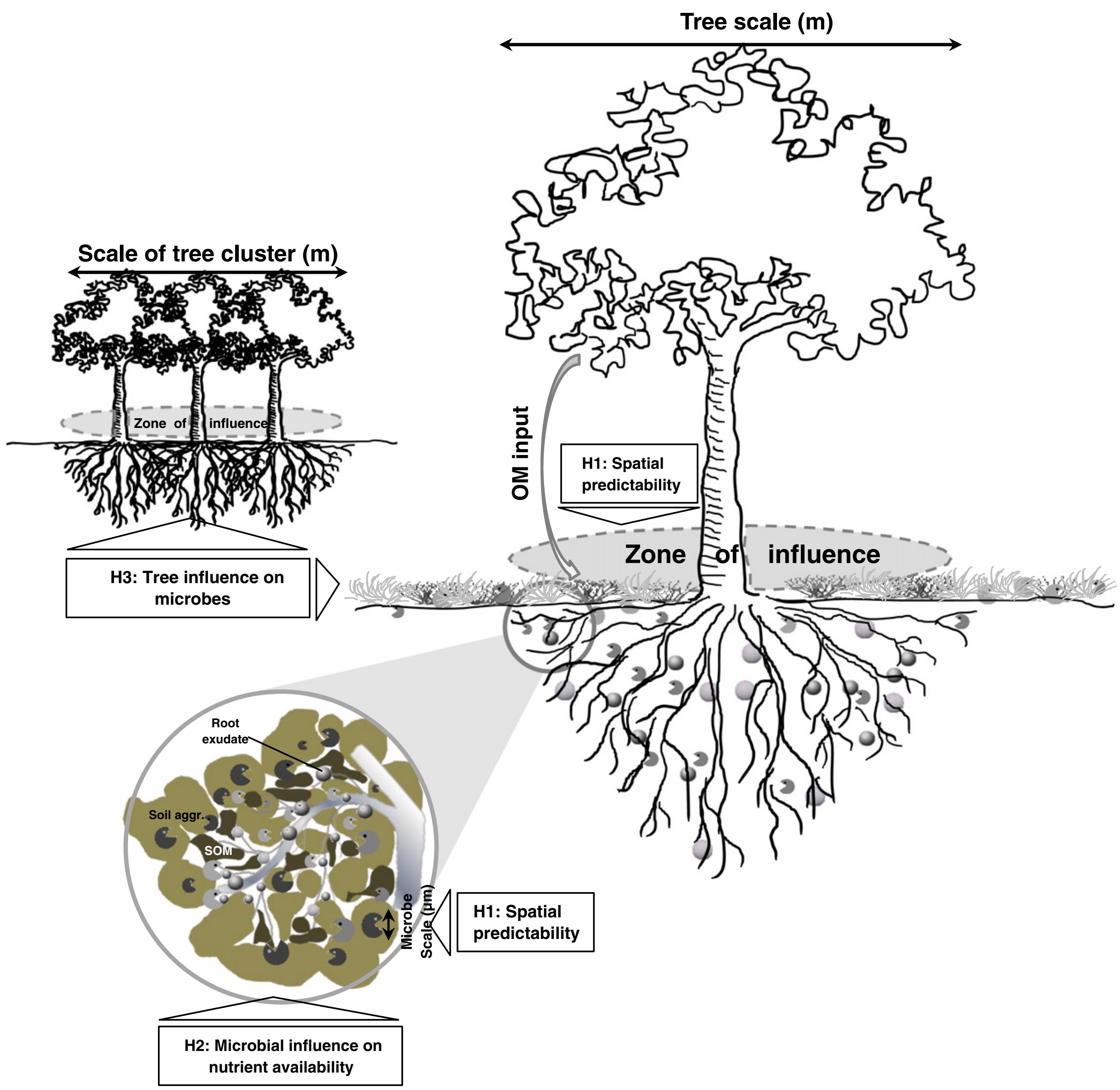

Fig. 1. Schematic diagram showing different parts of the working hypotheses.