

## Using airborne laser scanning to predict plant species richness and assess conservation threats in the oil sands region of Alberta's boreal forest



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### ABSTRACT

Timely and cost-effective monitoring of biodiversity across large areas is a major challenge, yet an important component of monitoring programs that inform policy and conservation strategies. Recent advances in Airborne Laser Scanning (ALS) provide new opportunities to simultaneously measure vegetation structure and terrain morphology at fine spatial scales. However, there is limited research on whether ALS metrics correlate with biodiversity measures. Here we used vascular plant data from 283 quarter-hectare (50 m × 50 m) plots from the boreal forest in northeast Alberta, Canada, to evaluate the potential for ALS-derived metrics to explain species richness patterns for vascular plants, as well as for four growth forms: herbaceous (including forbs and graminoids) and woody plants. We found canopy height from ALS was the most consistent and important (positive) factor related to local patterns in vascular plant species richness. Multivariate regression models of ALS-derived metrics explained 20–35% of the variation in species richness among vascular plants and the four subclasses. When considering the current distribution of *in situ* oil sands leases in the region, vascular plant richness inside of the leases is higher than outside. Areas delineated for woodland caribou conservation had lower average plant richness suggesting that it will do little to protect hotspots of vascular plant diversity in Alberta's boreal forest. Our results highlight the value of using fine-scale measures of ALS-derived vegetation structure to explain, predict, and potentially monitor local plant diversity for a high latitude forested ecosystem.

### 1. Introduction

Given recent and projected trends in climate change and human disturbance, biodiversity threats continue to be a major conservation concern (Sala et al., 2000; Thuiller, 2007). In order to understand trends in biodiversity and subsequently prioritize conservation efforts, it is essential to better understand environment-biodiversity relationships and to derive efficient methods for monitoring biodiversity change (Araújo and Rahbek, 2006; Kreft and Jetz, 2007). Taxonomic richness of species (alpha diversity), most often obtained directly from field surveys, is the most typical measure of biodiversity (Thuiller, 2007). However, it is not practical to monitor biodiversity in this way across large regions. A major challenge in managing biodiversity is therefore to link biodiversity measures at local scales to cost-effective monitoring across large areas (Mairota et al., 2015). Appropriate surrogates for direct assessments of biodiversity are therefore needed.

Advances in remote sensing technology have created opportunities for monitoring habitat and vegetation structure at local to global scales, leading to potentially better, more economical, and faster alternatives to field surveys (Pimm et al., 2015).

Although some studies suggest that multispectral passive optical sensors can be used to predict biodiversity at large scales (Coops et al., 2008; John et al., 2008; Zhang et al., 2016), most passive spectrum-derived satellite indices do not consider vertical structure of vegetation (except for the forest canopy height in open canopy forests, see Montesano et al., 2017), a key driver of biodiversity at local scales (MacArthur and MacArthur, 1961; Bergen et al., 2009). Moreover, new insights and methods are needed to recognize that vegetation structure and species composition differ even in two adjoining sites sharing a consistent regional species pool (Cook et al., 2002). Indeed, the physical structure of vegetation has long been noted by scientists to explain variation in species diversity, particularly for animals, in part because it

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relates to possible mechanisms of ecological complexity and niche partitioning (MacArthur and MacArthur, 1961; Kalko and Handley, 2001). However, metrics related to vertical distribution and stratification of vegetation have historically been feasible only through collection of field data (Baker and Wilson, 2000) and thus limiting their application to local case studies.

Recent advances in Airborne Laser Scanning (ALS) technology now provide opportunities for measuring and monitoring the structure and complexity of vegetation across larger areas. This includes measures of canopy cover, height class distribution of vegetation, and maximum canopy height (Bergen et al., 2009). These metrics of vegetation structure have been used to predict the richness of mammals, bats, vertebrates, particularly for birds (Bradbury et al., 2005; Clawges et al., 2008; Vierling et al., 2008; Davies and Asner, 2014; Coops et al., 2016; Davies et al., 2016) with little done to assess whether ALS metrics explain local patterns in plant diversity.

Plant diversity at local scales (i.e., community level) is known to be affected by many different factors, including biome-scale environmental conditions or regional-to-local factors of topography, environmental heterogeneity, vegetation type, and vegetation structure (e.g., Moser et al., 2005; Kreft and Jetz, 2007; Fine, 2015). In particular, vegetation structure (e.g. canopy height) is considered to be an important factor shaping plant diversity (Wolf et al., 2012; Gatti et al., 2017). Exploring the factors affecting plant diversity at the community level therefore requires understanding of both regional climate factors and local environmental variables, including those that can be measured by ALS, i.e. vegetation structure metrics such as canopy height, percent of returns above a specified height, and return proportion at specified height intervals. Here, we use 283 plant biodiversity plots from the boreal forest in northeast Alberta, Canada, an area undergoing rapid landscape change due to oil sands developments, to examine whether ALS vegetation and terrain measurements, in combination with other environmental variables, relate to patterns of plant species richness. Establishing this relationship will enable landscape-scale predictions of conservation values.

The boreal forest is the largest terrestrial biome on the earth, playing a major role in global biodiversity conservation and ecosystem function (Melillo et al., 1993; Näsholm et al., 1998). The biome is, however, sensitive to global climate change and human disturbance (Sala et al., 2000; Larsson and Danell, 2001). Understanding biodiversity patterns (e.g. biodiversity hotspots) in the boreal forest, as well as their relationships with local to regional factors, is one key step for managing biological conservation and monitoring change due to exogenous (e.g. climate change) and endogenous (e.g. habitat fragmentation) threats. This includes a better understanding of the implications of exploration and extraction of oil in Alberta's oil sands (Rooney et al., 2012), the world's largest oil reserve (Sherrington, 2005), on plant biodiversity hotspots. And to explore whether the locations of plant biodiversity hotspots overlap with those of other major conservation objectives, in particular areas of woodland caribou (*Rangifer tarandus*) habitat, which represent the current focus of conservation initiatives in Canada's boreal forest (Schneider et al., 2010).

## 2. Materials and methods

### 2.1. Materials

#### 2.1.1. Study area

The study area was located in the boreal forest of northeast Alberta, Canada ranging in latitude from 55.3° N to 57° N (Fig. 1). This area is part of the Boreal Forest Natural Region, which includes the lower portion of the Athabasca River and Lake Athabasca (Natural Regions Committee, 2006). Elevations in the area range from 231 m to 863 m a.s.l., with annual precipitation and mean annual temperatures ranging from 430 mm to 492 mm and from −1.2 °C to 0.3 °C, respectively. On the uplands, soils are typically Brunisols, while wetland areas are

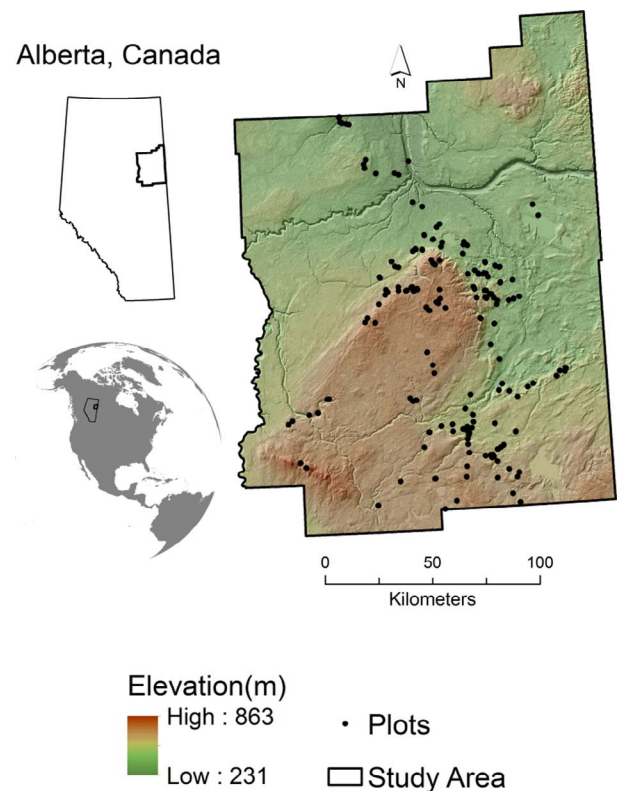


Fig. 1. Study area in Alberta, Canada and plot locations.

Mesisols, Organics, Gleysols, and Grey Luvisols. Forests in the area are comprised of a mosaic of deciduous, mixed wood and coniferous stands, with upland stands dominated by *Populus*, *Picea*, and *Pinus* species., while lowland areas are represented by fens, swamps, and bogs (Natural Regions Committee, 2006; Zhang et al., 2014).

#### 2.1.2. Plot data

Plot data were collected in the summers of 2012–2015 with a plot size of 50 m × 50 m (0.25 ha) based on stratified random sampling. Vascular plants were identified to species in each plot and recorded as present/absence data. Unknown specimens were collected and identified later in the lab to species. See Zhang et al. (2014) for more details on field methods. In total, 602 plots were completed, but only 283 plots overlapped with ALS data (spatial coverage limited) on both vegetation structure and topography-derived variables and thus were used in this study. Since the underlying drivers and assembly mechanisms of plant diversity may differ across growth forms (Mao et al., 2013), all plants were classified into five growth forms (subdivisions) based on records from Floras (<http://www.efloras.org/>). These subdivisions included (1) all vascular plants, (2) herbaceous plants (further separated to (3) forbs and (4) graminoids), and (5) woody plants. Only native species were considered in this paper. Non-native species were infrequently encountered and included only sparse cover of a small number of species (e.g. *Taraxacum officinale* in upland sites). It should be noted, however, that plots were not placed directly on human disturbances, such as vegetated well sites, pipelines, or clearcuts, but were in the region of general forest disturbances and habitat fragmentation. Therefore, we are not testing here the direct effect of footprints from industrial practices on plant richness, but rather what factors affect natural patterns of plant diversity and where does that diversity occur within the broader region.

#### 2.1.3. Airborne laser scanning metrics and environmental variables

Airborne laser scanning data were generated from aerial surveys conducted between 2005 and 2013. Point densities averaged 1.9

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